Wayne E. Sabbe

Arkansas Soil Fertility Studies 2019

Nathan A. Slaton, Editor

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Cover: Potassium deficiency in soybean.

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WAYNE E. SABBE ARKANSAS SOIL FERTILITY STUDIES – 2019 –

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Arkansas Agricultural Experiment Station
University of Arkansas System
Division of Agriculture
Fayetteville, Arkansas 72704

DEDICATED IN MEMORY OF

Wayne E. Sabbe

Wayne E. Sabbe was born June 17, 1937 in Rugby, North Dakota. He received his B.S. degree in soil science from North Dakota State University in 1959, and his Ph.D. from Oklahoma State University in 1963. Dr. Sabbe started work with the University of Arkansas in 1963 as a crop physiologist with the United States Department of Agriculture, Agricultural Research Service. In 1966, he was appointed assistant professor and in 1975, he advanced to professor. Dr. Sabbe spent his complete academic career with the university until he retired from the Department of Crop, Soil, and Environmental Sciences in 1999. During his career in the department, he was the leader and mainstay for soil testing in Arkansas. Evident of the respect and admiration of his colleagues is the fact that he was elected by the college faculty to serve as the first faculty chair in the 1990s. He also served as an interim head of the department, chair of the Dean's Faculty Advisory Council, chair of the Promotion and Tenure Committee, and in numerous other important committee positions. As both a crop physiologist and a soil scientist, Dr. Sabbe's broad, practical view was important to researchers, farmers, and extension personnel as well as students. During his career, he was advisor to 16 M.S. and 10 Ph.D. candidates, and some 90 others asked him to serve on their graduate committees.

Dr. Sabbe extended the Soil Testing and Diagnostic laboratories at Arkansas to include services other than soil testing, such as manure, forage, water, and plant analyses. His expertise in soil and plant analysis extended regionally, nationally, and internationally. In 1997, Dr. Sabbe was recognized with the prestigious J. Benton Jones Award given at the International Soil Testing Symposium by the Soil Testing and Plant Analysis Council. This recognition was prefaced by years of service to groups ranging from the Arkansas Plant Food Association to the Southern Regional Soil Testing Work Group and the Board of Directors of Council for Agricultural Science and Technology (CAST), as well as the American Society of Agronomy (ASA), Soil Science Society of America (SSSA), Certified Crop Adviser (CCA), the Soil Testing and Plant Analysis Council, and the European Society of Agronomy.

From 1991 to 2000, 52 presentations on his research were given at regional, national, and international meetings. His publications on soil amendments for plant nutrition were and still are important for the producer and researcher alike. Several of his publications explored the possibilities of using exchange resins to substitute for the time- and labor-intensive greenhouse approach to evaluate season-long nutrient release. The SSSA requested that he be lead author on two chapters in their Soil Testing and Plant Analysis publication and on a monograph on cotton. Internationally, he worked with plant-soil nutrition, and hosted scientists on short-term visits to Arkansas. In 1992, he fulfilled an off-campus sabbatical to Australia to expand the use of Near Infrared Spectroscopy for analysis of nitrogen and starch in cotton leaves.

Dr. Sabbe edited this research series when it was titled Arkansas Soil Fertility Studies from the publication's inception in 1989 until his retirement in 1999. In recognition of Dr. Sabbe's contributions to soil testing and fertility, this publication was renamed the Wayne E. Sabbe Arkansas Soil Fertility Studies in his memory starting with the 2001 publication.

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 2019 Arkansas Soil Fertility Studies publication includes 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 soil samples submitted during 2018. 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.

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https://arkansas-ag-news.uark.edu/research-series.aspx

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Contents

Arkansas Soil-Test Summary for Samples Collected in 2018

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

Abstract

Soil-test data from samples submitted to the University of Arkansas System Division of Agriculture's Marianna Soil Test Laboratory (MSTL) in 2018 were categorized according to geographic area (GA), county, soil association number (SAN), and selected cropping systems. Descriptive statistics of the soil-test data were calculated for categorical ranges for pH, phosphorus (P), potassium (K), zinc (Zn), and sulfur (S). In 2018, 107,963 client soil samples were analyzed by the MSTL. Of the total samples, 35,685 were submitted as field-average samples, representing 789,394 acres for an average of 22 acres/sample. Grid soil samples accounted for 69,978 or 65% of all submitted samples. Soil samples from the Bottom Lands and Terraces, and Loessial Plains, GA with row-crop agriculture, represented 67% of the total field-average samples and 33% of the total acreage. Soil association numbers show that most samples were taken from soils common to row-crop and pasture production areas. Crop codes indicate that land used for i) row-crop production accounted for 74% and 33%, ii) hay and pasture for 24% and 25%, and iii) home lawns and gardens accounted for 2% of sampled acreage and 25% of submitted samples, respectively. This report includes a summary of Mehlich-3 extractable soil S. The Mehlich-3 extractable soil-S median annual value tended to decline by 0.3 to 0.6 ppm/year between 2006 to 2018 when examined by the crop grown before soil sample collection. Rice had the highest overall median soil-test S at 25 ppm and showed little or no decline across time.

Introduction

The University of Arkansas System Division of Agriculture has a rich history in agricultural services including soil testing. The Fertilizer Tonnage Fee was established in the 1950s with the funds used to provide Arkansas citizens with low-cost soil-testing services for nutrient management and research. The Arkansas Soil Testing Program has grown over the years and now is believed to be the second-largest public soil-testing program in the United States with regard to the number of soil samples analyzed annually. Although some proportion of agricultural soil samples, primarily grid samples collected from row-crop fields, are sent to private laboratories, the majority of soil samples are believed to be submitted to and analyzed by the University of Arkansas System Division of Agriculture's Marianna Soil Test Laboratory (MSTL) located in Marianna, Ark. The large number of soil samples analyzed annually by the MSTL creates a tremendous database that can be used to assess soil chemical properties for different land-use systems within Arkansas.

Each calendar year we summarize data from soil-test results to examine how selected soil chemical properties are distributed across the Arkansas landscape with focus on soil pH, and Mehlich-3 extractable soil nutrients phosphorus (P), potassium (K), and zinc (Zn) because these properties are the ones used most frequently for nutrient management. This report summarizes soil pH and P, K, and Zn availability indices from samples submitted during 2018 and includes a special summary of Mehlich-3 extractable soil-test sulfur (S).

Procedures

Soil-test data from samples submitted to the MSTL between 1 January 2018 and 31 December 2018 were categorized according to geographic area (GA), county, soil association number (SAN), and selected cropping systems. The GA and SAN were derived from the General Soil Map, State of Arkansas (Base 4-R-38034, USDA, and University of Arkansas Agricultural Experiment Station, Fayetteville, Ark., December 1982).

Soil samples are categorized as either field-average or grid samples based on how the soil submission is completed. Because grid soil samples are frequently submitted in high volume, selected information, such GA, SAN, previous crop and crop to be grown, is often not completed on the forms. Field-average samples are defined as samples that had all or nearly all information fields completed. Some proportion of the field-average samples may be grid samples that had all information fields completed. The information tables presented in this report may contain slightly different sample or acreage numbers for field-average samples. The difference in values is because information not completed on the sample submission form excludes the sample(s) from certain data queries performed to create this summary.

Descriptive statistics of the soil-test data were calculated for categorical ranges for pH, P, K, and Zn. Soil pH and Mehlich-3 extractable soil nutrient (i.e., P, K, and Zn) availability index values that indicate the relative level of soil fertility. Soil pH is determined by electrode while stirring in a 1:2 volume-to-volume soil:water mixture (Sikora and Kissel, 2014). The Mehlich-3 extraction process is described by Zhang et al.

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(2014). The nutrient concentrations in Mehlich-3 extracts are determined using inductively coupled plasma optical emission spectrometers (ICAP, Spectro Arcos). The MSTL participates in the Agricultural Laboratory Proficiency Program (ALP; https://collaborative-testing.com/) quality assurance and quality control program to ensure that soil-test analytical information provided to customers is accurate and precise. Mehlich-3 extractable S data were also summarized using 2018 data as well as data from samples analyzed since 2006 to examine trends in soil-test S across time.

Results and Discussion

Between 1 January 2018 and 31 December 2018, there were 119,469 soil samples analyzed by the MSTL. After removing 10,438 standard-solution and check-soil samples measured for quality assurance, the total number of client (e.g., researchers, growers, and homeowners) samples was 109,031 comprising 1068 research samples and 107,963 samples from the public (Table 1). A total of 35,685 of the submitted soil samples were collected using the field-average sampling technique, representing 789,394 acres for an average of 22 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 72,278 samples were grid samples collected primarily from row-crop fields.

The number of soil samples analyzed and submitted by clients in 2018 was 36% lower than the previous six-year mean of 187,255 (±21,215) due to the above-average rainfall that occurred from early fall 2018 through the spring of 2019. Wet field conditions prevented growers and consultants from collecting soil samples from many agricultural fields during this period. October, November, and December are the months that the MSTL typically receives and analyzes approximately 21%, 22%, and 12%, respectively, accounting for more than 50% of the annual total samples analyzed. The number of samples analyzed during October, November, and December 2018 was 47,499 samples less than the previous six-year average.

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 Crittenden (11,872 samples, 82% of county grid samples); Little River (8433, 74%); Clay (5969, 82%); St. Francis (4525, 88%); and Desha (4378, 77%) counties submitted the most grid soil samples for analyses and accounted for 50% 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 often very low for some counties.

Soil samples from the Bottom Lands and Terraces, and Loessial Plains, primarily row-crop areas, represented 33% of the total field-average samples and 67% of the total acreage for samples submitted with a geographic area designation (Table 2). The average number of acres represented by each field-average soil sample from the ten geographic areas ranged from 7 to 46 acres/sample. Soil association numbers show that most samples were taken from soils common to row-crop and forage production areas (Table 3). The soil associations having the most samples submitted were 4 (Captina-Nixa-Tonti), 44 (Calloway-Henry-Grenada-Calhoun), 24 (Sharkey-Alligator-Tunica), 17 (Kenn-Ceda-Avilla), and 12 (Leadvale-Taft). However, the soil associations representing the largest acreage were 24, 44, 45 (Crowley-Stuttgart), 4, and 12, which represented 24%, 16%, 11%, 6%, and 3% 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 68% of the sampled acreage and 32% of submitted samples, ii) hay and pasture production accounted for 25% of the sampled acreage and 26% of submitted samples, and iii) home lawns and gardens accounted for 2% of sampled acreage and 25% of submitted samples (Table 4). Among row crops listed in Table 4, 57% of the soil samples were collected following soybean in the crop rotation. The cumulative acreage soil sampled following soybean represents about 8% of the annual soybean acreage, which totaled 3.24 million harvested acres in 2018, respectively (USDA-NASS, 2018).

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 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 6.1 to 6.7 (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 in Arkansas are 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 collected following rice and soybean in the rotation and the lowest median K concentrations occur in soils following non-irrigated grain sorghum, wheat, rice, and corn. Soils collected following cotton have the highest median K concentration. The median soil-test K is lowest in soils used for hay production. The median soil-test P and K for the hay crop codes decreased rapidly for several years following manure application regulations but the fertility decline has since slowed. The Low to Medium median soil-test P and K values for soils used for forage production likely require P and K fertilization to maximize yields and maintain soil fertility. The highest median concentrations of P and Zn occur in soils used for home gardens, fruit production and landscape/ornament plant production.

The availability of soil sulfur (S) for crop growth is important for its role in plant protein formation. Table 8 summarizes Mehlich-3 extractable S in Arkansas soils from 2006-2018 by previous crop using the median concentration. The annual results suggest soil-test S for most every row-crop category except rice soil-test S has gradually declined across time. Linear regression indicates the slope coefficient ranges for most crops range from -0.3 to -0.6 ppm Mehlich-3 S/year, except rice which had a slope of -0.1 ppm Mehlich-3 S/year. Suboptimal levels of S concentration are estimated to occur at <10 ppm of soil S. Fertilizer recommendations for a Low S soil-test level are available for warm-season grass hay and pasture codes when soil-test S is ≤12 ppm of S. The lowest median S values from 2006-2018 were for corn, cotton, grain sorghum, and soybean and were highest in rice, home lawn, and small fruit. The S concentration of all previous-crop categories remained the same or was reduced by 5 ppm for cool-season grass hay and rice at 6 ppm from 2006 to 2018. These results are not conclusive evidence that soil-S availability is declining because the trends in soil sample collection times have shifted from late-winter to mid-to-late fall sample collection time which could influence soil-S concentrations.

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 2018, 58% of the samples and 93% 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 2018 through 31 December 2018.

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	76,493	10	1856	2	41	Lee	133,247	17	1777	2	75
Ashley	4943	1	209	0	24	Lincoln	2339	0	130	0	18
Baxter	2416	0	389	0	6	Little River	5469	1	11,422	11	48
Benton	11,055	1	1125	1	10	Logan	3475	0	393	0	9
Boone	14,264	2	830	1	17	Lonoke	47,376	6	2325	2	20
Bradley	600	0	54	0	11	Madison	6392	1	392	0	16
Calhoun	650	0	21	0	31	Marion	1117	0	152	0	7
Carroll	11,686	2	586	1	20	Miller	3213	0	278	0	12
Chicot	3626	1	117	0	31	Mississippi	43,522	6	4948	5	9
Clark	3073	0	253	0	12	Monroe	12,139	2	559	1	22
Clay	12,124	2	12,395	12	1	Montgomery	1125	0	96	0	12
Cleburne	5407	1	426	0	13	Nevada	1118	0	99	0	11
Cleveland	1080	0	83	0	13	Newton	2010	0	172	0	12
Columbia	1158	0	119	0	10	Ouachita	612	0	110	0	6
Conway	8542	1	336	0	25	Perry	5036	1	214	0	24
Craighead	12,273	2	10,300	10	1	Phillips	3474	0	1004	1	4
Crawford	10,803	1	693	1	16	Pike	751	0	70	0	11
Crittenden	4375	1	13,279	12	0	Poinsett	36,394	5	1800	2	20
Cross	63,028	8	1598	2	39	Polk	5320	1	409	0	13
Dallas	936	0	70	0	13	Pope	8251	1	559	1	15
Desha	10,984	1	5723	5	2	Prairie	662	0	362	0	2
Drew	3480	0	635	1	6	Pulaski	3115	0	845	1	4
Faulkner	8658	1	779	1	11	Randolph	9932	1	956	1	10
Franklin	4677	1	255	0	18	Saline	2766	0	1709	2	2
Fulton	3917	1	302	0	13	Scott	2858	0	150	0	19
Garland	2065	0	1505	1	1	Searcy	2967	0	215	0	14
Grant	455	0	94	0	5	Sebastian	5193	1	557	1	9
Greene	11,097	1	4226	4	3	Sevier	5064	1	193	0	26
Hempstead	4358	1	300	0	15	Sharp	4922	1	348	0	14
Hot Spring	894	0	139	0	6	St. Francis	2480	0	5119	5	49
Howard	5522	1	304	0	18	Stone	1871	0	211	0	9
Independence	3742	1	428	0	9	Union	1944	0	315	0	6
Izard	4302	1	292	0	15	Van Buren	1675	0	214	0	8
Jackson	20,857	3	1416	1	15	Washington	24,142	3	2782	3	9
Jefferson	16,577	2	1157	1	14	White	5507	1	670	1	8
Johnson	3065	0	341	0	9	Woodruff	3845	1	220	0	18
Lafayette	4276	1	176	0	24	Yell	6040	1	261	0	23
Lawrence	24,573	3	3116	3	8	Sum or Average	789,394		107,963		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 2018 through 31 December 2018.

Geographic area	Acres sampled	% of total acres	No. of samples	% of total samples	Acres/ sample
Ozark Highlands - Cherty Limestone and Dolomite	74,075	12	6415	22	12
Ozark Highlands - Sandstone and Limestone	9754	2	657	2	15
Boston Mountains	17,402	3	1516	5	12
Arkansas Valley and Ridges	46,897	8	3673	13	13
Ouachita Mountains	27,319	4	4208	15	7
Bottom Lands and Terraces	244,051	39	5337	19	46
Coastal Plain	24,168	4	1877	7	13
Loessial Plains	168,593	27	4087	14	41
Loessial Hills	7150	1	801	3	9
Blackland Prairie	473	0	24	0	20
Sum or Average	619,882		28,595		22

Table 3. Sample number, total acreage by soil association number (SAN), average acreage per sample, and median soil pH and Mehlich-3 extractable phosphorus (P), potassium (K), and zinc (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 2018 through 31 December 2018.

SAN	Soil association	Acres sampled	% of total acres	No. of samples	% of total samples	Acres/ sample	Median pH	Median P	Median K	Median Zn
1.	Clarksville-Nixa-Noark	11,832	2	836	3	14	6.4	69	131	5.5
2.	Gepp-Doniphan-Gassville-Agnos	6795	1	727	3	9	6.6	49	134	5.0
3.	Arkana-Moko	19,806	3	1152	4	17	6.5	89	154	8.7
4.	Captina-Nixa-Tonti	35,404	6	3657	13	1	6.5	102	156	9.2
5.	Captina-Doniphan-Gepp	86	0	18	0	5	6.2	75	129	5.6
6.	Eden-Newnata-Moko	152	0	25	0	6	6.9	45	125	8.9
7.	Estate-Portia-Moko	454	0	32	0	14	6.4	71	79	6.8
8.	Brockwell-Boden-Portia	9300	2	625	2	15	6.4	31	99	3.0
9.	Linker-Mountainburg-Sidon	3787	1	393	1	10	6.3	50	105	3.6
10.	Enders-Nella-Mountainburg-Steprock	13,615	2	1123	4	12	6.2	72	111	5.3
11.	Falkner-Wrightsville	189	0	14	0	14	5.8	285	163	15.4
12.	Leadvale-Taft	21,424	4	1860	7	12	6.2	55	109	5.3
13.	Enders-Mountainburg-Nella-Steprock	5754	1	339	1	17	6.3	39	98	3.2
14.	Spadra-Guthrie-Pickwick	3615	1	142	1	26	5.9	88	113	7.3
15.	Linker-Mountainburg	15,915	3	1318	5	12	6.1	55	107	5.0
16.	Carnasaw-Pirum-Clebit	4038	1	281	1	14	5.9	62	102	4.8
17.	Kenn-Ceda-Avilla	8268	1	2071	7	4	6.1	51	119	5.4
18.	Carnasaw-Sherwood-Bismarck	4842	1	1428	5	3	6.2	56	108	4.5
19.	Carnasaw-Bismarck	7425	1	82	0	91	6.2	58	181	3.2
20.	Leadvale-Taft	995	0	229	1	4	6.2	103	113	7.9
21.	Spadra-Pickwick	1751	0	117	0	15	6.1	34	84	3.8
22.	Foley-Jackport-Crowley	20,048	3	628	2	32	6.7	25	107	3.5
23.	Kobel	13,136	2	331	1	40	6.4	26	112	2.7
24.	Sharkey-Alligator-Tunica	149,854	24	2247	8	67	6.6	43	173	3.0
25.	Dundee-Bosket-Dubbs	9214	2	484	2	19	6.6	36	109	2.5
26.	Amagon-Dundee	9204	2	307	1	30	6.6	48	132	4.0
27.	Sharkey-Steele	321	0	21	0	15	6.4	66	209	7.6
28.	Commerce-Sharkey-Crevasse-Robinsonville	834	0	109	0	8	6.2	41	196	3.3
29.	Perry-Portland	5938	1	200	1	30	6.4	46	165	3.9
30.	Crevasse-Bruno-Oklared	57	0	5	0	11	5.8	268	270	28.2
31.	Roxana-Dardanelle-Bruno-Roellen	7466	1	245	1	31	6.3	37	137	3.6
32.	Rilla-Hebert	19,869	3	555	2	36	6.5	43	125	2.5
33.	Billyhaw-Perry	2736	0	93	0	29	6.6	36	213	2.2
34.	Severn-Oklared	4691	1	61	0	77	6.9	57	126	4.0
35.	Adaton	0	0	0	0	0	0	0	0	0
36.	Wrightsville-Louin-Acadia	651	0	47	0	14	6.1	45	93	4.4
37.	Muskogee-Wrightsville-McKamie	32	0	4	0	8	5.4	21	106	2.3
38.	Amy-Smithton-Pheba	1020	0	79	0	13	6.0	35	68	2.9
39.	Darco-Briley-Smithdale	1	0	1	0	100	6.5	15	42	2.7
40.	Pheba-Amy-Savannah	658	0	39	0	17	6.1	93	108	7.2
41.	Smithdale-Sacul-Savannah-Saffell	7744	1	609	2	13	6.0	80	97	8.0
42.	Sacul-Smithdale-Sawyer	8967	2	925	3	10	6.2	59	96	5.4
43.	Guyton-Ouachita-Sardis	5778	1	224	1	26	5.9	114	106	11.9
44.	Calloway-Henry-Grenada-Calhoun	100,340	16	2759	10	36	6.7	28	98	3.4
45.	Crowley-Stuttgart	68,253	11	1328	5	51	6.5	26	106	3.1
46.	Loring	1211	0	55	0	22	6.3	52	97	4.8
47.	Loring-Memphis	5459	1	737	3	7	6.5	34	112	3.7
48.	Brandon	480	0	9	0	53	6.5	28	86	3.0
49.	Oktibbeha-Sumter	473	0	24	0	20	6.2	97	127	9.4
	Sum or Average	619,882		28,595		22	6.3	63	124	5.6

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 2018 through 31 December 2018.

Previous crop	Acres sampled	% of total acres	No. of samples	% of total samples	Acres/ sample
Corn	41,020	6	1395	4	29
Cotton	111,725	16	2177	6	51
Grain sorghum, non-irrigated	384	0	14	0	27
Grain sorghum, irrigated	10,816	2	81	0	134
Rice	52,224	8	1114	3	47
Soybean	252,561	36	6463	19	39
Wheat	1688	0	127	0	13
Cool-season grass hay	5403	1	350	1	15
Native warm-season grass hay	3990	1	259	1	15
Warm-season grass hay	27,408	4	1555	5	18
Pasture, all categories	132,104	19	6499	19	20
Home garden	3714	1	3104	9	1
Turf	1435	0	670	2	2
Home lawn	7396	1	5340	16	1
Small fruit	605	0	412	1	2
Ornamental	1498	0	962	3	2
Miscellaneous[a]	39,329	6	3563	11	11
Sum or Average	693,300		34,085		20

[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 2018 through 31 December 2018.

	Soil pH[a]						Mehlich-3 soil phosphorus[b] (ppm)					
Geographic area	**<5.4**	**5.4-5.7**	**5.8-6.2**	**6.3-6.9**	**>6.9**	**Md[c]**	**<16**	**16-25**	**26-35**	**36-50**	**>50**	**Md[c]**
	---(% of sampled acreage)---						--(% of sampled acreage)--					(ppm)
Ozark Highlands - Cherty Limestone and Dolomite	4	8	22	39	27	6.7	4	7	8	11	70	110
Ozark Highlands - Sandstone and Limestone	4	11	25	40	20	6.4	22	20	12	11	35	32
Boston Mountains	9	14	29	32	16	6.2	7	12	10	13	58	65
Arkansas Valley and Ridges	12	16	26	31	15	6.2	12	13	11	12	52	54
Ouachita Mountains	11	18	29	34	8	6.1	6	12	12	16	54	56
Bottom Lands and Terraces	3	6	20	48	23	6.6	8	16	20	25	31	39
Coastal Plain	12	19	26	29	14	6.1	11	10	8	11	60	70
Loessial Plains	5	9	20	33	33	6.6	17	30	23	16	14	27
Loessial Hills	8	10	21	34	27	6.5	23	16	13	13	35	34
Blackland Prairie	0	21	33	17	29	6.2	13	8	4	4	71	97
Average	7	13	25	34	21	6.4	12	14	12	13	49	58

	Mehlich-3 soil potassium[b] (ppm)						Mehlich-3 soil zinc[b] (ppm)					
Geographic area	**<5.4**	**61-90**	**91-130**	**131-175**	**>175**	**Md[c]**	**<1.6**	**1.6-3.0**	**3.1-4.0**	**4.1 8.0**	**>8.0**	**Md[c]**
	--(% of sampled acreage)--					(ppm)	--(% of sampled acreage)--					(ppm)
Ozark Highlands - Cherty Limestone and Dolomite	10	14	18	18	40	171	5	12	7	25	51	10.0
Ozark Highlands - Sandstone and Limestone	20	24	23	15	18	98	19	30	10	24	17	3.2
Boston Mountains	19	20	21	14	26	109	8	23	11	25	33	4.9
Arkansas Valley and Ridges	17	22	23	15	23	106	10	21	10	23	36	5.1
Ouachita Mountains	13	21	28	19	19	114	5	20	15	33	27	4.7
Bottom Lands and Terraces	5	14	25	20	36	143	10	40	18	21	11	3.1
Coastal Plain	25	21	20	12	22	96	10	18	7	21	44	6.7
Loessial Plains	8	30	39	16	7	100	12	34	16	27	11	3.3
Loessial Hills	18	20	27	17	18	111	15	28	10	22	25	3.7
Blackland Prairie	13	25	13	8	41	127	0	13	4	25	58	9.4
Average	15	21	24	15	25	118	9	24	11	25	31	5.4

[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 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 2018 through 31 December 2018.

	Soil pH[a]						Mehlich-3 soil phosphorus[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[c]
	----- (% of sampled acreage) -----						---- (% of sampled acreage) ----					(ppm)
Arkansas	2	5	12	32	49	6.9	10	28	24	21	17	30
Ashley	9	12	34	32	13	6.2	28	18	11	12	31	30
Baxter	6	5	12	22	55	7.1	10	9	7	11	63	73
Benton	6	10	23	41	20	6.4	3	6	7	11	73	111
Boone	1	7	22	49	21	6.5	3	9	10	12	66	78
Bradley	7	11	17	48	17	6.4	17	7	2	7	67	119
Calhoun	0	29	19	38	14	6.3	0	0	5	33	72	64
Carroll	1	8	23	41	27	6.5	2	4	3	6	85	124
Chicot	3	7	12	28	50	6.9	4	15	12	16	53	53
Clark	15	27	26	22	10	5.9	15	20	11	13	41	41
Clay	2	4	18	58	18	6.6	11	22	21	21	25	34
Cleburne	11	12	24	37	16	6.3	8	20	17	14	41	39
Cleveland	15	18	29	17	21	6.1	5	0	4	5	86	179
Columbia	14	16	28	30	12	6.1	8	13	7	14	58	71
Conway	14	19	27	23	17	6.0	19	11	8	8	54	61
Craighead	2	5	14	48	31	6.7	9	13	13	18	47	48
Crawford	14	12	26	29	19	6.2	11	12	12	14	51	53
Crittenden	4	6	17	44	29	6.6	12	27	23	22	16	30
Cross	1	2	5	20	72	7.4	16	30	21	18	15	28
Dallas	21	29	20	16	14	5.7	23	24	16	7	30	27
Desha	6	13	22	33	26	6.5	16	19	16	19	30	35
Drew	10	13	36	33	8	6.1	14	31	20	15	20	28
Faulkner	14	12	22	35	17	6.3	15	15	13	15	42	41
Franklin	10	23	34	28	5	6.0	8	15	13	10	54	57
Fulton	7	12	28	37	16	6.3	17	20	17	16	30	32
Garland	9	15	31	36	9	6.2	3	10	13	18	56	57
Grant	16	27	30	17	10	5.9	17	14	9	12	48	45
Greene	4	8	23	47	18	6.5	11	19	17	19	34	38
Hempstead	17	25	34	16	8	5.9	12	8	11	9	60	78
Hot Spring	10	23	23	33	11	6.1	11	12	7	7	63	79
Howard	10	25	30	20	15	6.0	6	5	5	6	78	184
Independence	6	11	34	35	14	6.2	9	15	15	15	46	44
Izard	8	11	28	38	15	6.3	15	21	18	12	34	34
Jackson	2	9	15	30	44	6.8	27	25	20	10	18	25
Jefferson	5	10	22	41	22	6.5	8	14	21	26	31	39
Johnson	6	19	32	36	7	6.2	8	10	12	14	56	58
Lafayette	9	15	26	28	22	6.3	11	15	10	14	50	50
Lawrence	3	7	20	45	25	6.5	17	27	21	16	19	28
Lee	2	4	20	65	9	6.5	2	8	27	37	26	40
Lincoln	15	12	22	33	18	6.2	16	9	8	7	60	62
Little River	2	5	20	52	21	6.5	9	22	20	22	27	35
Logan	15	21	33	25	6	6.0	16	14	12	10	48	46
Lonoke	7	14	27	39	13	6.3	15	27	21	16	21	29
Madison	4	16	28	34	18	6.3	4	7	5	10	74	112
Marion	3	3	11	33	50	7.0	3	12	7	8	70	99
Miller	9	16	24	31	20	6.3	10	10	11	14	55	56
Mississippi	1	3	14	66	16	6.6	2	8	15	28	47	48
Monroe	12	11	28	30	19	6.2	15	18	18	23	26	36
Montgomery	22	26	22	24	6	5.8	6	15	6	8	65	69
Nevada	13	25	27	26	9	5.9	7	13	11	15	54	53
Newton	4	7	29	41	19	6.3	2	5	15	15	63	63
Ouachita	13	22	30	21	14	6.0	16	12	7	16	49	50
Perry	15	24	36	21	14	5.9	22	19	11	11	37	31
Phillips	7	10	13	42	28	6.6	11	24	24	24	17	31
Pike	20	19	16	26	19	6.1	11	7	9	3	70	152
Poinsett	2	4	10	30	54	7.0	31	30	17	15	7	22
Polk	15	26	28	24	7	5.9	3	7	9	10	71	99
Pope	10	17	27	34	12	6.2	9	12	9	10	60	72
Prairie	5	8	6	44	27	6.6	40	31	11	10	8	18
Pulaski	16	13	17	33	21	6.3	6	10	6	12	66	76
Randolph	6	8	23	47	16	6.4	19	29	16	11	25	26

continued

Table 6. Continued.

	Soil pH[a]						Mehlich-3 soil phosphorus[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[c]
	----- (% of sampled acreage) -----						---- (% of sampled acreage) ----					(ppm)
Saline	12	16	25	36	11	6.2	8	15	14	17	46	46
Scott	9	19	35	24	13	6.0	13	15	9	8	55	61
Searcy	7	11	28	36	18	6.3	14	12	15	19	40	41
Sebastian	11	11	27	32	19	6.3	8	8	12	13	59	59
Sevier	16	23	24	32	5	6.0	2	4	6	7	81	124
Sharp	4	9	23	42	22	6.5	19	17	10	12	42	40
St. Francis	2	4	12	54	28	6.7	7	13	15	22	43	45
Stone	6	15	20	33	26	6.4	9	7	9	15	60	65
Union	11	11	24	39	15	6.3	15	10	6	15	54	54
Van Buren	5	14	30	35	16	6.3	7	14	9	12	58	62
Washington	4	7	24	36	29	6.5	3	5	8	12	72	92
White	10	14	28	34	14	6.2	12	16	11	10	51	56
Woodruff	6	10	24	55	5	6.4	16	25	17	21	21	32
Yell	9	24	33	24	10	6.0	6	10	7	10	67	118
Average	8	14	24	35	19	6.3	11	15	12	14	48	60

	Mehlich-3 soil potassium[b] (ppm)						Mehlich-3 soil zinc[b] (ppm)					
County	<61	61-90	91-130	131-175	>175	Md[c]	<1.6	1.6-3.0	3.1-4.0	4.1 8.0	>8.0	Md[c]
	----- (% of sampled acreage) -----					(ppm)	---- (% of sampled acreage) ----					(ppm)
Arkansas	2	20	46	20	12	113	3	18	20	45	14	4.5
Ashley	25	25	19	18	13	91	24	38	11	11	16	2.4
Baxter	8	13	17	21	41	153	6	14	7	17	56	10.2
Benton	12	14	20	20	34	139	4	10	9	25	52	8.9
Boone	13	14	16	12	45	155	3	17	9	26	45	6.8
Bradley	17	19	24	13	27	114	17	7	6	17	53	8.3
Calhoun	19	38	19	14	10	81	10	24	5	24	37	5.5
Carroll	10	9	11	14	56	202	3	6	4	20	67	11.5
Chicot	3	9	26	22	40	157	10	23	16	24	27	4.1
Clark	30	25	24	13	8	85	23	32	11	15	19	2.6
Clay	7	19	33	24	17	120	9	35	18	29	9	3.3
Cleburne	17	28	29	12	14	97	12	31	12	24	21	3.6
Cleveland	18	17	15	19	31	133	4	8	5	15	68	15.9
Columbia	29	28	28	8	7	81	11	19	8	16	46	6.5
Conway	21	15	18	13	33	124	15	15	11	20	39	5.3
Craighead	4	13	26	26	31	140	9	35	22	28	6	3.3
Crawford	21	24	24	14	17	98	5	28	13	28	26	4.3
Crittenden	3	10	16	17	54	191	14	36	26	22	2	3.1
Cross	10	40	32	10	8	90	9	40	19	24	8	3.1
Dallas	53	26	17	1	3	57	29	30	17	7	17	2.7
Desha	4	13	18	16	49	171	3	29	25	36	7	3.7
Drew	27	24	21	12	16	90	9	27	24	26	14	3.6
Faulkner	17	23	25	14	21	104	13	29	11	21	26	3.7
Franklin	14	23	24	17	22	117	4	25	16	26	29	4.4
Fulton	12	21	28	20	19	111	20	29	14	21	16	3.1
Garland	11	26	31	18	14	107	2	22	19	32	25	4.6
Grant	25	22	31	15	7	94	11	22	11	29	27	4.5
Greene	8	21	34	23	14	116	12	35	19	28	6	3.2
Hempstead	20	19	23	12	26	110	8	15	8	23	46	7.3
Hot Spring	21	18	17	9	35	116	11	20	12	27	30	5.2
Howard	11	17	19	15	38	140	3	7	4	17	69	15.3
Independence	25	23	22	14	16	94	19	26	9	23	23	3.7
Izard	22	23	29	14	12	98	22	32	14	19	13	2.8
Jackson	5	21	37	23	14	113	28	42	10	17	3	2.1
Jefferson	11	22	29	17	21	113	23	41	13	14	9	2.4
Johnson	12	25	27	15	21	110	7	21	13	26	33	5.2
Lafayette	13	17	21	13	36	128	16	30	11	19	24	3.5
Lawrence	12	24	31	17	16	108	15	42	13	19	11	2.7
Lee	1	5	20	26	48	170	14	63	17	6	0	2.3
Lincoln	29	25	12	10	24	87	16	17	8	22	37	5.0
Little River	2	12	38	23	25	128	19	41	17	20	3	2.6
Logan	27	20	20	11	22	94	16	22	11	17	34	4.1
Lonoke	8	22	31	17	22	113	20	45	13	14	8	2.4

continued

Table 6. Continued.

County	Mehlich-3 soil potassium[b] (ppm) <61	61-90	91-130	131-175	>175	Md[c]	Mehlich-3 soil zinc[b] (ppm) <1.6	1.6-3.0	3.1-4.0	4.1 8.0	>8.0	Md[c]
	----- (% of sampled acreage) -----					(ppm)	---- (% of sampled acreage) ----					(ppm)
Madison	15	11	19	16	39	138	5	10	11	22	52	8.5
Marion	7	17	22	11	43	146	8	11	11	17	53	9.8
Miller	22	25	22	12	19	94	8	26	8	27	31	4.8
Mississippi	2	11	24	28	35	149	3	30	24	37	6	3.8
Monroe	6	34	36	14	10	99	21	37	14	24	4	2.5
Montgomery	21	26	22	15	16	100	9	19	10	27	35	5.5
Nevada	17	20	25	17	21	106	7	19	5	41	28	5.3
Newton	13	11	16	19	41	150	8	24	17	23	28	4.2
Ouachita	36	30	15	16	3	69	14	34	6	22	24	3.4
Perry	26	21	16	13	24	95	7	40	16	22	15	3.2
Phillips	2	19	47	22	10	115	35	47	8	8	2	1.9
Pike	29	14	14	16	27	102	19	13	3	4	61	12.6
Poinsett	13	31	22	7	27	98	5	29	19	36	11	3.9
Polk	19	23	24	16	18	104	6	18	10	22	44	6.5
Pope	18	17	19	17	29	120	7	20	10	22	41	6.2
Prairie	23	21	37	14	5	96	37	37	10	13	3	2.0
Pulaski	13	21	28	18	20	112	5	13	8	25	49	7.9
Randolph	13	22	30	20	15	111	10	34	15	30	11	3.4
Saline	10	17	29	23	21	122	6	17	13	38	26	5.2
Scott	22	25	15	13	25	97	3	17	9	25	46	6.8
Searcy	19	21	22	18	20	106	24	29	11	19	17	2.8
Sebastian	8	23	23	23	23	122	1	10	10	34	45	7.2
Sevier	24	15	20	13	28	107	2	5	5	22	66	15.4
Sharp	17	24	21	16	22	107	24	23	11	22	20	3.3
St. Francis	2	9	19	21	49	174	30	48	13	8	1	2.0
Stone	19	21	19	17	24	110	11	23	10	31	25	4.8
Union	28	24	21	11	16	89	13	21	6	20	40	5.6
Van Buren	22	19	21	14	24	104	15	29	11	19	26	3.6
Washington	9	12	17	18	44	162	2	8	6	30	54	8.8
White	21	24	23	11	21	99	14	22	11	28	25	4.4
Woodruff	8	16	39	22	15	119	19	43	15	21	2	2.5
Yell	12	17	20	12	39	137	4	12	6	23	55	9.7
Average	16	20	24	16	24	116	12	26	12	23	27	5.2

[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 7. The percentage of sampled acres as distributed within five soil-test 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 2018 through 31 December 2018.

	Soil pH[a]						Mehlich-3 soil phosphorus[b] (ppm)					
Previous crop	<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[c]
	--(% of sampled acreage)--						--(% of sampled acreage)--					(ppm)
Corn	4	6	17	49	24	6.6	18	21	21	17	23	30
Cotton	0	2	14	58	26	6.6	3	13	21	31	29	39
Grain sorghum, non-irrigated	21	0	14	50	15	6.3	0	29	7	7	57	51
Grain sorghum, irrigated	3	11	25	51	10	6.3	3	9	22	38	28	41
Rice	7	9	18	37	29	6.6	23	33	20	15	9	23
Soybean	3	5	18	41	33	6.7	12	28	25	21	14	29
Wheat	13	19	26	32	10	6.1	9	22	13	17	39	41
Cool-season grass hay	6	11	32	37	14	6.3	9	15	14	14	48	47
Native warm-season grass hay	9	29	32	24	6	5.9	19	21	14	12	34	33
Warm-season grass hay	14	19	30	30	7	6.1	11	16	11	12	50	50
Pasture, all categories	7	15	31	37	10	6.2	11	11	10	11	57	64
Home garden	4	5	13	30	48	6.9	3	4	4	6	83	151
Turf	10	9	26	35	20	6.3	6	9	9	12	64	67
Home lawn	13	15	25	34	13	6.2	6	11	12	17	54	55
Small fruit	15	15	22	32	16	6.2	8	9	8	9	66	78
Ornamental	7	8	12	29	44	6.8	7	6	10	13	64	75
Average	9	11	22	38	20	6.4	9	16	14	16	45	55

	Mehlich-3 soil potassium[b] (ppm)						Mehlich-3 soil zinc[b] (ppm)					
Previous crop	<5.4	61-90	91-130	131-175	>175	Md[c]	<1.6	1.6-3.0	3.1-4.0	4.1 8.0	>8.0	Md[c]
	--(% of sampled acreage)--					(ppm)	--(% of sampled acreage)--					(ppm)
Corn	10	21	36	16	17	109	16	33	18	27	6	3.1
Cotton	3	14	17	27	39	155	11	58	18	11	2	2.5
Grain sorghum, non-irrigated	21	43	29	0	7	68	14	29	14	21	22	3.4
Grain sorghum, irrigated	1	5	33	27	34	142	9	72	15	3	1	2.4
Rice	6	30	31	14	19	105	11	44	15	24	6	2.9
Soybean	5	24	36	16	19	111	11	35	19	28	7	3.2
Wheat	12	28	30	20	10	103	23	35	11	24	7	2.5
Cool-season grass hay	30	22	21	12	15	85	10	28	15	19	28	3.7
Native Warm-season grass hay	35	23	21	10	11	79	21	22	10	24	23	3.7
Warm-season grass hay	34	23	18	10	15	80	13	27	12	23	25	4.0
Pasture, all categories	17	18	20	14	31	119	10	20	9	23	38	5.8
Home garden	6	13	18	16	47	166	3	8	5	17	67	14.2
Turf	27	21	21	14	17	93	6	15	11	34	34	6.0
Home lawn	7	18	29	22	24	125	3	16	14	38	29	5.4
Small fruit	13	21	28	19	19	112	8	20	6	24	42	5.9
Ornamental	13	22	28	18	19	112	4	10	7	23	56	9.3
Average	16	22	26	16	21	110	11	30	12	23	24	4.9

[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 median (Md) Mehlich-3 extractable sulfur (S) by year and 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 2006 through 31 December 2018.

Previous crop	S[a] (ppm) by year 2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average by previous crop
	(Median ppm)													
Corn	13	16	17	12	11	11	10	11	10	12	9	10	10	12
Cotton	13	13	15	12	10	10	10	10	13	9	8	8	8	11
Grain sorghum, non-irrigated	16	16	17	12	13	11	11	11	10	8	9	10	12	12
Grain sorghum, irrigated	11	17	17	12	10	9	9	9	9	11	8	8	11	11
Rice	27	25	26	25	23	26	23	25	26	27	25	26	21	25
Soybean	14	14	17	14	12	12	11	12	11	12	10	10	10	12
Wheat	16	17	19	14	13	13	10	13	12	12	11	14	11	13
Cool-season grass hay	21	19	21	18	15	15	16	16	15	15	13	14	13	16
Native warm-season grass hay	18	18	21	17	15	14	14	15	15	14	13	13	14	15
Warm-season grass hay	19	19	21	17	16	15	14	15	14	16	14	14	14	16
Pasture, all categories	18	19	22	18	17	16	17	17	16	16	15	15	16	17
Home garden	18	19	22	18	16	16	16	17	15	15	14	15	16	17
Turf	17	17	19	16	13	14	13	15	14	14	11	14	12	15
Home lawn	22	22	23	19	18	16	16	17	16	16	15	16	16	18
Small fruit	21	22	21	20	18	17	17	18	15	17	15	17	16	18
Ornamental	20	22	24	18	18	15	16	17	16	15	14	15	16	17
Average by year	18	19	21	17	15	15	14	15	15	15	13	14	14	

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

Assessment of Bermudagrass Forage Yield and Nutrient Uptake in Response to Phosphorus and Potassium Fertilization

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Abstract

Hay cut systems exhaust soil nutrients by removing large amounts of vegetative material with each cutting, and nutrients are not returned via manure or fertilizer. Soil nutrient deficiencies limit productivity and result in thin forage stands, ultimately reducing forage yields and forage quality. Thus, field studies were conducted to monitor the effects of varying phosphorus (P) and potassium (K) fertilizer rates on bermudagrass (*Cynodon dactylon* L.) productivity. Two pairs of P-rate and K-rate replicated trials were initiated in separate fields in Batesville, Ark., and in Fayetteville, Ark. Each fertilizer was applied at five rates and compared to an untreated check, arranged in a randomized complete block design and replicated five times in each location. In P-rate trials, triple superphosphate was applied at rates of 0, 30 (× 1), 60 (30 × 2), 90 (30 × 3), 120 (40 × 3), and 150 (50 × 3) lb P_2O_5/acre with split applications applied at green-up (× 1), following harvest 1 (× 2), and following harvests 1 and 2 (× 3). In the K-rate trial, muriate of potash was applied at rates of 0, 70 (35 × 2), 150 (50 × 3), 225 (75 × 3), 300 (100 × 3), and 375 (125 × 3) lb K_2O/acre, using previously defined timings for split applications. Data were collected for hay yield and forage nutrient concentration at each cutting, analyzing P and K concentrations.

Introduction

In Arkansas, there are 1.3 million acres of hayland production, with an additional 3.2 million acres of pasture (USDA-NASS, 2017). Thus, decisions regarding soil nutrient management in forage production will affect more acres than any other agricultural commodity crop in the state. Surveys indicate that the majority of southern pastures and hayland are not regularly soil tested and that, of the tested acres, many are deficient in critical soil nutrients (Ball et al., 2015). Further, hayland acres are commonly not fertilized annually. With the large amount of aboveground biomass removed from each site, deficiencies of critical soil nutrients can quickly develop.

This project was designed to monitor yield responses associated with application rates of phosphorus (P) and potassium (K) and to further assess forage nutrient capture using forage samples at each harvest. Too little of either P or K fertilizer could stress the system as nutrients in hay are removed from the field but never replaced. In contrast, excess application of either P or K fertilizer could result in unnecessary expenditures with no benefits to bermudagrass hay yields or forage quality. Thus, the objective of this study is to compare the hay yields, nutrient uptake, and soil nutrient concentrations and to develop optimal fertilizer recommendations for bermudagrass hay production in Arkansas.

Procedures

Field studies were initiated in the spring of 2019 to evaluate the effects of P and K fertilization on bermudagrass hay yields, nutrient removal, and soil nutrient content. Trials were located in Fayetteville, Ark., at the Milo J. Shult Agricultural Research & Extension Center on a soil mapped as a Pickwick silt loam and in Batesville, Ark., at the Livestock & Forestry Research Station on a soil mapped as a Peridge silt loam. Visual inspection of each site in spring 2019 determined both exhibited uniform stands of bermudagrass. Each selected site was managed uniformly with no history of fertilization experiments with varying fertility rates. Records indicate that 'Greenfield' bermudagrass was sprigged at the Fayetteville site in 2012 and that 'Hardie' bermudagrass was sprigged at the Batesville site in 1984.

Prior to fertilizer treatment application, composite soil samples were collected from a 0- to 4-inch depth in each plot, with each composite sample composed of five 1-inch-wide cores. Soils were dried at 150 °F, crushed to pass a 2-mm diameter sieve, analyzed for water pH (1:2 soil weight:water volume ratio), and extracted for plant-available nutrients using the Mehlich-3 method (Table 1). Phosphorus and K rates for this experiment were selected using results from a previously executed study published by Slaton et al. (2011).

In the K rate trial, fertilizer K was applied over two to three applications to reach cumulative season-total rates. Muriate of potash (62% K_2O) was applied at rates of 0, 70 (35 × 2), 150 (50 × 3), 225 (75 × 3), 300 (100 × 3), and 375 (125 × 3) lb K_2O/acre, with split applications occurring at green-up, following the first harvest, and following the second harvest. This trial was conducted at two sites, and environmental differences affected the timing of fertilizer applications. Therefore, fertilizer applications during green-up, following the first harvest, and following the second harvest occurred on 10 May and 15 May, 1 July and 8 July, 16 August and 7 August, at Fayetteville and Batesville, respectively. A blanket application of 100 lb/acre of

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triple superphosphate (46% P_2O_5) was applied at green-up, for a season total of 46 lb P_2O_5/acre. Nitrogen fertilizer (granulated urea, 46% N) was applied at 100 lb urea/acre in three split applications including at green-up, after the first harvest, and after the second harvest, for a season total of 138 lb N/acre.

In the P rate trial, fertilizer P was applied over two to three applications to reach the cumulative season-total rates. Triple superphosphate was applied at rates of 0, 30 (× 1), 60 (30 × 2), 90 (30 × 3), 120 (40 × 3), and 150 (50 × 3) lb P_2O_5/acre, with split applications occurring at the same dates and timings as the K rate trial for each respective site. A blanket application of 150 lb muriate of potash/acre was applied at green-up for a total of 93 lb K_2O/acre. Similar to the K rate trial, 100 lb urea/acre was applied at green-up, after the first harvest, and after the second harvest, for a season total of 138 lb N/acre.

To ensure no contamination between plots, fertilizers were applied by hand. Treatment fertilizers were pre-weighed and broadcast by hand in each plot (10 ft × 24 ft, 240 sq ft) at the previously disclosed timings. Blanket fertility applications were pre-weighed for the entire experimental area of each trial and each site (7200 sq ft) and broadcast in two directions, using a hand-cranked rotary spreader.

Plots were harvested using a self-propelled sickle-bar mower, adjusted to a 2.0- to 2.5-inch cutting height. The harvested area was calculated using the width of the mower blade (3.8 ft) multiplied by the distance cut within each plot. Operators cut plots to approximately 20 feet within each plot; however, even with careful operation, variation occurred in plots. Thus, plot lengths were recorded for each plot after each harvest and used to calculate the harvested area. The fresh weight of harvested biomass was collected immediately after each cutting. To determine moisture content, samples (~500 g) were collected from each plot, weighed fresh then dried and weighed. Hay yields in this summary are all reported as dry matter yields. Hay yield totals were calculated by summing dry matter yields per harvested area from each harvest within a season.

Each fertility study was conducted as a 2 × 6 factorial with two locations and six fertilizer treatments. At each site, plots were arranged in a randomized complete block design with five replications. As designed, fixed effects included fertility treatment, location, and the interaction of fertility with location, while rep nested within location was treated as a random effect. Forage yield data from individual harvests and the season total were subjected to analysis of variance (ANOVA) using the GLIMMIX procedure in SAS (v. 9.4, SAS Institute, Cary, N.C.). Means associated with fertilizer treatments at each location were of greater interest than combined means across locations; thus, separate ANOVA were conducted and reported for each location, despite a lack of a significant interaction between main effects of fertilizer and location (data not shown). Means were separated using Fisher's protected least significant difference (LSD) at an $\alpha = 0.05$ significance level. Residual panels were observed, and it was determined that no transformations were necessary for the data set to meet the ANOVA assumptions of normality.

Results and Discussion

In K rate trials, no significant effect of fertilizer-K rate was observed for total bermudagrass hay yield at either location (Table 2). There were no statistical differences observed among yields at any harvest, in either location; however, a numerical trend indicates that total yields were lowest among plots receiving no K fertilizer. It is important to note that our selected statistical parameters suggest these differences would not be observed if the same trial were repeated. These results suggest that K was available in sufficient quantity in the soil to maintain hay yields in all treatments. It is likely that lower K fertilizer rate treatments and the untreated control will display a further reduction in yield in subsequent growing seasons as the soil K level is depleted.

Similar to K rate trials, no significant effect of fertilizer-P rate was observed on total bermudagrass hay yields in either location (Table 3). Total yields were not statistically different in either site, and we do not consider the second harvest yield differences measured in Batesville to be of great interest because the no-P control yield was similar to all other P rates. Yield data suggest soil-test P at both sites was sufficient to maintain yields, regardless of the applied fertilizer-P treatment (Table 1). Of the two tested nutrients, K exhibited a larger numerical effect on dry matter yield. However, total yields were stable among both trials, indicating that soil-test P and K levels were sufficient to mask the effects of the fertilizer-P or -K rates that were less than crop P or K removal in the first year of study.

Bermudagrass forage-K concentration increased as fertilizer-K rate increased, across all harvests and locations (Table 4). Additionally, the total lb K_2O/acre removed with bermudagrass hay increased as the fertilizer-K rate increased. Thus, plots receiving the greatest fertilizer-K rates accumulated the highest concentration of foliar K and removed the largest amounts of K in the harvested hay. However, no yield increase was observed in response to the higher fertilizer-K rates. Therefore, much of the fertilizer-K applied at higher rates (e.g., 375 lb K_2O/acre) resulted in luxury consumption removing K in the harvested forage without any yield benefit. The season-total recovery of the applied fertilizer-K by forage declined numerically from 51% to 32% at Fayetteville and 62% to 30% at Batesville as fertilizer-K rate increased.

Bermudagrass forage-P concentration was not affected by the fertilizer-P rate (Table 5). No significant differences were observed in forage-P concentrations at any harvest in either location. In Fayetteville, the total P removal was not affected by fertilizer-P rate; however, in Batesville, the forage P removal increased as the fertilizer-P rate increased. This is an interesting finding because no differences were observed in the total yields (Table 3) nor forage P concentrations (Table 5) in response to the fertilizer-P rate. Differences in forage P removal in Batesville were small in magnitude with little variation among the intermediate P rates. The season-total recovery of the applied fertilizer-P by forage, calculated by difference, suggested that recovery of the applied fertilizer-P at Fayetteville where soil-test P was Above Optimum, averaged 5%, but at Batesville where the soil-test P level was Medium, forage recovery of the applied fertilizer-P averaged 10% among P rates.

Practical Applications

Preliminary findings of this experiment indicate that no yield responses to P or K fertilization will be observed when the soil-test K level is Low (61 to 90 ppm) and the soil-test P level is Medium (26 to 35 ppm, Batesville) or Above Optimum (>50 ppm, Fayetteville). However, it would be misguided to interpret these findings as an indication that bermudagrass hay production requires no P or K fertilization. Instead, the proper conclusion is that the current data set is incomplete and does not account for the cumulative effect of the fertility treatments over multiple growing seasons. Thus, it is critical that this study be continued to evaluate the long-term consequences of the suboptimal P and K fertilization rates. Long-term monitoring of yields, nutrient removal, and soil nutrient levels will provide insight into the effects of cumulative P and K deficiencies. Further, long-term results will fine-tune P and K fertility recommendations for bermudagrass hay production offered by the University of Arkansas System Division of Agriculture.

Acknowledgments

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Table 1. Initial soil chemical property means (n = 30; 0- to 4-in. depth) for each location and fertilizer trial.

Location	Trial	pH	P	B	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu
			Mehlich-3 extractable nutrients										
			(ppm)										
Batesville	Phosphorus	5.67	29	0.33	66	979	43	16	9	109	309	0.50	0.59
Batesville	Potassium	5.63	32	0.34	65	947	33	18	8	120	325	0.45	0.59
Fayetteville	Phosphorus	5.64	96	0.33	79	918	47	12	22	236	181	7.96	2.60
Fayetteville	Potassium	5.44	72	0.26	68	739	45	12	7	203	191	6.20	2.22

Table 2. Bermudagrass hay yields in response to potassium (K) fertilization in Fayetteville, Ark., and Batesville, Ark., during the 2019 growing season.[a]

Seasonal total	Potassium trial							
	Fayetteville				Batesville			
K_2O rate[b]	Total	Harvest 1	Harvest 2	Harvest 3	Total	Harvest 1	Harvest 2	Harvest 3
(lb K_2O/acre)	(lb forage/acre)							
0	6909	2597	1738	2574	6369	2277	1716	2375
70$^{\times 2}$	6940	2666	1993	2281	6804	2370	1721	2713
150$^{\times 3}$	7691	2732	2183	2777	7255	2979	2031	2245
225$^{\times 3}$	7594	2856	1954	2784	6977	2687	1712	2579
300$^{\times 3}$	7813	2894	2146	2774	7251	2789	1838	2624
375$^{\times 3}$	7785	3040	2079	2665	7320	2947	1775	2599
	(*P*-value)							
Fertilizer	0.2240	0.2735	0.3530	0.5550	0.3614	0.1344	0.4305	0.3633

[a] Means were separated according to Fisher's protected least significant difference (LSD). Means followed by the same letter do not differ at the α = 0.05 level. Means lacking letters indicate that the main effect of fertilizer was not significant ($P > 0.05$).

[b] The superscripted value indicates the number of split applications to apply the season-total K rate. Potassium fertilizer treatments were applied at green-up and after first and second harvests.

Table 3. Bermudagrass hay yields in response to phosphorus (P) fertilization in Fayetteville, Ark., and Batesville, Ark., during the 2019 growing season.[a]

Seasonal total	Phosphorus trial							
	Fayetteville				Batesville			
P_2O_5 rate[b]	Total	Harvest 1	Harvest 2	Harvest 3	Total	Harvest 1	Harvest 2	Harvest 3
(lb P_2O_5/acre)	(lb forage/acre)							
0	7593	2988	2085	2520	6113	2161	1768 ab	2185
30[×1]	7205	2494	2217	2494	6328	2542	1575 b	2211
60[×2]	7797	3148	2064	2586	6195	2249	1805 ab	2141
90[×3]	7633	2611	2277	2745	6605	2380	1916 a	2310
120[×3]	7817	2910	1985	2923	6254	2182	1633 b	2439
150[×3]	7733	2977	1944	2811	6919	2454	1977 a	2488
	(*P*-value)							
Fertilizer	0.6828	0.5210	0.1172	0.1685	0.2044	0.6546	0.0298	0.1587

[a] Means were separated according to Fisher's protected least significant difference (LSD). Means followed by the same letter do not differ at the α = 0.05 level. Means lacking letters indicate that the main effect of fertilizer was not significant ($P > 0.05$).
[b] The superscripted value indicates the number of split applications to apply the season-total P rate. Phosphorus fertilizer treatments were applied at green-up and after first and second harvests.

Table 4. Bermudagrass forage potassium (K) concentration and total K_2O removal in response to K fertilization in Batesville, Ark., and Fayetteville, Ark., during the 2019 growing season.[a]

Seasonal total	Fayetteville				Batesville			
	Forage K concentration			Total K_2O	Forage K concentration			Total K_2O
K_2O rate[b]	Harvest 1	Harvest 2	Harvest 3	removal[c]	Harvest 1	Harvest 2	Harvest 3	removal
(lb K_2O/acre)	(%)			(lb K_2O/acre)	(%)			(lb K_2O/acre)
0	1.278 a	1.176 d	1.040 e	96.8 e	1.404 c	1.436 d	1.254 e	103.6 e
70[×2]	1.706 c	1.706 c	1.382 d	132.6 d	1.662 bc	2.172 bc	1.674 d	147.0 d
150[×3]	1.686 c	1.954 bc	1.914 c	170.3 c	1.538 bc	2.142 c	2.342 c	170.2 cd
225[×3]	1.808 bc	2.076 b	2.082 bc	180.4 bc	1.820 ab	2.530 ab	2.464 bc	186.0 bc
300[×3]	1.988 ab	2.030 b	2.196 ab	194.6 ab	1.748 ab	2.662 a	2.770 a	203.8 ab
375[×3]	2.152 a	2.508 a	2.356 a	216.1 a	2.004 a	2.748 a	2.684 ab	214.5 a
	(*P*-value)							
Fertilizer	<0.0001	<0.0001	<0.0001	<0.0001	0.0069	<0.0001	<0.0001	<0.0001

[a] Means were separated according to Fisher's protected least significant difference (LSD). Means followed by the same letter do not differ at the α = 0.05 level. Means lacking letters indicate that the main effect of fertilizer was not significant ($P > 0.05$).
[b] The superscripted value indicates the number of split applications to apply the season-total K rate. Potassium fertilizer treatments were applied at green-up and after first and second harvests.
[c] Total K_2O removal was calculated by multiplying forage K concentration by dry matter yield at each harvest, multiplying by a conversion factor (1.205), then summing the values from each harvest.

Table 5. Bermudagrass forage phosphorus (P) concentration and total P_2O_5 removal in response to P fertilization in Batesville, Ark., and Fayetteville, Ark., during the 2019 growing season.[a]

Seasonal total	Fayetteville				Batesville			
	Forage P concentration			Total P_2O_5	Forage P concentration			Total P_2O_5
P_2O_5 rate[b]	Harvest 1	Harvest 2	Harvest 3	removal[c]	Harvest 1	Harvest 2	Harvest 3	removal
(lb P_2O_5/acre)	(%)			(lb P_2O_5/acre)	(%)			(lb P_2O_5/acre)
0	0.368	0.498	0.450	74.5	0.236	0.316	0.320	40.3 c
30[×1]	0.398	0.508	0.452	74.1	0.266	0.372	0.352	46.3 bc
60[×2]	0.400	0.518	0.518	83.5	0.282	0.336	0.338	44.0 c
90[×3]	0.392	0.482	0.472	78.3	0.250	0.314	0.360	46.1 bc
120[×3]	0.394	0.506	0.460	79.7	0.300	0.360	0.412	51.2 ab
150[×3]	0.420	0.538	0.488	84.0	0.272	0.358	0.34	53.7 a
	(*P*-value)							
Fertilizer	0.3921	0.3675	0.0589	0.2858	0.3753	0.239	0.0717	0.0066

[a] Means were separated according to Fisher's protected least significant difference (LSD). Means followed by the same letter do not differ at the α = 0.05 level. Means lacking letters indicate that the main effect of fertilizer was not significant ($P > 0.05$).
[b] The superscripted value indicates the number of split applications to apply the season-total K rate. Potassium fertilizer treatments were applied at green-up and after first and second harvests.
[c] Total P_2O_5 removal was calculated by multiplying forage P concentration by dry matter yield at each harvest, multiplying by a conversion factor (2.29), then summing the values from each harvest.

Yield Response of Summer Grasses to Phosphorus and Potassium Fertilization in Arkansas

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Abstract

Fertilization represents a significant portion of the cost of growing summer grasses in Arkansas. Nitrogen (N) is the most limiting fertilizer, followed by potassium (K) and phosphorus (P). Trials were established to study the response of summer grasses to phosphorus (P) and potassium (K) fertilization. Treatments consisted of 0, 40, 80 and 120 lb P_2O_5/acre applied in a single application. Additional treatments included rates equivalent to 40, 80 and 120 lb P_2O_5/acre applied after each harvest. Potassium treatments consisted of rates equivalent to 0, 50, 100, 150 and 200 lb K_2O/acre applied in a single application. Additional treatments included rates equivalent to 50, 100 and 150 lb K_2O /acre. Studies were established at the University of Arkansas System Division of Agriculture's Livestock and Forestry Research Station (LFRS), near Batesville, Ark., in a field planted to bermudagrass (*Cynodon dactylon* L.) and at a field near Mount Ida, Ark., in a field planted to bahiagrass (*Paspalum notatum* Flugge). There was a significant yield response to K fertilization at both study sites for the first harvest (June) and season-total, but no treatment effect was observed during the second and third cutting. Low rainfall and excessive heat may have contributed to the lack of response. A single phosphorus study was established at the Livestock and Forestry Research Station, in a soil testing in the medium to optimum range. The treatment effect was significant for each cutting, despite the variability in treatment means, as evidenced by the relatively large coefficient of variation (CV).

Introduction

Every year, more than 5 million acres of land are used in Arkansas to produce hay or for cattle grazing. Low cattle prices force farmers to manage a considerable portion of the hay and pastureland under low input. Fertilization represents a significant percentage of the costs of producing a bale of hay. However, even with hay and pastures representing the largest cropping area in the state, only about 17% of the area is soil sampled (DeLong et al., 2019). The lack of soil sampling and soil-test-based decisions results in over- or under application of some nutrients, particularly phosphorus (P) and potassium (K). Recent soil-test data has shown that, with the exception of nutrient surplus areas, more than one-half of the samples from pastures and forages test deficient for P and K (DeLong et al., 2019).The lack of conclusive guidelines on forage response to P and K fertilization rate under the varying soils and geographical locations in Arkansas makes it difficult to talk to a producer about investing in fertilizers. There have been sporadic efforts to conduct P and K rate response studies (Slaton et al., 2011; Slaton et al., 2012), with inconsistent results. So, there is an imperative need to establish studies to evaluate the rate response of warm-season grasses to P and K fertilization, under suboptimum soil test P and K levels, and under the varying soils and geographical locations in Arkansas.

Procedures

Research plots were established at the Livestock and Forestry Research Station (LFRS), near Batesville, Ark., and at a producer's field near Mount Ida (MI), Ark., in 2019. The soil at the LFRS is mapped as a Peridge silt loam. The soil at the MI location is mapped as a Littlefir-Bismarck complex. Soil samples were collected before the first application of fertilizer, from eight points inside each testing plot. The soil was extracted for plant-available nutrients using the Mehlich-3 procedure. Soil pH was measured in a 1:2 soil: water (vol:vol) mixture. Treatments consisted of rates equivalent to 0, 40, 80, and 120 lb P_2O_5/acre applied in a single application as triple superphosphate (46% P_2O_5). Additional treatments included rates equivalent to 40, 80, and 120 lb P_2O_5/acre applied after each harvest. Potassium treatments consisted of rates equivalent to 0, 50, 100, 150, and 200 lb K_2O/acre applied in a single application as muriate of potash (60% K_2O). Additional treatments included rates equivalent to 50, 100 and 150 lb K_2O/acre after each harvest. Treatments were applied manually, immediately after harvest. Tifton 44 bermudagrass (*Cynodon dactylon* L.) was the forage established at the LFRS site, while bahiagrass (*Paspalum notatum* Flugge) was the species at MI.

The plot dimensions were 10 ft wide by 20 ft long with treatments arranged in a randomized complete block design and replicated four times. At greenup and following the first and second hay cutting, 150 lb N/acre was applied as ammonium nitrate for a season total-N rate that approximated 450 lb N/acre. Similarly, a season-total rate of 270 lb P_2O_5/acre was applied as triple superphosphate (46% P_2O_5) in three split applications (at greenup, after harvest 1 and after harvest 2) of 90 lb P_2O_5/acre to the K trial and a season-total rate of 360 lb K_2O/acre was applied in three split applications of 120 lb K_2O/acre as muriate of potash (60% K_2O) to the P trial.

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[3] County Extension Agent and County Extension Agent, respectively, Lonoke County.

At harvest, a section 3.5-ft wide by 18-ft long was cut from the center of each plot using a self-propelled mower (www.walker.com) at a height of 3.5 to 4 inches. Weights were recorded, with a subsample collected for moisture and nutrient analysis. The subsample was dried in a forced-air dryer at 140 °F until constant weight. The whole subsample for 3 of the 4 replications, for the LFRS only, was ground to pass a 2-mm sieve and further subjected to digestion with HNO_3 and H_2O_2 for nutrient analysis. The study at LFRS was harvested on 20 June, 6 August, and 12 September, while the study at MI was harvested 1 June, 10 July, and 12 August. Samples from MI have yet to be processed.

Dry matter yields were analyzed by location with the PROC GLM procedure in SAS (SAS Institute, Inc., Cary, N.C.). Dry forage yields from each harvest time and season total were compared with the least significant difference procedure at a significance level of 0.10.

Results and Discussion

Table 1 shows descriptive statistics of selected soil chemical properties. The soil-test K levels at the LFRS are classified as Very Low according to the current soil test interpretation, and seem to be uniform across the testing site, based on the low standard deviation. However, soil-test P levels at the LFRS fall in the Medium to Optimum range. The soil-test K levels at MI are classified in the Low category, while the soil-test P level is classified as Medium. The suboptimal K levels at both locations would suggest a possible yield response to supplemental K fertilizer. The soil-test magnesium, particularly at the LFRS, is Very Low. The potential effect on observed results is unknown at this moment.

Potassium Study

Table 2 shows a significant yield response of bahiagrass at MI to K fertilization for the first harvest (1 June) and season total harvest at MI, but K fertilization had no effect on forage yield for harvest times 2 and 3. The lack of sufficient rainfall at the site probably masked the potential treatment effects. During the second growing cycle, the site received about 8 inches of rain, however much of the total rainfall occurred in two rainfall events. The lack of rain and the abnormally high temperatures experienced during the growing cycle delayed harvest for 7 days. A similar situation occurred during the third growing cycle. There was a trend for season total yield to increase, above the control plots, with increasing fertilizer application. Under the conditions of this study, for the first harvest and for the season total, forage yields were maximized with rates equivalent to 150 lb K_2O/acre.

Bermudagrass forage yields at the LFRS were significantly increased with K-fertilizer applications during harvest 1, but not for harvests 2 and 3 (Table 3). A significant yield difference was also observed among treatments for the season total harvest. Yields were maximized by application of 100 lb K_2O/acre. The second and third fertilizer application do not appear to have had any effect on yields, perhaps due to the weather conditions experienced for the duration of the study. The magnitude of forage yield gains above the control was not as consistent as in the MI site, perhaps due to experimental error. Under the conditions of the test at LFRS, about one-half of the season total yield was obtained in the first cut. The opportunity to maximize yield potential after greenup with larger fertilizer applications requires further evaluation.

The tissue-K concentration for the single application treatments at LFRS showed a decreasing trend with harvest time. The tissue-K concentrations in the 50 and 100 lb K_2O/acre treatments were in the deficiency range (< 1.5%), although yields were maximized at 100 lb K_2O/acre. Those treatments receiving sequential fertilizer-K applications showed sufficient tissue concentration levels (Table 4). Total K removed with the biomass ranged from 84 to 122 lb K/acre, which is equivalent to 101 to 147 lb K_2O/acre..

Phosphorus Study

Significant yield responses to P fertilization were observed for each harvest time at the LFRS (Table 5). Yield gains with fertilizer-P application were numerically higher for most of the treatments during harvest time 1 compared with the yields obtained in harvest times 2 and 3. Data shows that yield gains from single application treatments were reduced considerably during harvest times 2 and 3. Season total yield gains from treatments that included sequential applications were twice as large, in some instances, than those observed with single applications. The tissue-P concentrations were in the Optimum range, according to standard guidelines, and increased with fertilizer treatment particularly in those treatments that received sequential applications (Table 6).

Practical Applications

The preliminary findings of this study show forage yield increases with fertilization were observed when bermudagrass and bahiagrass were grown in fields that had soil-test K levels considered suboptimal to maximize yield potential. Bahiagrass yields increased by 6% to 42% at a site near Mount Ida, Ark., that tested Low in soil-test K. Bermudagrass yields increased between 3% to 42% in a site at the Livestock Forestry Research Station, near Batesville, Ark. It is believed that the potential benefits of K fertilization were limited by the lack of rain and excessive heat during the summer months in 2019. Almost one-half of the season-total yield was obtained in the first cut, after green up. In a P fertilization study, bermudagrass yields almost doubled with P fertilization in a soil testing Optimum. The response to P fertilization was significant, with the greatest yields obtained from fertilizer-P application at a seasonal-total rate of 360 lb P_2O_5/acre.

Acknowledgments

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Table 1. Descriptive statistics of selected soil chemical properties, from tests plots, before treatment applications. Samples were analyzed using the Mehlich-3 procedure (n = 40).

Location		P	K	Ca	Mg	S	Zn
		(mg/kg)					
Batesville - K study	Mean	38	55	721	22	13	0.7
	Standard deviation	12	9	106	3.3	1.9	0.2
Batesville - P study	Mean	38	45	716	22	13	1
	Standard deviation	15	7	145	3	2	10
Mount Ida - K study	Mean	31	73	387	82	11	4.2
	Standard deviation	11	19	149	28	1	1.1

Table 2. Average forage yield response of bahiagrass to varying potassium fertilization rates and frequencies and statistical parameters for the site located near Mount Ida, Ark.

Total K_2O rate	K_2O rate and frequency	First harvest	Second harvest	Third harvest	Season total
(lb/acre)		(lb dry matter/acre)			
0	--	1584	850	996	3509
50	50 x 1	1683	979	1075	3835
100	100 x 1	1812	1012	1151	3842
150	150 x 1	2230	1033	1163	4474
200	200 x 1	2126	1146	1173	4439
150	50 x 3[a]	1753	1149	1179	4124
300	100 x 3	2396	1212	1225	4850
450	150 x 3	2339	1303	1232	4730
$LSD_{0.10}$		316	NS[b]	NS	536
CV (%)		13.1	19.3	16.1	10.5
P-value		0.0004	0.11	0.65	0.002

[a] Number of fertilizer applications.
[b] NS = not significant.

Table 3. Average forage yield response of bermudagrass to varying potassium fertilization rates and frequencies and statistical parameters for the site located at the Livestock and Forestry Research Station (LFRS) near Batesville, Ark.

Total K_2O rate	K_2O rate and frequency	First harvest	Second harvest	Third harvest	Season total
(lb/acre)		(lb dry matter/acre)			
0	--	1889	1626	1241	4816
50	50 x 1[a]	2058	1821	1253	5329
100	100 x 1	2687	1842	1272	5887
150	150 x 1	2537	1846	1275	5662
200	200 x 1	2584	1884	1300	5891
150	50 x 3	1749	1933	1324	4980
300	100 x 3	2254	1943	1353	5325
450	150 x 3	2334	1956	1464	5538
$LSD_{0.10}$		372	NS[b]	NS	624
CV (%)		15.3	19.5	17.6	10.7
P-value		0.009	0.876	0.83	0.05

[a] Number of fertilizer applications.
[b] NS = not significant .

Table 4. Average (n = 3) potassium concentration in bermudagrass tissue and potassium uptake according to fertilizer treatment at the study site located at the Livestock and Research Forestry Station (LFRS), near Batesville, Ark.

		Tissue K concentration			K uptake			
Total K_2O rate	K_2O rate and frequency	First harvest	Second harvest	Third harvest	First harvest	Second harvest	Third harvest	Season total
(lb/acre)		(% K)			(lb K/acre)			
0	--	2.0	1.7	1.2	39.5	29.3	14.9	83.7
50	50 x 1[a]	2.2	1.7	1.5	46.2	29.3	18.1	93.7
100	100 x 1	1.8	1.7	1.4	49.3	34.6	20.1	104.1
150	150 x 1	2.3	2.0	1.8	60.2	38.4	20.4	119.1
200	200 x 1	2.6	2.1	1.6	64.9	35.9	21.1	122.1
150	50 x 3	1.5	1.7	1.8	25.3	39.2	21.13	85.7
300	100 x 3	1.6	2.1	1.8	36.2	39.4	23.4	99.2
450	150 x 3	1.8	2.4	1.9	40.7	39.9	24.3	104.51
$LSD_{0.1}$		NS[b]	NS	0.33	17.72	NS	NS	20.96
CV (%)		24.71	22.01	14.22	27.43	19.71	21.11	14.51
P-value		0.18	0.36	0.02	0.02	0.39	0.27	0.04

[a] Number of fertilizer applications.
[b] NS = not significant.

Table 5. Average forage yield response of bermudagrass to varying phosphorus fertilization rates and frequencies and statistical parameters for the site located at the Livestock and Forestry Research Station (LFRS) near Batesville, Ark.

Total P_2O_5 rate	P_2O_5 rate and frequency	First harvest	Second harvest	Third harvest	Season total
(lb/acre)		(lb dry matter/acre)			
0	--	1889	1626	1241	4816
0	--	1608	864	1177	3649
40	40 x 1[a]	2293	1098	1232	4622
80	80 x 1	2375	1091	1297	4763
120	120 x 1	2601	1331	1236	5170
120	40 x 3	2262	1406	1636	5304
240	80 x 3	2310	1801	1779	5890
360	120 x 3	2512	2426	1903	6843
LSD (0.10)		504	360	234	679
CV (%)		20.5	23.4	14.8	12.2
P-value		0.005	<0.0001	<0.0001	<0.0001

[a] Number of fertilizer applications.

Table 6. Average (n = 3) phosphorus concentration in bermudagrass tissue and phosphorus uptake according to fertilizer treatment at the study site located at the Livestock and Forestry Research Station (LFRS), near Batesville, Ark.

		Tissue P concentration			P uptake			
Total P_2O_5 rate	P_2O_5 rate and frequency	First harvest	Second harvest	Third harvest	First harvest	Second harvest	Third harvest	Season total
------------------(lb/acre)-----------------		---------------------(% P)---------------------			----------------------------- (lb P/acre) ---------------------------			
0	--	0.37	0.39	0.43	6.32	3.00	4.24	13.57
40	40 x 1[a]	0.37	0.43	0.44	9.03	4.36	5.47	18.87
80	80 x 1	0.33	0.47	0.44	7.99	5.02	5.67	18.68
120	120 x 1	0.32	0.48	0.55	8.51	5.90	6.21	20.63
120	40 x 3	0.32	0.54	0.51	6.89	6.34	8.76	22.00
240	80 x 3	0.32	0.53	0.57	7.25	8.76	10.38	26.41
360	120 x 3	0.38	0.57	0.56	10.17	13.45	10.25	33.89
$LSD_{0.1}$		NS[b]	NS	0.33	17.72	NS	NS	20.96
CV (%)		24.71	22.01	14.22	27.43	19.71	21.11	14.51
P-value		0.18	0.36	0.02	0.02	0.39	0.27	0.04

[a] Number of fertilizer applications.
[b] NS = not significant.

Spatial Variability of Soil-Test Potassium and Other Soil Properties in Ten Arkansas Discovery Farm Fields

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Abstract

The Arkansas Discovery Farm Program has primarily been documenting nitrogen and phosphorus loss via edge-of-field water runoff on real working farms since 2010 by utilizing state-of-the-art automated water sampling equipment. Potassium (K) loss documentation in water runoff was initiated in 2017 to better understand K loss potential in water runoff and lead to increased farm profitability and/or efficiency. Although little is known about K loss potential via water runoff, less is known of the relation of soil-test K (STK) spatial variability to K loss in water runoff. This report focuses on STK spatial variability of four Arkansas Discovery Farms representing ten sites managed for either hay, row-crop, poultry, or beef production. Sites were grid soil sampled showing the highest STK values at the lowest elevations or drainage points in the field for row-crop sites while the highest levels for sites around poultry houses occurred in front of and behind poultry houses. Across sites, mean STK values for the 0- to 4- or 0- to 6-inch sampling depth ranged from 83 to 264 ppm K. Samples taken at the 4- to 8- or 6- to 12-inch depth showed a lower range of mean STK (72 to 172 ppm K). The coefficient of variation range for STK across sites was also greater for shallower sample depths (18% to 84%) relative to deeper sample depths (25% to 68%). A better understanding of STK spatial variability and the potential relationship between K loss in water runoff will ultimately lead to greater farm profitability and sustainability in the use of K fertilizer management.

Introduction

Arkansas Discovery Farms are working farms where automated water monitoring equipment is installed to quantify nutrient and sediment loss at the field scale (Sharpley et al., 2016; Daniels et al., 2018). For environmental reasons, phosphorus, nitrogen, and sediment losses (Daniels et al., 2019) have been the primary focus of the Arkansas Discovery Farms program since its initiation in 2010. In 2017, potassium (K) monitoring also became a priority. Although K runoff poses no water quality concern, soil- and fertilizer-K loss does represent an economic loss for producers. Along with economic questions, there is little known about the potential for K loss in runoff from agricultural production systems in Arkansas. Furthermore, little is known about how spatial variability of K and other soil properties might relate to K loss in water runoff.

The aim of this project is to better understand the interactions of soil-test K (STK) and other soil chemical properties under row-crop and livestock production systems on Arkansas Discovery Farms to aid in farmer profitability. More specific goals are to (a) quantify K losses in edge-of-field runoff water; (b) quantify the spatial variability, both horizontally and vertically, of K and other selected soil properties; and (c) look for any relationship between K variability and K loss at edge-of-field runoff. As edge-of-field K losses have been reported previously (Sharpley et al., 2019), this report focuses on research to assess soil K variability as a function of land management.

Procedures

Currently, 12 Arkansas Discovery Farms are actively monitoring water runoff across the state, but this report contains soil-test data from 4 Arkansas Discovery Farms encompassing 10 separately monitored fields (Fig. 1). Field size, management, and K fertilizer source, rate, and application timing are listed in Table 1. Site identifiers listed in this report correspond to the site names listed in an earlier series (Sharpley et al., 2019) reporting K loss in water runoff.

The Stevens farm (Stevens 2, 3, and 4), located in Desha County in the Bayou Macon Watershed is a row-crop operation where corn (*Zea mays* L.) and cotton (*Gossypium hirsutum* L.) are primarily grown. Conservation tillage (stale seedbed) and cover crops (cereal rye; *Secale cereal* L.) are implemented on the majority of this farm.

The Marley farm (Marley 2 and 3), located in Washington County in the Beaver Lake-Upper White River Watershed, is a poultry and beef-grazing operation. Soil sampling and water quality monitoring was conducted around 6 poultry houses and in an adjacent hayfield that also functions as a buffer strip (Fig. 2).

The Moore farm (Moore 1, 2, 3, and 4), located in Washington County in the Illinois River Watershed, is a poultry, beef, forage, and row-crop (i.e., corn and soybean, *Glycine max* Merr.) production operation. The Moore-1 field (Table 1 and Fig. 2) is unique in that it is a hay-soybean double-crop field where a winter annual forage is harvested in the spring,

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and soybean is planted in the spring and harvested in the fall. New poultry houses were designed with conservation practices (grassed waterways and large concrete pads at the house entrance) to reduce nutrient runoff. Soil and water quality samples were taken in the areas surrounding the poultry houses (Fig. 2).

The Morrow farm (Morrow-1), located in Washington County in the Illinois River Watershed, is a beef and sheep operation that utilizes rotational grazing. Soil and water quality measurement samples were taken on a 24-acre grazing pasture.

Soil samples were taken with a 0.875-inch diameter probe on a 0.10-acre grid at Marley-2, Marley-3, Moore-2, Moore-3, and Moore-4 or 1.0-acre grid at Stevens-1, Stevens-2, Stevens-3, Moore-1, and Morrow-1 to capture variability across the sampling area (often a defined field with uniform management). Soil cores were taken at the grid center and 15 feet in front, behind, and on either side of the center point for a total of 5 cores representing the corresponding grid point. All sites were soil sampled in 2019 before K fertilizer was applied, with the exception of Moore-1, which had broiler litter applied at a rate of 3 ton/acre two weeks before soil samples were collected.

Soil sampling depth recommendations in Arkansas are 0 to 6 inches for corn and cotton and 0 to 4 inches for soybean, forages, and pasture. To capture variability with depth in the soil profile, soil cores were taken at the 0- to 6- and 6- to 12-inch depths for cotton and corn fields (i.e., Stevens-1, Stevens-2, and Stevens-3) and the 0- to 4- and 4- to 8-inch depths for Marley-2, Marley-3, Moore-1, Moore-2, Moore-3, and Moore-4. Soil samples were analyzed by the University of Arkansas System Division of Agriculture Marianna Soil Test Laboratory for pH, electrical conductivity (EC), and Mehlich-3 extractable nutrients (Tables 2, 3, and 4)

For each sampling site, soil pH, EC, P, and K for the deeper sample depths (dependent variable) were regressed against the shallower depth to look for any correlation between the two soil depths (Table 5). Maps in Fig. 2 represent interpolated STK concentrations using a minimum curvature spline technique (i.e., Spline with Barriers) using ArcGIS Spatial Analysis (ESRI, Redlands, Calif.), manually classified with break values that correspond to the University of Arkansas System Division of Agriculture's Cooperative Extension Service STK categories (Very Low = < 61; Low = 61 to 90; Medium = 90 to 130; Optimum = 131 to 175; Above Optimum > 175 ppm K). A 6th category (> 215 ppm K, the median value of all STK values above 175 ppm in our dataset) was added to highlight areas containing very high STK levels contained in this dataset, as this might have an effect on the amount of K lost via water runoff.

Results and Discussion

Sites Managed for Row-Crop Production

Summary statistics for measured soil properties for each of the row-crop sampling sites and depth intervals are shown in Table 2, while the spatial distributions for surface STK are shown in Fig. 2. Mean STK ranged from 163 (Stevens-2) to 200 ppm K (Stevens-3) for the 0- to 6-inch samples, while the mean STK for the 6- to 12-inch depth ranged from 119 (Stevens-4) to 154 ppm (Stevens-3). Decreasing STK with increasing soil depth is consistent with other published results (Childs and Jencks, 1967).

According to the Cooperative Extension Service soil-test recommendations, all row-crop sites have mean STK values that are in the Optimum (131 to 175 ppm) or Above Optimum (> 175 ppm) categories for corn or cotton. For corn and cotton grown on soils in the Optimum STK category, a "maintenance" recommendation of 30 to 60 lb K_2O/acre is advised with specific rates depending on the crop and yield goal. All sites managed for row-crop production contained mean STK values categorized as Optimum or Above Optimum (Table 2), yet 90 lb K_2O/acre or more was applied (Table 1). Soils with higher STK levels may be prone to higher losses of K in runoff, although no research has been published to support or refute this.

Linear regression results of the 0- to 4- or 6-inch sample depth with the 4- to 8- or 6- to 12-inch sample depth for selected soil properties are listed in Table 5. The STK values in the 6- to 12-inch depth were 78% (Stevens-2, $R^2 = 0.57$), 100% (Stevens-3, $R^2 = 57$), 75% (Stevens-4, $R^2 = 0.67$), and 54% (Moore-1, $R^2 = 0.63$) of the STK values at the 0- to 6-inch depth. Fryer et al. (2019a; 2019b) also reported positive and strong linear relationships between STK from shallow (0 to 4 inches) and deep (0 to 12 or 0 to 18 inches) soil samples in Arkansas fields cropped to rice and soybean.

The coefficient of variation (CV) of STK in the surface depth ranged from 18% at Stevens-2 to 41% for site Moore-1 (Table 2). The range of CV agrees with other Arkansas research (Espinoza and Ismanov, 2019) where the CV for STK ranged from 17% to 33% across nearly 1800 acres of land in row-crop production sampled with 1-acre grids. The CV for STK for the 6- to 12-inch depth was numerically higher than the surface depth, except for Moore-1. Soil-test K maps for the surface depth (Fig. 2) revealed that the largest acreage, was in fact, associated with the range containing the site mean.

In Fig. 2, the acreage in red (STK > 215 ppm) for Stevens-2, Stevens-3, and Stevens-4 corresponds to the lowest field elevation, in close proximity of where the edge-of-field monitoring stations are located. Like Stevens-2,-3, and-4, STK values at Moore-1 were highest in field areas having the lowest elevations. The gradients of STK at Moore-1 had an inverse relationship with terrain slope with the lowest STK occurring on 20% to 40% hill slopes, while higher STK coincided with flatter (i.e., < 20% slope) and lower level terrain. Since crop selection and fertilizer application are managed uniformly at each site (i.e., same crop and single broadcasted fertilizer rate), these higher STK values may be the result of several factors. First, drainage water from runoff generated by rainfall or irrigation accumulates at the low elevation drainage points for a prolonged period as compared to the rest of the field. This prolonged saturation may limit yield as compared to the rest of the field thereby allowing STK to build as the crop may not take up or remove as much K. Second, soluble K may be moving with runoff water from the rest of the field and be deposited at these lower elevations as runoff velocity slows (Sharpley, 1985). Clay and organic matter, soil components that retain K and contribute to cation exchange capacity, may erode from the highest field elevations and be deposited at lower elevations. Following harvest, plant residue may also accumulate at lower field elevations followed by K leaching from the plant material which is subsequently sorbed by underlying soil, in a manner similar to phosphorus (Sharpley, 1981).

Sites Managed for Forage Production

Mean STK values for Marley-3 and Morrow-1 were 83 and 113 ppm K for the 0- to 4-inch depth, respectively, while mean STK for the 4- to 8-inch depth was 81 and 72 ppm for Marley-3 and Morrow-1, respectively (Table 3). Variability in STK as indicated by the CV was slightly higher for both Marley-3 (43%) and Morrow-1 (40%) sites in the 0- to 4-inch depth as compared to the 4- to 8-inch depth where the CV was 28% for Marley-3 and 32% for Morrow-1. Soil-test K maps (Fig. 2) revealed that the mean was within the range containing the most acreage in the field. Table 5 shows that relatively strong relationships exist for STK in the 0- to 4-inch depth regressed against the 4- to 8-inch depth for Marley-3 (R^2 = 0.78) and Morrow-1 (R^2 = 0.81).

Sites around Poultry Production Facilities

Mean STK values for sites next to poultry houses that are not typically fertilized or used for haying or grazing ranged from 128 ppm at Marley-2 to 264 ppm at Moore-3 for the 0- to 4-inch depth while mean STK at the 4- to 8-inch depth ranged 101 ppm for Marley-2 to 172 at Moore-3 (Table 4). The CV for STK in the 0- to 4-inch depth ranged from 27% for Moore-2 to 84% at Moore-4 while the CV ranged from 27% for Moore-2 to 68% at Moore-4 for the 4- to 8-inch depth. The CV for STK at Marley-2, Moore-3, and Moore-4 indicated greater variability at the 0- to 4-inch depth than fields used for row-crop (Table 2) or forage production (Table 3). Much of the variability in STK may be explained by the proximity of sampling points at the front of poultry houses and near the house ventilation fans (Fig. 2). Red map areas indicating STK > 215 ppm at sites Marley 2, Moore 3, and Moore 4 were observed where litter is prone to spillage during cleanout of litter and bird harvesting from the broiler houses. Poultry litter typically contains 60 lb K_2O/ton (Sharpley et al., 2009). Another factor that may have exacerbated the variability around the poultry houses was the cut-and-fill dirt work performed during the construction of the raised foundations, inevitably mixing soils with varying chemical and physical properties. Due to the spatial variability around the poultry production houses, the linear relationships between surface and subsoil STK were highly variable having R^2 values ranging from 0.00 (Moore 4) to 0.95 R^2 (Moore 3, Table 5).

Practical Applications

As agriculture strives for greater sustainability, a better understanding of the fate and transport of K in soils will aid soil K fertility management and fertilizer application decisions (i.e., as mineral fertilizer and manure). Previous reports from this work have shown that a substantial amount of K can be lost in runoff from cropped, grazed, and hayed land and from areas around poultry production houses. While the fate and transport of K in soil and runoff is complex, it can influence farm profitability and environmental stewardship.

This study suggests that K can accumulate at the low elevation areas in row-crop and hay fields next to the drainage points and next to poultry houses. The field/landscape areas in which K accumulation occurs are likely the result of complex and interrelated factors, which this study shows are related to land management, site hydrology, and surface drainage patterns. The accumulation of K in soil around poultry houses is likely the result of litter spillage during poultry house cleanout and bird harvesting.

The variability in STK and other chemical properties in fields used for forage and row-crop production is greatest in the shallow soil depth presumably due to spatially variable nutrient applications, animal loafing areas, crop yield, and uneven crop residue dispersal. This is not the case where soils at our sampling sites were heavily modified by activities such as poultry house construction and exhaust fans. Ongoing research will investigate the relationship between STK and K runoff.

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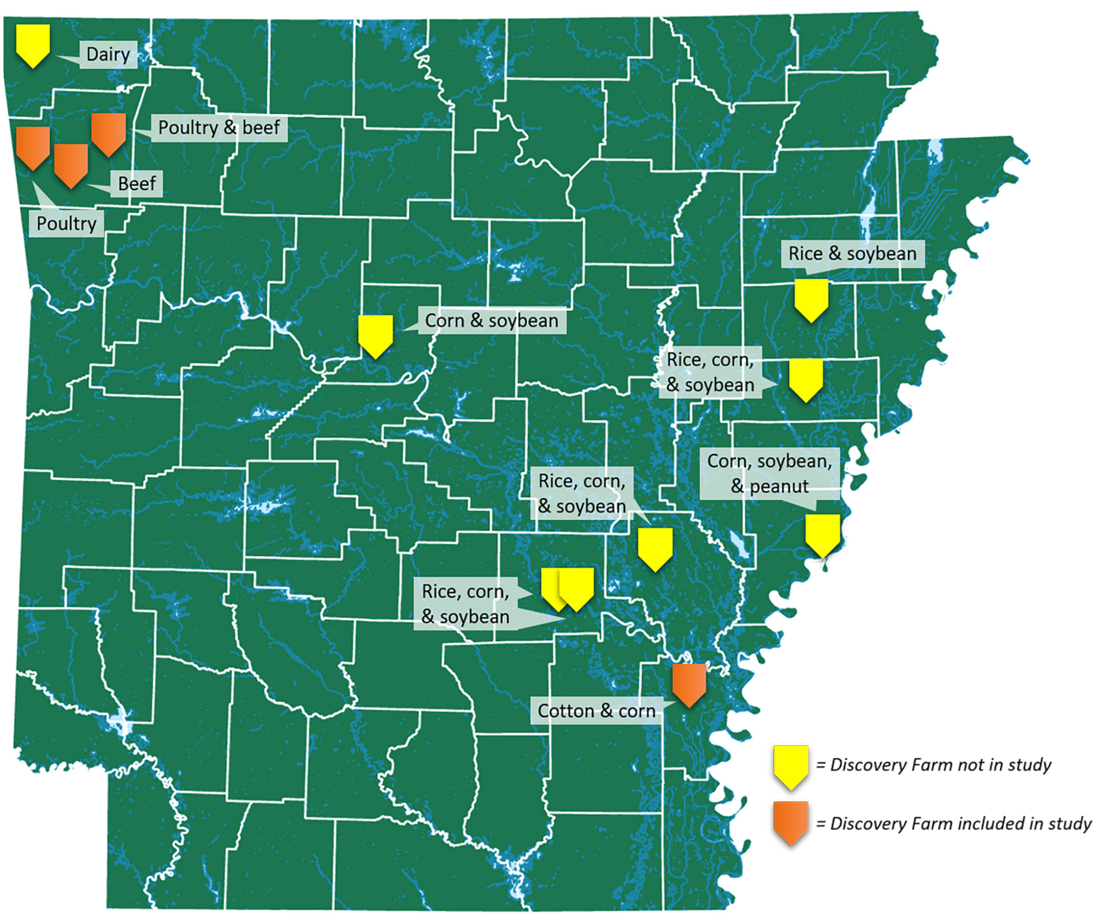
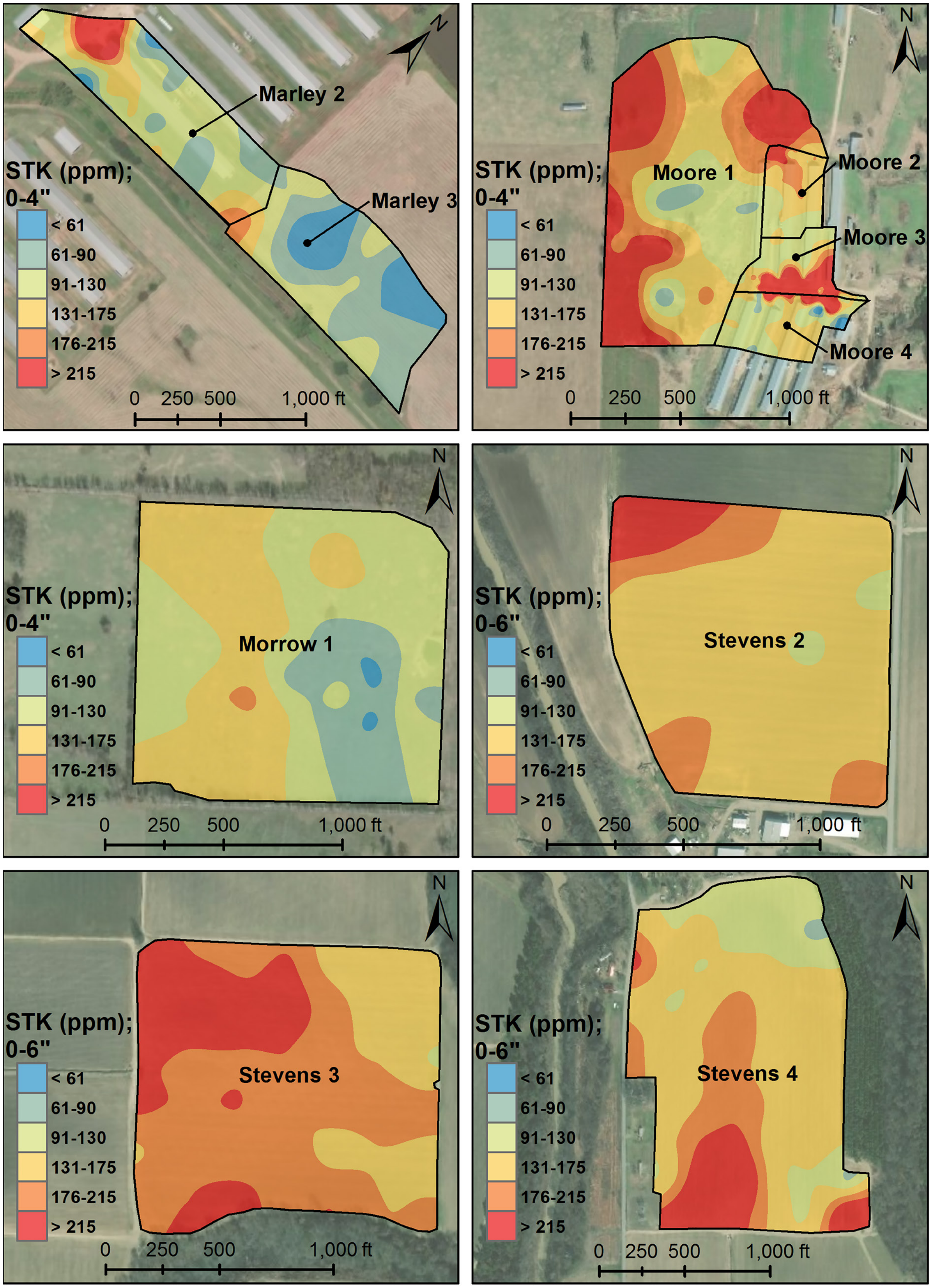


Fig. 1. Locations of University of Arkansas System Division of Agriculture Arkansas Discovery Farms. Map created using shapefiles from the Arkansas GIS Office (gis.arkansas.gov).



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Fig. 2. Surface (0- to 4-inch or 0- to 6-inch) variability maps of soil-test K (STK) interpolated using 1.0-acre (Stevens-2, -3, -4, Morrow-1, and Moore-1 sites) or 0.10-acre (Marley-2 and -3, and Moore-2, -3, and -4) grids.

Table 1. Site description and potassium management.

			Potassium management								
			Amount applied			Date applied			Application method		
Site ID	Field size	Management	2017	2018	2019	2017	2018	2019	2017	2018	2019
	(acres)		------ (lb K_2O/acre) --------								
Stevens-2	22	Cotton production[a]	90[c]	90[c]	90[c]	May 10	May 29	June 11	----------Broadcast---------		
Stevens-3	37	Cotton production[a]	90[c]	90[c]	90[c]	May 10	May 29	June 12	----------Broadcast---------		
Stevens-4	42	Cotton production[a]	90[c]	90[c]	90[c]	May 10	May 29	June 13	----------Broadcast---------		
Marley-2	3.6	Poultry houses	--	--	--	--	--	--	--	--	--
Marley-3	7.9	Hay production	150[d]	150[d]	170[d]	Mar 3	Feb 12	Aug 19	----------Broadcast---------		
Moore-1	30.7	Hay/Soybean[b]	151[d]	151[d]	151[d]	Apr 4	May 2	May 1	----------Broadcast---------		
Marley-2	3.6	Poultry houses	--	--	--	--	--	--	--	--	--
Moore-2	2.4	Poultry house rear	--	--	--	--	--	--	--	--	--
Moore-3	2.5	Poultry house front	--	--	--	--	--	--	--	--	--
Moore-4	3.3	Poultry house front	--	--	--	--	--	--	--	--	--
Morrow-1	24	Hay production	78[d]	--	78[d]	Sep 29	--	Aug 18	----------Broadcast---------		

[a] Cereal rye cover crop was utilized on Stevens-2 and Stevens-3 fields, but a cover crop was not utilized on Stevens-4 field.
[b] Moore-1 is a hay and double-crop soybean field where winter annual forage is harvested and soybean is planted in the spring.
[c] Commercial fertilizer (muriate of potash) was the K source.
[d] Broiler litter was applied at a rate of 2.5 (Marley-3) and 3 (Moore-1) ton/acre, and hen litter was applied at a rate of 3 ton/acre at the Morrow-1 farm. The amount of K_2O applied was determined by multiplying the "as is" % K content of the litter nutrient analysis by 1.2046 and then multiplying by the pounds of litter applied per acre.

Table 2. Variability and mathematical averages of selected soil properties from soil samples taken at 1-acre grids at two soil sample depths on University of Arkansas System Division of Agriculture's Arkansas Discovery Farm fields managed for row-crop production.

		0- to 6-inch depth				6- to 12-inch depth			
Site ID	Soil property	Mean	CV (%)[c]	Min	Max	Mean	CV (%)	Min	Max
Stevens-2	pH	7.0	5	5.8	7.4	7.1	5	6.4	7.5
n = 24[a]	EC (µmhos/cm)[b]	97	16	67	136	81	27	55	149
	P (ppm)	44	43	18	105	15	76	7	62
	K (ppm)	163	18	123	259	120	25	81	187
	Ca (ppm)	1337	18	990	2034	1633	18	1224	2300
	Mg (ppm)	240	24	155	403	356	29	192	584
	S (ppm)	7	23	5	11	7	60	3	16
	Fe (ppm)	213	14	144	264	189	14	139	243
	Mn (ppm)	52	24	36	76	36	38	17	68
	Zn (ppm)	1.7	22	1.2	2.5	1.2	26	0.7	2
	Cu (ppm)	1.8	11	1.4	2.2	1.9	11	1.4	2.3
	B (ppm)	0.8	26	0.4	1.3	0.7	25	0.4	1
Stevens-3	pH	6.6	4	6	7	6.9	4	6.1	7.2
n = 42	EC (µmhos/cm)	115	17	81	154	108	57	52	347
	P (ppm)	62	26	28	103	35	41	17	75
	K (ppm)	200	19	131	318	154	34	86	268
	Ca (ppm)	1444	34	630	2644	1751	30	814	2744
	Mg (ppm)	273	64	94	758	438	67	98	1182
	S (ppm)	10	21	7	19	11	92	3	52
	Fe (ppm)	270	12	214	373	269	13	203	360
	Mn (ppm)	66	31	18	100	44	57	3	100
	Zn (ppm)	3.1	170	1.2	33.1	1.6	48	0.5	4.2
	Cu (ppm)	2.0	23	1.4	3.7	2.0	15	1.5	2.5
	B (ppm)	0.7	33	0.4	1.1	0.6	32	0.3	1.2
Stevens-4	pH	6.8	4	5.9	7.4	7.0	5	5.1	7.4
n = 55	EC (µmhos/cm)	118	24	56	183	81	34	41	156
	P (ppm)	69	40	24	155	44	65	14	164
	K (ppm)	166	31	82	319	119	40	51	239
	Ca (ppm)	1357	34	590	2537	1505	34	663	2553
	Mg (ppm)	236	47	100	526	321	55	88	718
	S (ppm)	8	23	4	12	7	61	2	19
	Fe (ppm)	237	16	150	343	231	22	130	359
	Mn (ppm)	86	36	16	162	54	64	3	182
	Zn (ppm)	3.6	57	0.9	12.9	2.1	75	0.4	9.7
	Cu (ppm)	1.4	31	0.7	2.3	1.4	34	0.5	2.5
	B (ppm)	0.7	49	0.1	1.5	0.6	52	0	1.2
Moore-1	pH	6.5	8	4.5	7.1	6.3	6	5.3	6.9
n = 27	EC (µmhos/cm)	203	60	57	661	151	100	65	734
	P (ppm)	211	61	2	441	141	78	1	366
	K (ppm)	185	41	65	373	137	38	66	275
	Ca (ppm)	1609	30	782	2636	1336	38	573	2646
	Mg (ppm)	199	48	98	528	179	67	66	478
	S (ppm)	54	206	13	588	69	283	9	1022
	Fe (ppm)	172	33	95	322	146	38	82	298
	Mn (ppm)	218	38	95	340	221	31	110	339
	Zn (ppm)	15.8	52	1.4	28.6	8.5	63	1.0	22.1
	Cu (ppm)	4.7	39	1.5	7.6	4.0	37	1.1	6.9
	B (ppm)	0.4	60	0.1	1.0	0.2	62	0.1	0.6

[a] n, number of soil sample or grid sample points.
[b] EC (µmhos/cm), Electrical Conductivity.
[c] CV (%), coefficient of variation.

Table 3. Variability and mathematical averages of selected soil properties from soil samples taken at 1-acre grids at two soil sample depths on University of Arkansas System Division of Agriculture's Arkansas Discovery Farm fields managed for forage production.

		0- to 4-inch depth				4- to 8-inch depth			
Site ID	Soil property	Mean	CV (%)[c]	Min	Max	Mean	CV (%)	Min	Max
Marley-3	pH	5.8	4	5.4	6.3	6.0	8	4.9	6.7
n = 18[a]	EC (µmhos/cm)[b]	191	28	121	322	137	45	83	320
	P (ppm)	135	26	78	215	62	66	28	201
	K (ppm)	83	43	31	193	81	40	23	144
	Ca (ppm)	1740	21	1125	2431	1696	27	1088	2692
	Mg (ppm)	237	41	121	463	247	77	102	843
	S (ppm)	35	70	19	122	37	102	14	160
	Fe (ppm)	312	16	230	416	239	19	164	331
	Mn (ppm)	91	35	49	147	87	74	19	202
	Zn (ppm)	12.4	17	8.7	15.8	3.6	54	1.4	8.1
	Cu (ppm)	6.3	17	3.8	8.2	3.9	21	2.7	5.6
	B (ppm)	0.3	29	0.2	0.5	0.3	47	0.1	0.5
Morrow-1	pH	6.3	4	5.8	6.7	5.9	4	5.4	6.3
n = 33	EC(µmhos/cm)	160	24	62	234	94	38	51	197
	P (ppm)	69	36	31	120	27	57	9	78
	K (ppm)	113	28	55	191	72	32	37	130
	Ca (ppm)	1056	21	742	1605	729	23	478	1110
	Mg (ppm)	93	15	64	124	67	21	43	100
	S (ppm)	19	15	14	27	15	29	9	33
	Fe (ppm)	139	23	88	214	101	12	83	133
	Mn (ppm)	216	25	117	336	188	28	101	308
	Zn (ppm)	4.9	29	2.6	8.3	1.7	32	0.7	3.1
	Cu (ppm)	3.7	19	2.6	5.2	2.3	20	1.2	3.7
	B (ppm)	0.1	45	0	0.2	0.0	180	0	0.1

[a] n, number of soil sample or grid sample points.
[b] EC (µmhos/cm), Electrical Conductivity.
[c] CV (%), coefficient of variation.

Table 4. Variability and mathematical averages of selected soil properties from soil samples taken at 1-acre grids at two soil sample depths on University of Arkansas System Division of Agriculture's Arkansas Discovery Farm field sites surrounding poultry houses.

		0- to 4-inch depth				4- to 8-inch depth			
Site ID	Soil property	Mean	CV (%)[c]	Min	Max	Mean	CV (%)	Min	Max
Marley-2	pH	5.8	16	3.9	8.4	5.8	14	4.0	6.9
n = 34[a]	EC (µmhos/cm)[b]	296	53	135	850	269	92	80	1297
	P (ppm)	129	79	18	512	80	74	3	227
	K (ppm)	128	62	75	424	101	30	67	207
	Ca (ppm)	2514	132	804	20692	1885	39	1084	4477
	Mg (ppm)	193	33	98	398	181	40	70	492
	S (ppm)	80	137	18	629	200	229	10	2242
	Fe (ppm)	241	23	39	328	225	15	159	297
	Mn (ppm)	127	33	45	217	118	33	33	177
	Zn (ppm)	23.4	75	4.9	70.6	7.4	50	2.4	19.2
	Cu (ppm)	5.2	52	1.5	14.1	4.0	36	1.5	7.2
	B (ppm)	0.30	81	0.1	1.2	0.2	50	0.1	0.4
Moore-2	pH	5.8	10	4.4	6.9	6.1	9	4.6	6.8
n = 23	EC (µmhos/cm)	248	68	92	925	261	150	67	1966
	P (ppm)	126	62	9	293	131	88	6	465
	K (ppm)	171	27	100	268	147	27	70	223
	Ca (ppm)	1515	46	638	3995	1789	71	649	7071
	Mg (ppm)	347	65	118	1035	408	98	107	2038
	S (ppm)	76	217	12	807	280	372	8	5034
	Fe (ppm)	178	24	101	272	178	31	85	274
	Mn (ppm)	124	27	84	209	119	32	83	223
	Zn (ppm)	14.2	64	2.9	43.8	8.8	66	1.8	24.0
	Cu (ppm)	2.9	33	1.5	4.9	3.3	47	1.1	6.3
	B (ppm)	0.2	43	0.1	0.4	0.2	59	0.1	0.6
Moore-3	pH	7.2	11	5.3	8.8	6.9	11	4.5	8.0
n = 27	EC (µmhos/cm)	404	73	14	1123	323	93	46	1488
	P (ppm)	225	143	1	1338	91	137	1	475
	K (ppm)	264	82	105	1005	172	56	91	452
	Ca (ppm)	3403	60	822	8458	2170	57	776	5706
	Mg (ppm)	341	66	157	1302	347	89	158	1468
	S (ppm)	95	95	14	381	155	203	16	1597
	Fe (ppm)	130	18	103	196	124	25	68	186
	Mn (ppm)	149	36	68	265	166	39	55	352
	Zn (ppm)	30.2	80	0.8	92.3	8.3	93	0.6	29.4
	Cu (ppm)	2.3	38	0.6	4.1	1.9	59	0.6	4.7
	B (ppm)	0.7	83	0.1	2.3	0.4	77	0.1	1.1
Moore-4	pH	7.4	7	6.2	8.7	7.4	6	6.4	8.2
n = 33	EC (µmhos/cm)	363	64	94	1036	349	74	91	1234
	P (ppm)	67	193	2	699	21	126	1	111
	K (ppm)	192	84	88	919	133	68	68	606
	Ca (ppm)	4334	76	1526	14398	3299	82	976	15849
	Mg (ppm)	452	33	204	788	490	43	170	1087
	S (ppm)	105	103	12	465	141	134	20	938
	Fe (ppm)	126	28	69	221	117	29	70	222
	Mn (ppm)	165	33	36	299	189	35	48	327
	Zn (ppm)	18.0	129	1.0	105.8	5.7	109	0.7	30.2
	Cu (ppm)	2.3	57	0.7	6.8	1.8	30	0.7	3.3
	B (ppm)	0.6	121	0.1	2.8	0.4	243	0.1	5.6

[a] n, number of soil sample or grid sample points.
[b] EC (µmhos/cm), Electrical Conductivity.
[c] CV (%), coefficient of variation.

Table 5. Linear regression equations and coefficient of determination (R^2) comparing selected surface and subsoil chemical properties for 10 University of Arkansas System Division of Agriculture's Arkansas Discovery Farm fields.

Site ID[a]	Management	Soil property	Linear R^2 value	Equation[b]
Stevens-2	Cotton production w/cover crop	pH	0.39	y = 0.580x + 3.10
n = 24[c]		EC (µmhos/cm)[d]	0.61	y = 1.090x - 24.71
		P (ppm)	0.79	y = 0.533x - 8.52
		K (ppm)	0.57	y = 0.781x - 7.30
Stevens-3	Cotton production w/cover crop	pH	0.17	y = 0.414x + 4.13
n = 42		EC (µmhos/cm)	0.30	y = 1.731x - 91.14
		P (ppm)	0.59	y = 0.679x - 7.18
		K (ppm)	0.57	y = 1.060x - 58.03
Stevens-4	Cotton production w/o cover crop	pH	0.43	y = 0.843x + 1.27
n = 55		EC (µmhos/cm)	0.30	y = 0.524x + 18.64
		P (ppm)	0.73	y = 0.861x - 15.85
		K (ppm)	0.67	y = 0.750x - 6.23
Marley-2	Poultry Houses	pH	0.40	y = 0.620x + 2.24
n = 34		EC (µmhos/cm)	0.21	y = 0.744x + 56.91
		P (ppm)	0.20	y = 0.300x + 46.13
		K (ppm)	0.02	y = 0.064x + 93.96
Marley-3	Hay production	pH	0.62	y = 1.450x - 2.44
n = 18		EC (µmhos/cm)	0.65	y = 0.920x - 38.99
		P (ppm)	0.70	y = 0.980x - 70.68
		K (ppm)	0.78	y = 0.802x + 14.23
Moore-1	Hay and soybean double-crop	pH	0.69	y = 0.680x + 1.93
n = 27		EC (µmhos/cm)	0.57	y = 0.943x - 40.79
		P (ppm)	0.61	y = 0.662x + 1.27
		K (ppm)	0.63	y = 0.537x + 37.27
Moore-2	Poultry house rear	pH	0.67	y = 0.762x + 1.65
n = 23		EC (µmhos/cm)	0.84	y = 2.106x - 261.69
		P (ppm)	0.66	y = 1.204x - 20.66
		K (ppm)	0.85	y = 0.786x + 12.62
Moore-3	Poultry house front	pH	0.59	y = 0.821x + 1.09
n = 27		EC (µmhos/cm)	0.43	y= 0.756x + 60.41
		P (ppm)	0.61	y = 0.290x + 29.05
		K (ppm)	0.95	y = 0.561x + 41.54
Moore-4	Poultry house front	pH	0.05	y = 0.184x + 6.00
n = 33		EC (µmhos/cm)	0.00	y = 0.025x + 340.17
		P (ppm)	0.24	y = 0.095x + 14.06
		K (ppm)	0.00	y = - 0.011x + 135.17
Morrow-1	Hay Production	pH	0.27	y = 0.472x + 2.92
n = 33		EC (µmhos/cm)	0.11	y = 0.309x + 45.00
		P (ppm)	0.56	y = 0.477x - 5.67
		K (ppm)	0.81	y = 0.650x - 1.38

[a] Sample depths contained in the regression on Stevens-2, Stevens-3, and Stevens-4 fields are 0- to 6- (x-axis) and 6- to 12-inch (y-axis) depths, while all other sites have correlated sample depths of 0 to 4 inches (x-axis) and 4 to 8 inches (y-axis).

[b] Linear regression equation (y = mx + b) where y represents the subsoil value, x = topsoil value, m = linear slope coefficient, and b = the y-axis intercept.

[c] n = the number of observations used in the regression.

[d] EC (µmhos/cm), Electrical Conductivity.

Investigating Corn Response to Magnesium on a Deficient Soil in Arkansas

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Abstract

Magnesium (Mg) deficiency in Arkansas soils is uncommon, but can negatively impact corn (*Zea mays* L.) growth and grain yield. Two fields (D2 and F4) in Fayetteville, Ark., were identified as sites for this study due to low soil-test Mg and relatively high potassium (K) to Mg ratios. The following treatments were applied preplant and incorporated into the seedbed: untreated check, 30, 60, and 90 lb Mg/acre; 24 lb S/acre; 45, 90, and 135 lb K_2O/acre. In addition, all plots received 30 lb N/acre preplant and 200 lb N/acre between the V6 and V8 growth stages. Whole-plant above-ground biomass samples were collected at the V6 growth stage and ear-leaf samples were collected at the R1 growth stage. No significant difference was measured in grain yield (P = 0.9534) in D2; however, a significant difference in grain yield was measured in F4 (P < 0.0001). Corn in F4 exhibited significant differences in K concentrations in the tissue at both the V6 (P = 0.0114) and R1 (P = 0.0162) growth stages. Corn in the D2 field exhibited significant differences in Mg concentration at the V6 (P < 0.0001) and R1 (P = 0.0144) growth stages. These results suggest that the interactions of Mg and K within the soil are not well understood and further research is needed to predict corn responses to Mg fertilization.

Introduction

Most often, magnesium (Mg) deficiency will present itself on plants grown in sandy and acidic soils. Due to the small percentage of acres cropped to these soils in the state, occurrences of Mg deficiency on soils in row-crop production are rarely observed in Arkansas; however, problematic soils can limit yield. The lack of Arkansas-based Mg research has led to adopting broad management recommendations and corrective actions. The specifics on how corn grown in Arkansas soils responds to Mg fertilization and the role potassium (K) has on Mg availability and uptake need to be investigated to provide accurate recommendations when Mg deficiency occurs.

Results from Rehm and Sorensen (1985) show that high application rates of K decrease the plant uptake of Mg. These findings suggest that even on moderate pH silt loam or clayey textured soils, fields with adequate Mg fertility could still experience Mg deficiency due to the interaction of K on Mg uptake. The ratio of K to Mg in the soil and plant tissue has been proposed to predict under which conditions this antagonism may occur.

Current recommendations from the University of Arkansas System Division of Agriculture suggest that soil-test Mg concentrations below 75 lb Mg/acre indicate the potential for Mg deficiency and an application of Mg should be made to prevent a potential Mg deficiency (Espinoza and Ross, 2009). Recommendations also suggest the use of in-season tissue sampling to more accurately detect potential Mg deficiencies in the corn crop. Sufficiency ranges are used to classify the nutritional status of crop tissue. The lower limit of a sufficiency range represents a tissue nutrient concentration that defines the boundary between deficient and adequate. The upper limit of a sufficiency range defines the boundary of adequate and excessive or potentially toxic levels. Tissue nutrient concentrations that are less than the lower limit of the sufficiency range are classified as deficient, concentrations that fall between the two limits are sufficient, and concentrations that are greater than the upper limit may be excessive. The proposed sufficiency ranges for corn in the mid-South between seedling and up to tasseling are 0.15% to 0.60% Mg and 2.0% to 3.0% K (Campbell and Plank, 2000). Similar sufficiency ranges have been set for tasseling corn at 0.15% to 0.60% Mg and 1.8% to 3.0% K. Similar to the sufficiency ranges for nutrient concentration, sufficiency ranges have also been set for common cation ratios. The sufficiency range for the K to Mg ratio in corn tissue is 8:1 to 16:1 (Espinoza and Ross, 2009).

Once tissue analysis results have indicated Mg deficiency, the current recommendation is to apply Mg through one of several different sources to correct the deficiency. The preferred Mg source is dolomitic lime as it is the most economical source. Several other sources are available including magnesium sulfate, magnesium oxide, and foliar options. The recommended application rate is 20 to 40 lb Mg/acre. Improving the details of these recommendations requires field-based research on Mg-deficient soils in Arkansas. Therefore, the objectives of this study were to investigate the response of corn to Mg fertilization and to explore the effect of high levels of soil K and high soil K to Mg ratios on corn K and Mg tissue concentrations and grain yield.

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Procedures

Plots were established at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark., on 10 April 2019. The two fields (D2 and F4) selected for this study were Captina silt loam soils (Soil Survey Staff, 2017) and contained Mehlich-3 extractable, soil-test Mg concentrations of 25 and 43 ppm, respectively (Table 1). Composite soil samples were collected from each replication at the time of planting and analyzed at the University of Arkansas System Division of Agriculture's Fayetteville Agricultural Diagnostic Laboratory in Fayetteville, Ark. (Table 1). Seedbeds were established on 36-inch row spacing. Plots were 12-ft wide (4 rows) by 30-ft long. The hybrid Pioneer 1464VYHR was planted on 10 April 2019 at a seeding rate of 35,000 seeds/acre.

Eight treatments were applied preplant and incorporated into the seedbed. The 8 treatments included: 0 (untreated check), 30, 45, and 90 lb Mg/acre; 24 lb S/acre; and 45, 90, and 135 lb K_2O/acre. Magnesium treatments were applied as $MgSO_4$ (13% Mg), the S treatment was applied as $(NH_4)_2SO_4$ (24% S), and the K treatments were applied as KCl (60% K_2O). All plots received 30 lb N/acre preplant and 200 lb N/acre as urea (46% N) at the V6 growth stage as a sidedress application. All treatments were replicated 4 times as a randomized complete block design in each field. Soil samples were collected prior to preplant fertilizer treatment application to establish a baseline of soil nutrients. Five soil cores were collected from the 0- to 6-inch depth and composited from each replication. All plots were sampled at the V6 growth stage (671 GDU) for whole-plant aboveground biomass from a 3-ft section of bordered row and ear-leaf (leaf subtending the ear) samples that were collected at the R1 growth stage (1398 GDU). All tissue samples were oven-dried until a constant mass was achieved, ground, and analyzed for nutrient content. The K:Mg ratio for tissue analysis was calculated as the concentration of K (ppm) divided by the concentration of Mg (ppm). For soil analysis, the K:Mg ratio was calculated as K (cmolc/kg) divided by Mg (cmolc/kg). Grain yield was calculated by harvesting the center two rows of each plot using a small plot combine and adjusting to 15.5% moisture. Three to four soil cores were collected from the 0- to 6-inch depth and composited from each plot after harvest and submitted for analysis of Mehlich-3 extractable nutrients.

Data analysis was completed using the statistical software R v. 3.5.1 (R Core Team, Vienna, Austria). Analysis of variance was used to determine significant differences and mean separation was performed using Tukey's honestly significant difference test at an alpha value of 0.05. Fields were analyzed separately due to the interaction created by differing native soil conditions.

Results and Discussion

Yield

The average grain yield for D2 and F4 fields was 220 and 216 bu./acre, respectively. The untreated check plots averaged 224 bu./acre in D2 and 194 bu./acre in F4. Although the two fields were in close proximity and on the same soil series, different responses were observed among the treatments for each field. As seen in Fig. 1, there was a significant difference in grain yield in F4 ($P < 0.0001$) while there was no significant difference in D2 ($P = 0.9534$). In the F4 field, all treatments receiving Mg, the S treatment, and the lowest K application rate resulted in the highest corn grain yield. The increase in grain yield for these treatments over the untreated control ranged from 30 to 41 bu./acre.

Whole-Plant V6 Tissue Concentrations

Tissue collected at the V6 growth stage was analyzed for nutrient concentration as well as total aboveground nutrient uptake. Several differences were observed in nutrient concentration at the V6 growth stage. In D2, significant differences were found in K ($P = 0.0011$) and Mg ($P < 0.0001$) concentrations as well as the K:Mg ratio ($P < 0.0001$). In addition to the letter separation, Fig. 2 also shows how the nutrient concentrations relate to the sufficiency ranges represented by the green rectangles. At the V6 growth stage in D2, plant tissue from all treatments was above the sufficiency range of K and the K:Mg ratio, while the treatment containing the highest application rate of Mg barely reached the sufficiency range for Mg concentration and all other treatments were below the Mg sufficiency range.

In F4, significant differences were found in K concentrations ($P = 0.0114$; Fig. 2); however, no significant differences were observed in whole-plant Mg concentrations ($P = 0.4999$) or in the K:Mg ratio ($P = 0.1691$) at the V6 growth stage. Similar to D2, the K concentrations and K:Mg ratios of corn grown in F4 were above the sufficiency range at the V6 growth stage. Corn Mg concentrations for all treatments in F4 were close to the boundary between deficient and sufficient. Nutrient uptake in D2 was not significantly different for N ($P = 0.1783$), K ($P = 0.0721$), or Mg ($P = 0.1757$); however, sulfur (S) uptake was significantly different ($P = 0.0002$). Similarly, no significant differences were detected in the nutrient uptake of N ($P = 0.9864$), K ($P = 0.6108$), Mg ($P = 0.9826$) or S ($P = 0.1794$) in F4. In addition to nutrient concentration differences in the tissue, visual Mg deficiency symptoms were observed at the V6 growth stage in varying degrees of severity in accordance with the fertilizer treatments.

R1 Ear-Leaf Tissue Concentrations

Overall, the ear-leaf tissue collected at R1 exhibited lower numerical K concentrations than samples collected at V6 across all treatments (2.5% K at R1 and 4.7% at V6); however, the R1 samples contained similar numerical Mg concentrations as the V6 samples (0.12% Mg at R1 and 0.14% Mg at V6). Ear-leaf samples collected at the R1 growth stage contained fewer significant differences in nutrient concentration than the whole-plant samples collected at the V6 growth stage. In D2, the only significant response variable was Mg ($P = 0.0144$; Fig. 3). Ear-leaf K concentration ($P = 0.6555$) and the K:Mg ratio ($P = 0.0681$) were not significant. Concentrations of K were well within the sufficiency range, but Mg concentrations were deficient and K:Mg ratios were still above the desired range. The only response variable that was significant in F4 was ear-leaf K concentration ($P = 0.0162$) while ear-leaf Mg concentration ($P = 0.1345$) and the K:Mg ratio ($P = 0.1726$) were not significantly affected by treatments. Similar to D2, the K concentrations were considered sufficient and the Mg concentrations were in the sufficient range, but several treatments contained Mg concentrations near the lower end of the sufficiency range. Ultimately, Mg concentrations were still deficient, leading to K:Mg ratios that were above the desired range.

End-of-Season Soil Samples

Soil samples collected after harvest showed several key significant differences. Mehlich-3 extractable soil concentrations of K ($P = 0.0427$ in D2 and $P = 0.0015$ in F4; Fig. 4) and Mg ($P < 0.0001$ in D2 and $P = 0.0002$ in F4; Fig. 5) and the soil K:Mg ratio ($P < 0.0001$ in D2 and $P < 0.0001$; Fig. 6) were significantly different in D2 and F4. Magnesium concentrations in the soil generally increased with increasing application rate of Mg; while treatments that did not receive any Mg were not statistically different than the untreated check in both fields. The lowest rate of Mg was not statistically different than the untreated check. Treatments that received K tended to increase the postharvest soil-test K, but were not always significantly different than the untreated check or treatments which did not receive K. The high application rates of Mg resulted in a significantly greater soil-test Mg at the end of the season over the untreated check in both fields. When 30 lb Mg/acre was applied, the postharvest soil-test Mg concentrations were 11 and 7 ppm greater than the preplant soil Mg concentrations in D2 and F4, respectively. When 60 lb Mg/acre was applied, soil-test Mg concentrations increased by 42 ppm in D2 and 33 ppm in F4. Similarly, application rates of 90 lb Mg/acre resulted in an increase of 60 and 36 ppm in soil Mg concentration in D2 and F4, respectively.

There is no definitive evidence to explain the difference in yield response; however, the preplant and postharvest soil-test results in combination with the tissue results provide some possible explanations. At the V6 growth stage, the combination of excessive tissue-K concentrations and deficient tissue-Mg concentrations resulted in K:Mg ratios that were excessive across all treatments. Similarly, tissue-Mg concentrations at the R1 growth stage in D2 were all deficient, while two treatments in F4 contained Mg concentrations considered sufficient. All treatments in each field contained sufficient K concentrations at R1. All treatments in D2 were above the sufficiency range for the K:Mg ratio at R1; however, two treatments in F4 were considered sufficient and six treatments were excessive. These conclusions combined with the soil-test results suggest that the Mg was not effectively taken up and still remained in the soil. Based on the presence of high postharvest soil-test Mg concentrations and soil K:Mg ratios near or below the desired ratio of 1:1, a positive yield response to Mg fertilization is expected in the following year.

Practical Applications

With the research presented here and by continuing this study, recommendations can be developed for problematic, low Mg soils in Arkansas. Based on the preliminary results of this study, correcting Mg issues may require more than one growing season or the addition of greater rates of Mg when in the presence of high soil-test K concentrations. Soil conditions may further complicate these recommendations as pH, soil texture, and soil-test Mg concentration may affect the rate of Mg required. Future studies could evaluate the use of higher rates, alternate sources of Mg, and multiple year application effects.

Acknowledgments

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Table 1. Selected average soil chemical properties from two field trials (D2 and F4) at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark., collected before planting corn in 2019. Five cores per composite in each replication at 0- to 6-inches.

			Mehlich-3 Extractable Nutrients						
Field	**ECEC[a]**	**pH**	**P**	**K**	**Ca**	**Mg**	**S**	**Zn**	**K:Mg[b]**
	(cmol/kg)		----------	----------	----------	(ppm)	----------	----------	
D2	6.08	6.7	67	189	574	25	7	2.7	2.4
F4	8.37	5.6	80	166	690	43	18	8.9	1.2

[a] ECEC = Estimated Cation Exchange Capacity.
[b] K:Mg ratio calculated as the ratio of potassium (K) to magnesium (Mg) expressed on a cmolc/kg basis.

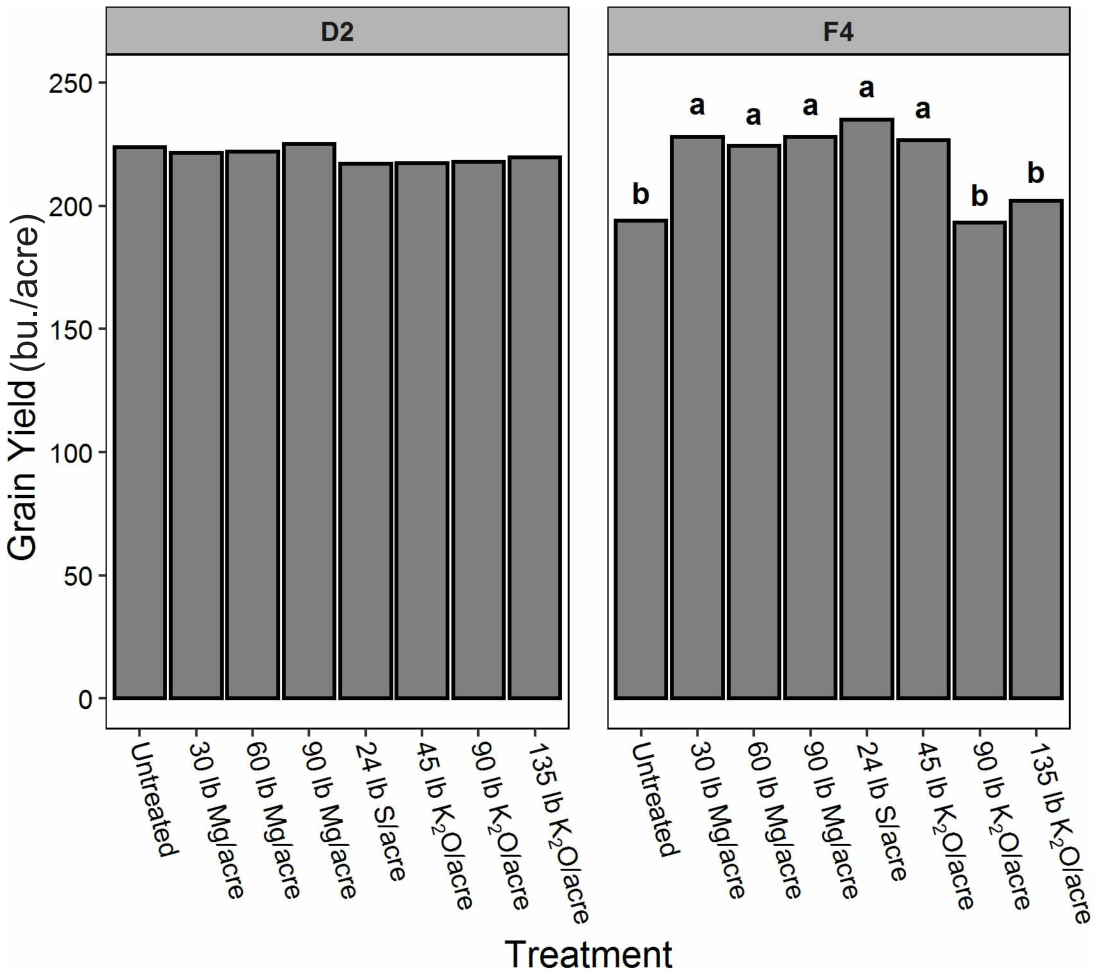

Fig. 1. Corn mean grain yield separated by treatment from two field trials (D2 and F4) conducted in 2019 at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas. Statistical significance determined at α = 0.05. Letters within each field that are not the same are statistically different as determined by Tukey's honestly significant difference test.

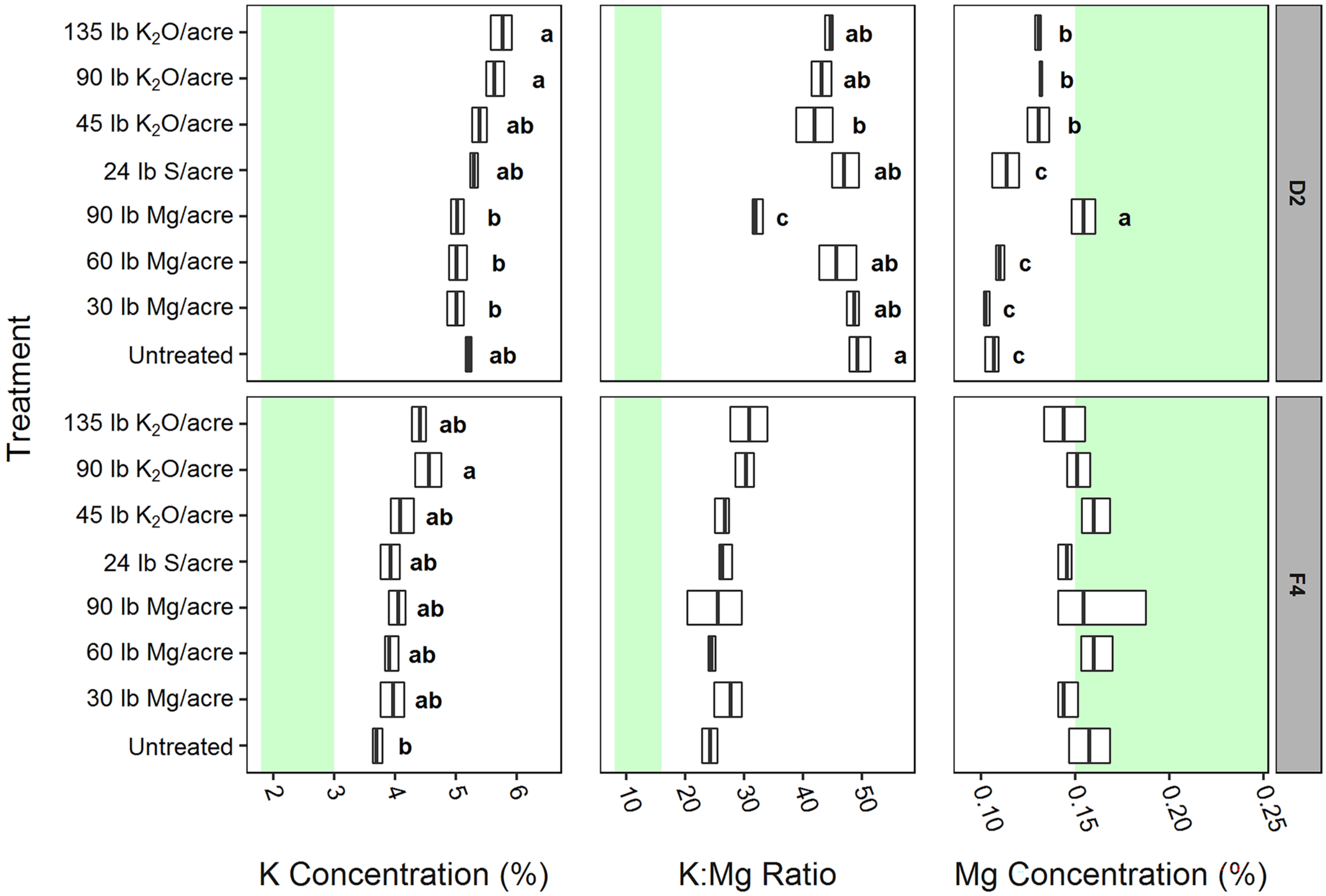

Fig. 2. Tissue K and Mg concentrations and the K:Mg ratio in the aboveground biomass of whole corn plants sampled at the V6 growth stage from two field trials (D2 and F4) conducted in 2019 at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas. The green shaded area represents the sufficiency ranges for each nutrient. Statistical significance determined at α = 0.05. Letters within each field and nutrient that are not the same are statistically different as determined by Tukey's honestly significant difference test.

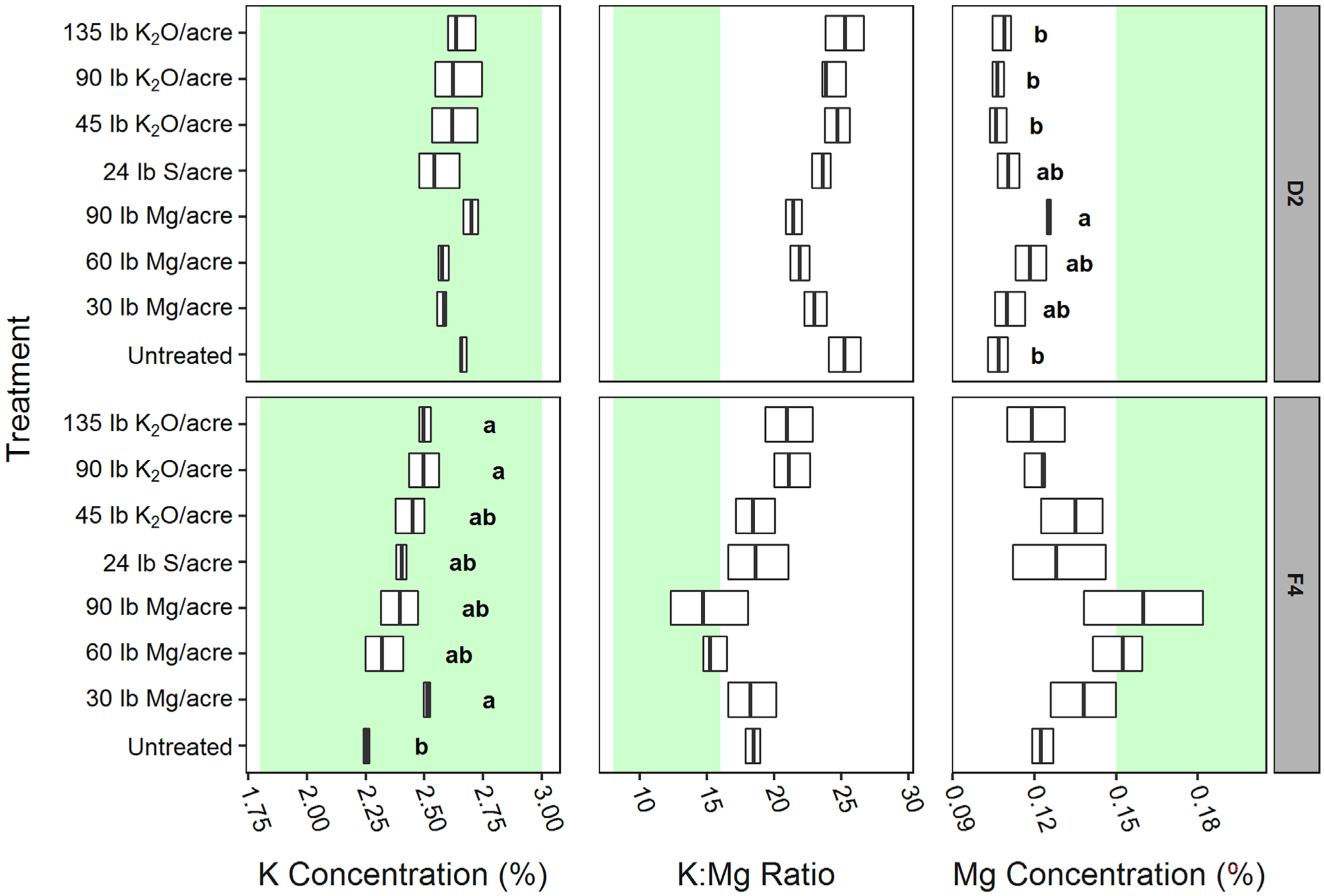

Fig. 3. Tissue K and Mg concentrations and the K:Mg ratio in the ear leaves sampled at the R1 growth stage from two field trials (D2 and F4) conducted in 2019 at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas. The green shaded area represents the sufficiency ranges for each nutrient. Statistical significance determined at α = 0.05. Letters within each field and nutrient that are not the same are statistically different as determined by Tukey's honestly significant difference test.

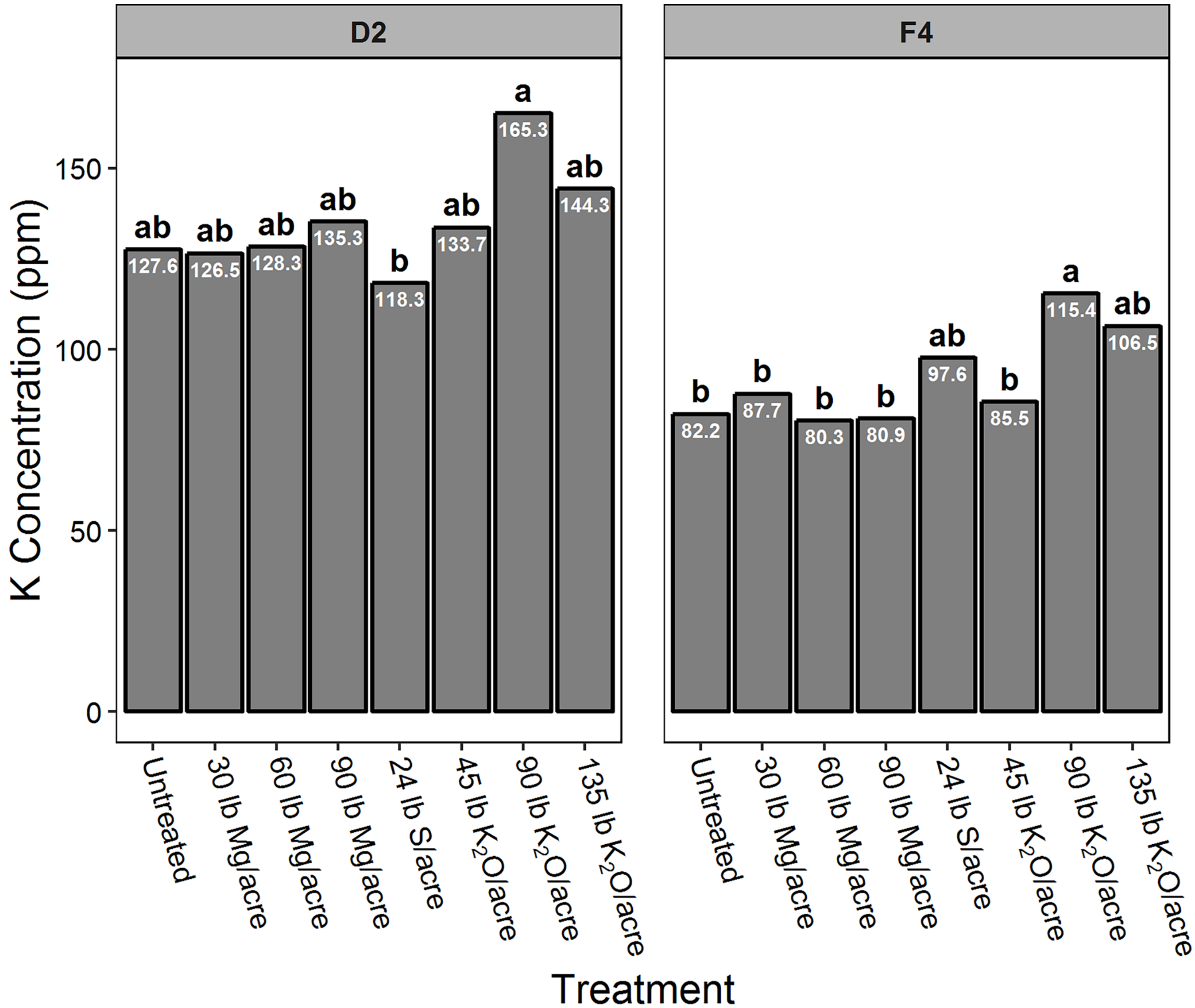

Fig. 4. The mean Mehlich-3 extractable soil potassium (K) concentration (ppm) for each treatment in each field (D2 and F4) from samples collected postharvest from the 0-to 6-inch depth at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas. Statistical significance was determined at α = 0.05. Letters within each field that are not the same are statistically different as determined by Tukey's honestly significant difference test.

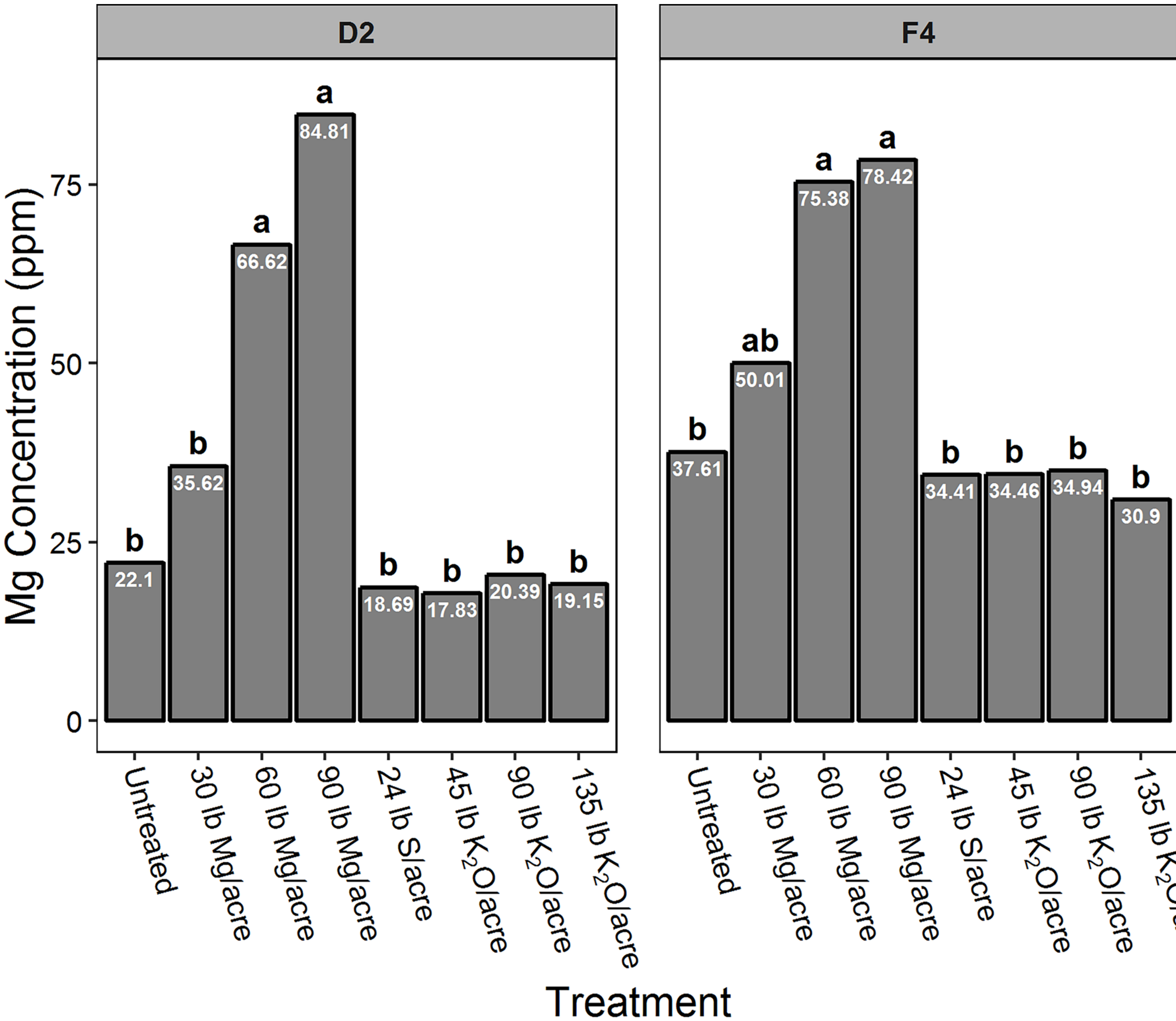

Fig. 5. The mean postharvest Mehlich-3 extractable soil magnesium (Mg) concentration (ppm) for each treatment in each field (D2 and F4) from samples collected postharvest from the 0-to 6-inch depth at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas. Statistical significance was determined at α = 0.05. Letters within each field that are not the same are statistically different as determined by Tukey's honestly significant difference test.

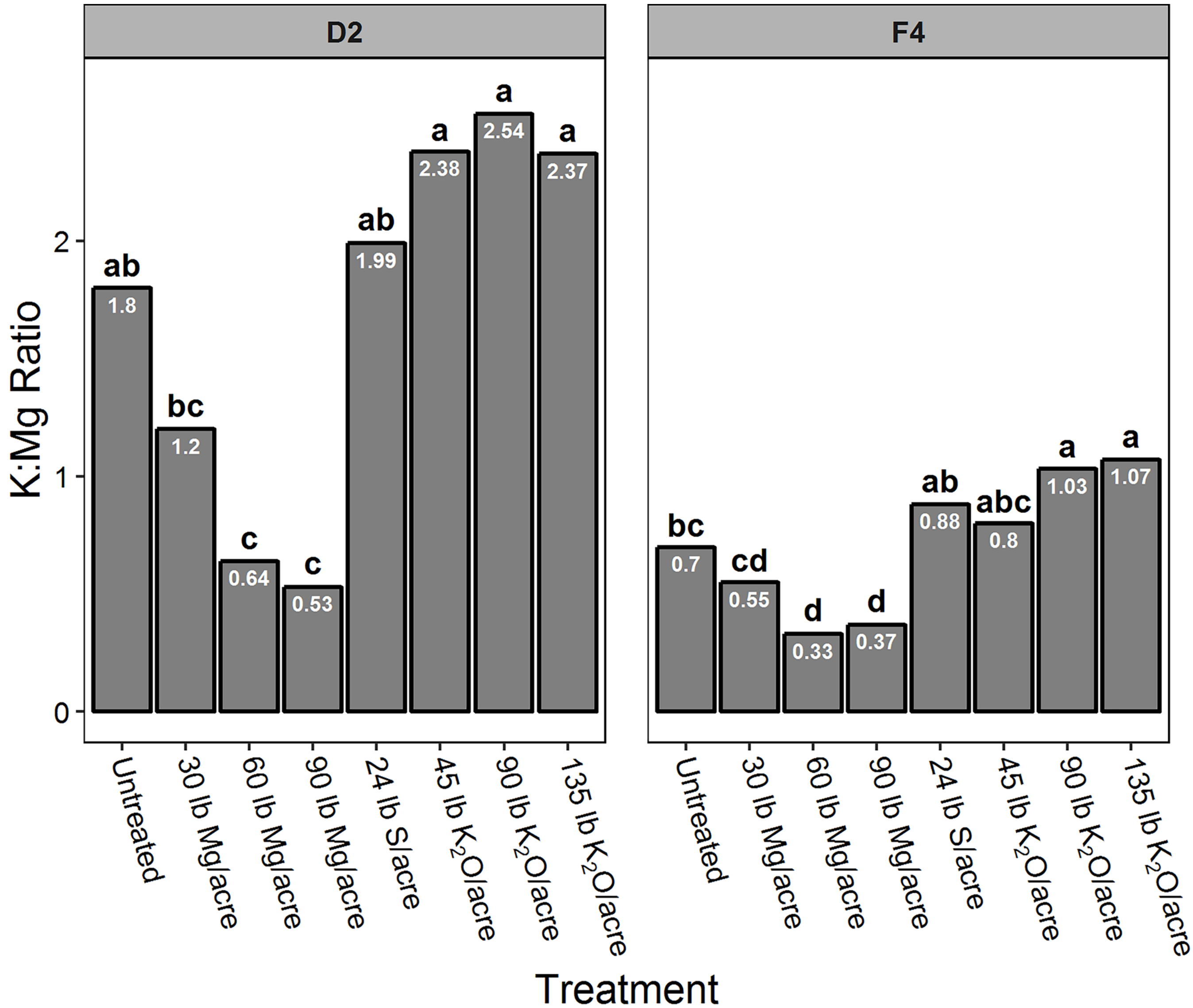

Fig. 6. The potassium (K) to magnesium (Mg) ratio from Mehlich-3 soil extracts for each treatment in each field (D2 and F4) from samples collected postharvest from the 0-to 6-inch depth at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas. K:Mg ratio calculated as the ratio of K and Mg expressed as cmolc/kg. Statistical significance determined at α = 0.05. Letters within each field that are not the same are statistically different as determined by Tukey's honestly significant difference test.

Effect of Soil-Applied Phosphorus and Potassium on Seedcotton Yield in Arkansas

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Abstract

In 2018, approximately 480,000 acres of cotton (*Gossypium hirsutum* L.) were harvested in Arkansas. Phosphorus (P) and potassium (K) are required for producing economically optimum seedcotton yield in Arkansas. Accurate soil-test-based fertilizer recommendations are the key to applying the right rates of P and K fertilizer for a cotton crop. Information from replicated field experiments on cotton response to P and K fertilization is the foundation of an accurate fertilizer recommendation. In 2019, seedcotton yield response to P or K fertilizer rate was evaluated at multiple sites in soils typically used for cotton production. Phosphorus fertilization did not significantly ($P > 0.10$) increase seedcotton yield at any of the four sites. Potassium fertilization significantly increased the seedcotton yield at three of the five sites. At the three K-responsive sites, the maximum seedcotton yield increase from K-fertilization ranged from 1025 to 1512 lb/acre, which is equivalent to 47% to 134% increase as compared to the cotton that did not receive any K. Potassium fertilization did not influence seedcotton yield when the Mehlich-3 soil-test K was greater than 90 ppm. The results will be added to a database on high-yielding cotton response to P or K fertilization in Arkansas. The database will be used to review and if needed revise the existing soil-test-based P and K fertility recommendations for cotton production.

Introduction

In 2018, approximately 480,000 acres of cotton were harvested in Arkansas, reflecting the positive effect of a more favorable market than in 2017. Phosphorus (P) and potassium (K) are involved in a variety of metabolic activities in cotton, thus they are required for producing optimal cotton yield and quality. From 1995 to 2015, the average Arkansas cotton lint yield increased from 635 to 1100 lb/acre, which represents a substantial increase in P and K removal from the soil nutrient reserves. The deficiency of either of these two nutrients may limit cotton yield in many agricultural soils if the nutrients removed by the harvested crop are not replenished by supplemental fertilization.

Reliable soil-test-based fertilizer recommendations are the key to applying the right fertilizer-P and -K rates. The development of accurate recommendations requires results from multiple sites and years. The objective of this research was to evaluate seedcotton yield response to soil-applied fertilizer-P or -K rate on soils typically used for cotton production in Arkansas.

Procedures

Phosphorus Experiments

Four P-fertilization trials were conducted in 2019 at the Lon Mann Cotton Research Station in Lee County (LEG91, LEG93, LEG95, and LEG97). The soil series and selected agronomic information for each site are listed in Table 1. The previous crop was cotton at LEG95 and corn at all the other sites. The test at LEG95 was the fourth year of applying the same rates of P to the same plots and the other tests were the second year of applying the same rates of P to the same plots.

Prior to P application, a composite soil sample was taken from the 0- to 6-inch depth of the no-P control treatment in each block. Each composite soil sample consisted of a total of 5 or 6 cores collected from the top of the bed and bed shoulder in an alternating sequence. 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. Soil particle size analysis was performed by the hydrometer method.

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 four (LEG91) or five (LEG93, LEG95, LEG97) times. Phosphorus treatments were applied onto the soil surface in a single application on the plot surface before planting at LEG91 and LEG93 and mechanically incorporated into the top 3- to 4-inches of the soil. The beds were then pulled with a hipper and cotton was planted on the top of the bed. At the other two sites (LEG95 and LEG97), P fertilizer was broadcast-applied onto the soil (bed) surface 6 to 21 days after planting (Table 1). All experiments were fertilized with a total of 120 lb N/acre as urea or urea ammonium nitrate in a single (preplant) or

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two split applications (i.e., preplant and first-square). Cotton was grown on beds and furrow-irrigated as needed. Each plot was 25-ft (LEG95, LEG98) or 40-ft (all other tests) long and 12.6-ft wide allowing for four rows of cotton spaced 38 inches apart. Cotton management closely followed the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations. The two center rows of cotton in each plot were harvested with a spindle-type picker equipped with an electronic weighing system. When appropriate, means were separated by the least significant difference (LSD) method and interpreted as significant when $P \leq 0.10$.

Potassium Experiments

Five replicated field experiments were conducted in 2019 including trials at the Lon Mann Cotton Research Station in Lee County (LEG92, LEG94, LEG96, LEG98), and Judd Hill Research Farm in Poinsett County (POG92). The agronomic information for K trials is listed in Table 1. Soil sample collection and analysis were performed the same as described for P tests. Soil property means are listed in Table 3. The test at LEG96 was the fourth year of applying the same P-treatments to the same plots and the other tests were the second year of applying the same P-treatments to the same plots.

Potassium application rates ranged from 0 to 200 lb K_2O/acre in 50 lb K_2O/acre increments at all sites. All K treatments were applied as muriate of potash onto the soil surface before planting (LEG92, LEG94, and LEG96) or 6 to 21 days after planting (Table 1). All preplant-applied K treatments were mechanically incorporated, the beds were pulled with a hipper, and cotton was planted on top of the bed. Nitrogen fertilizer management was the same as described for the P trials. The plot length was 25 ft at LEG96 and LEG98 and 40 ft at the other four locations. Plots at all locations were 12.6 ft wide allowing for 4 rows of cotton planted in 38-inch wide rows. All experiments had a randomized complete block design and each treatment was replicated 4 times at POG92 and LEG92 and 5 times at other sites. Cotton harvest and statistical analysis were done the same as described for P tests.

Results and Discussions

Phosphorus Experiments

The soil pH was from 6.3 to 7.2 and soil clay content ranged from 8% to 15% among the four sites (Table 2). Mehlich-3 extractable P ranged from 14 to 38 ppm. According to the current Cooperative Extension Service interpretation, the soil-test P level was Very Low (0 to 15 ppm) at LEG95, Low (16 to 25 ppm) at LEG91 and LEG93, and Optimum (35 to 50 ppm) at LEG97. According to the current soil-test-based P fertilization guidelines for cotton, 90 and 70 lb P_2O_5/acre are recommended for soils that are Very Low or Low, and no P fertilizer is recommended for soils that are Optimum or above.

Phosphorus fertilization did not significantly influence seedcotton yield at any of the four sites (Table 4). The lack of a benefit from P fertilization at LEG97, which has an Optimal soil-test P level, is consistent with our current interpretation of Mehlich-3 extractable soil-test P for cotton. However, the lack of a benefit from P fertilization at the three sites with Low (LEG91 and LEG93) and Very Low (LEG95) soil-test P suggests that the current thresholds for these soil-test categories may need to be revised.

Potassium Experiments

The average Mehlich-3 extractable soil K ranged from 72 to 137 ppm among the 5 sites (Table 3). According to the current soil-test interpretation, soil-test K was Low (61 to 90 ppm) at LEG92, LEG96, and POG92; Medium at LEG94 (91 to 130 ppm); and Optimum (131 to 175) at LEG98. The current fertilization guidelines for cotton production recommend 95, 60, and 45 lb K_2O/acre for soils rated Low, Medium, and Optimum, respectively, in soil-test K.

Potassium fertilization significantly ($P \leq 0.10$) affected seedcotton yield at the three sites with Low soil-test K (LEG92, LEG96, and POG92, Table 5). At the three K-responsive sites, K fertilization increased the maximum seedcotton yield 1025 to 1512 lb/acre highlighting the importance of K fertilization. Application of 50 (LEG92 and LEG96) or 150 (POG92) lb K_2O/acre was required to produce maximal seedcotton yield. The positive yield response to K fertilization at these 3 sites is consistent with current soil-test-based fertilizer-K recommendations. Potassium fertilization did not significantly influence the seedcotton yield at the three sites that had Medium or Optimum soil-test K.

Practical Applications

The 2019 yield results show that P fertilization did not affect the seedcotton yield at four fields having Mehlich-3 extractable P in the 0- to 6-inch depth that ranged from 14 to 38 ppm. The lack of a seedcotton yield benefit from P fertilization in soils rated Low or Very Low suggests that soil-test P thresholds need to be reevaluated. Cotton grown in soils having Low soil-test K (61 to 90 ppm) responded positively to K fertilization, but soils rated as having Medium or Optimum soil-test K did not respond to K fertilization. The results from the 2019 studies will be added to a database on cotton response to P and K fertilization to evaluate the utility of existing soil-test thresholds and develop more accurate fertilizer-P and -K rate recommendations for cotton.

Acknowledgments

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Table 1. Site identification code; test nutrient(s); soil series; cotton cultivar; and planting, fertilizer application, and harvest dates for trials conducted in Lee (LEG91, LEG92, LEG93, LEG94, LEG95, LEG96, LEG97, LEG98), and Poinsett (POG92) counties during 2019.

Site code	Test nutrient	Soil series	Hybrid	Planting date	Fertilization date	Harvest date
LEG91	P	Convent silt loam	DG3385B2XF	18-May	17-April	6-October
LEG92	K	Convent silt loam	DG3385B2XF	18-May	16-April	6-October
LEG93	P	Convent silt loam	DG3385B2XF	18-May	16-April	6-October
LEG94	K	Loring silt loam	DG3385B2XF	18-May	17-April	6-October
LEG95	P	Calloway silt loam	DG3385B2XF	18-May	31-May	6-October
LEG96	K	Convent silt loam	DG3385B2XF	18-May	30-May	6-October
LEG97, LEG98	P, K	Memphis silt loam	DG3385B2XF	18-May	24-May	6-October
POG92	K	Dundee silt loam	DeltaPine 1614	27-May	19-June	14-October

Table 2. Selected chemical property means of soil samples collected from the 0- to 6-inch depth before fertilizer P application for four P-fertilization trials established in Lee County during 2019.

Site ID	Soil pH†	Mehlich-3-extractable nutrients P	SD P‡	K	Ca	Mg	Cu	Zn	SOM§	Sand	Silt	Clay	Soil texture
		(ppm)							(%)				
LEG91	6.3	16	±1	82	857	236	1.3	0.9	1.7	26	61	13	Silt loam
LEG93	6.6	22	±3	67	1107	288	1.7	1.7	1.5	20	68	12	Silt loam
LEG95	6.4	14	±1	61	727	205	1.3	4.2	1.6	5	87	8	Silt
LEG97	7.2	38	±5	111	1292	319	1.7	1.3	1.8	34	51	15	Silt loam

† Soil pH was measured in a 1:2 (weight: volume) soil-water mixture.
‡ SD = Standard deviation of Mehlich-3 extractable soil-test P means.
§ Soil organic matter as measured by loss on ignition.

Table 3. Selected chemical property means of soil samples taken from the 0- to 6-inch depth before fertilizer-K application for five trials conducted in Lee (LEG92, LEG94, LEG96, LEG98), and Poinsett (POG92) counties during 2019.

Site ID	Soil pH†	Mehlich-3-extractable nutrients P	K	SD K‡	Ca	Mg	Cu	Zn	SOM§	Sand	Silt	Clay	Soil texture
		(ppm)							(%)				
LEG92	6.5	13	70	±5	1128	266	1.2	1.6	1.40	21	63	16	Silt loam
LEG94	6.6	31	112	±8	1279	360	1.8	1.0	1.9	20	60	20	Silt loam
LEG96	6.4	23	77	±9	813	226	1.7	4.5	1.7	-	-	-	-
LEG98	6.7	42	137	±16	1310	349	1.7	1.2	1.8	20	64	16	Silt loam
POG92	7.0	50	72	±3	1173	174	0.93	3.1	1.6	55	35	10	Sandy loam

† Soil pH was measured in a 1:2 (weight: volume) soil-water mixture.
‡ SD = Standard deviation of Mehlich-3 extractable soil-test P means.
§ Soil organic matter as measured by loss on ignition.

Table 4. Effect of P-fertilization rate on seedcotton yield for four trials conducted in Lee County (LEG91, LEG93, LEG95, and LEG97) Arkansas during 2019.

P rate	Seedcotton yield LEG91	LEG93	LEG95	LEG97
(lb P_2O_5/acre)	(lb/acre)			
0	2838	3177	2325	3337
40	2876	3487	3135	3564
80	3223	3369	2984	3262
120	2728	3711	2900	3457
160	2725	3312	2803	3684
C.V., %†	7.7	7.9	16.5	7.9
P-value‡	0.16	0.16	0.21	0.16

† CV = Coefficient of variation.
‡ Significance interpreted as *P*-value ≤ 0.10.

Table 5. Effect of fertilizer-K rate on seedcotton yield in six trials conducted in Lee (LEG92, LEG94, LEG96, LEG98), and Poinsett (POG92) counties during 2019.

	Seedcotton yield				
K rate	LEG92	LEG94	LEG96	LEG98	POG92
(lb K_2O/acre)	(lb/acre)				
0	1834 b‡	2850	2166 c	3208	1121 c
50	2845 a	2921	3191 a	3080	1985 b
100	3119 a	2874	2857 b	3188	2061 b
150	2950 a	3069	3093 ab	3301	2446 a
200	3152 a	2749	3032 ab	3330	2633 a
C.V., %†	8.0	7.1	9.4	7.2	8.3
P-value	0.0002	0.32	0.0001	0.5557	<0.0001

† CV, Coefficient of variation.

‡ Within a column, means followed by the same letter are not significantly different ($P < 0.10$).

Corn Grain Yield Response to Soil-Applied Phosphorus and Potassium in Arkansas

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Abstract

Corn (*Zea mays* L.) is an important row crop in Arkansas. Phosphorus (P) and potassium (K) are two important nutrients in corn nutrition. Reliable soil-test-based fertilizer recommendations are the most cost effective tools for sound P and K fertilization. Information from replicated experiments on corn response to P or K fertilization are the cornerstones of reliable soil-test recommendations. Replicated field experiments were conducted to evaluate corn response to fertilizer P and K rate on soils typically used for corn production. Phosphorus fertilization significantly ($P < 0.10$) increased corn grain yield at two sites rated Very Low in Mehlich-3 extractable soil-P. At the two P-responsive sites, maximum grain yield increase from P-fertilization ranged from 37 to 43 bu./acre, which is equivalent to a 23% to 26% increase as compared to the corn that did not receive any P. Potassium fertilization significantly increased corn grain yield at five sites with Low soil-test K. At the K-responsive sites, maximum grain yield increase from K fertilization ranged from 16 to 70 bu./acre, which is equivalent to a 23% to 26% increase as compared to the corn that did not receive any K. The grain yield of corn that received no fertilizer-K ranged from 98 to 211 bu./acre and the range of grain yields of corn fertilized with K was 123 to 227 bu./acre. Supplemental K fertilization did not influence corn grain yield when the soil-test K was Medium. The results will be added to a database on corn response to P or K fertilization in Arkansas. The database will be used to review and, if needed, revise the existing soil-test-based P and K fertility recommendations for corn production.

Introduction

Corn (*Zea mays* L.) is a major row crop in Arkansas. In 2018, approximately 645,000 acres of corn were harvested in Arkansas. The equivalent of 60 lb P_2O_5 and 45 lb K_2O/acre are removed from the soil by a grain yield of 175 bu./acre (International Plant Nutrition Institute, 2012). Between 1992 and 2018, the average corn grain yield in Arkansas increased from 130 to 181 bu./acre, which represents a substantial increase in P and K removal from the soil nutrient reserves. Phosphorus and K play important roles in many plant physiological processes such as energy transfer and carbohydrate metabolism. The deficiency of either nutrient will limit corn yield and reduce the growers' profits. Failure to replace the nutrients removed by the harvested grain with adequate fertilizer rates can lead to soil nutrient depletion and eventually yield-limiting nutrient deficiencies.

Applying the right rates of P and K enables the growers to maximize the net returns from corn production and minimize nutrient loss into the surrounding landscape. Reliable soil-test-based fertilizer recommendations are the most cost-effective tool for applying the right fertilizer-P or -K rates. The development of reliable soil-test-based fertilizer-P and -K rate recommendations requires data from a large number of trials. 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

Seven replicated P-fertilization trials were established in 2019 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS: SFZ97, SFZX91, and SFZX95), Lon Mann Cotton Research Station in Marianna (LMCRS: LEZ97), and commercial farms located in Cross (CRZ91), Lonoke (LOZ91), and Monroe (MOZ91) counties. Selected agronomic information is listed in Table 1.

The previous crop was corn at PTRS and CRZ91, cotton at LMCRS, and soybean at CRZ91 and MOZ91. Prior to P application, a composite soil sample was taken from the 0- to 6-inch depth of each replication (CRZ91, LOZ91, and MOZ91) or the plot that would receive 0 lb P_2O_5/acre (LEZ97, SFZ97, SFZX91, SFZX95). The on-farm experiments were a single-year test and all the other tests were in the second year of fertilizing the same plots with the same treatments. Each composite soil sample consisted of a total of 5 or 6 cores collected from the top of the bed and bed-shoulder in an alternating sequence.

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At sites CRZ91, LEZ97, LOZ91, and MOZ91, the fertilizer treatments were applied to the plot surface (top of the bed and furrow) after corn emergence and at all other sites, the beds were pulled after the fertilizer application. 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 at LEZ91, MOZ91, LOZ91, and CRZ91 where each treatment was replicated four times. Phosphorus treatments were applied onto the soil surface in a single application ranging from 19 days before planting to 7 to 9 days after emergence (Table 1). On 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 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 lb N/acre as urea ammonium nitrate in single, double, or three-way split applications (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- or 40-ft long and 10- to 12.6-ft wide allowing for four rows of corn spaced 30 or 38 inches apart depending on the location. Corn management closely followed the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) recommendations.

The middle two rows of each plot were harvested with a plot combine for sites at the LMCRS and PTRS. For trials located in commercial fields, one 12-ft section in each of the two center rows were hand-harvested and placed through a combine. The calculated grain yields were adjusted to a uniform moisture content of 15.5% before statistical analysis. When appropriate, means were separated by the least significant difference (LSD) method and interpreted as significant when $P \leq 0.10$.

Potassium Experiments

Seven replicated field experiments were conducted in 2019 including trials at the PTRS (SFZ92 and SFZ94), LMCRS (LEZ92 and LEZ94), and three commercial production fields located in Cross (CRZ92), Lonoke (LOZ82), and Monroe (MOZ92) counties. Agronomic information for the K trials is listed in Table 1. Soil sampling, K fertilization, and other practices were similar to the P studies. At sites LEZ92, LEZ94, SFZ92, and SFZ94, the beds were pulled after fertilizer K application. At the CRZ92, LOZ92 and MOZ92 sites, fertilizer K was applied on the soil surface. The K tests in Cross (CRZ92), Lonoke (LOZ92) and Monroe (MOZ92) counties were 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 at all sites except SFZ94 where the rates were applied in 40 lb K_2O/acre increments. 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 was the same as described for the P trials. All sites were furrow-irrigated with well water. Crop harvest and statistical analysis were similar to P tests described.

Results and Discussions

Phosphorus Experiments

The soil clay content ranged from 7% to 17% and soil organic matter ranged from 1.2% to 2.5% across the seven sites. The soil pH was from 6.1 to 7.3 and Mehlich-3 extractable P ranged from 10 to 54 ppm (Table 2). According to the current CES recommendations, the soil-test P level was Very Low (0 to 16 ppm) at LOZ91, SFZ97, SFZX91, and SFZX95; Low (16 to 25 ppm) at MOZ91; Medium (26 to 35 ppm) at CRZ91; and Above Optimum (> 50 ppm) at LEZ97. According to the current soil-test-based P fertilization guidelines for corn with a yield goal of >200 bu./acre, the Very Low, Low, Medium, or Optimum soil-test levels receive recommendations of 130, 110, 80, and 0 lb P_2O_5/acre, respectively.

Phosphorus fertilization significantly ($P < 0.10$) increased corn grain yield (Table 4) at two sites that had Very Low (SFZ97 and SFZX95) Mehlich-3 extractable soil-test P levels (Table 2). At the two P-responsive sites, the maximum grain yield increase from P fertilization ranged from 37 to 43 bu./acre, which is equivalent to 23% to 26% increase as compared to the corn that did not receive any P (Table 4). At SFZ97, the grain yield of corn that received no fertilizer P was 140 bu./acre, which was significantly lower than the yields of corn fertilized with P. At SFZX95, the yield of the corn that received no fertilizer P averaged 182 bu./acre, which was statistically lower than the yields of corn fertilized with >80 lb P_2O_5/acre. Corn yield was maximized by the application of 80 lb P_2O_5/acre. Phosphorus application rate did not significantly influence corn grain yield at the remaining five sites.

Potassium Experiments

The average Mehlich-3 extractable K ranged from 64 to 109 ppm (Table 3). The interpretation of soil-test K was Low (61 to 90 ppm) at the LEZ92, LOZ92, MOZ92, SFZ92, and SFZ94, and Medium (91 to 130 ppm) at LEZ94 and CRZ92. The current fertilization guidelines for corn with a yield goal of >200 bu./acre recommend 115 and 80 lb K_2O/acre for the Low and Medium soil-test K levels, respectively.

Potassium fertilization significantly ($P \leq 0.10$, Table 5) affected corn grain yield at LEZ92, LOZ92, MOZ92, SFZ92, and SFZ94, which all had Low soil-test K levels (Table 3). At these K-responsive sites, the grain yield of corn that did not receive any K was 98 to 211 bu./acre and the grain yield of corn that was fertilized with any K was 126 to 227 bu./acre, respectively. At the K-responsive sites, K fertilization increased the maximum corn grain yield 16 to 70 bu./acre, which is equivalent to 7% to 52%. The positive response to K fertilization at the five sites with Low soil-test K is consistent with current recommendations for soil-test-based fertilizer-K recommendations.

Practical Applications

The 2019 results show that P fertilization significantly increased corn grain yield at two of four sites where Mehlich-3 extractable P in the 0- to 6-inch depth was Very Low. The results suggest that soil-test P is inconsistent in predicting when corn will respond positively to P fertilization on soils having Very Low soil-test P levels. Potassium fertilization significantly increased corn grain yield at five sites which had Low soil test-K levels. Overall, the results suggest that soil-test K may accurately identify soils that require K fertilization to maximize corn yield. The results from these studies will be added to a database on modern corn hybrid response to P or K fertilization to evaluate the utility of existing soil-test thresholds and the recommended fertilizer-P and K rates needed to produce maximal corn yield.

Acknowledgments

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Table 1. Site identification code; test nutrient(s); soil series; corn hybrid; and planting, fertilizer application, and harvest dates for trials conducted in Cross (CRZ91 and CRZ92), Lee (LEZ92, LEZ94, LEZ97), Lonoke (LOZ91, LOZ92), Monroe (MOZ91, MOZ92), and St. Francis (SFZ92, SFZ94, SFZ97, SFZX91, SFZX95) counties during 2019.

Site code	Test nutrient(s)	Soil series	Corn hybrid	Row spacing	Planting date	Fertilization date	Harvest date
				(inches)			
CRZ91, CRZ92	P, K	Collins silt loam	Dekalb 64-32	30	11-April	26-April	06-Sept.
LEZ92	K	Convent silt loam	Pioneer P1197YHR	38	05-May	16-April	17-Sept.
LEZ94	K	Convent silt loam	Pioneer P1197YHR	38	05-May	17-April	17-Sept.
LEZ97	P	Memphis silt loam	Pioneer P1197YHR	38	05-May	24-May	17-Sept.
LOZ91, LOZ92	P, K	Stuttgart silt loam	Dekalb 6206	30	16-May	30-May	04-Sept.
MOZ91, MOZ92	P, K	Foley-Calhoun-Bonn Complex	Dekalb 6869	38	03-May	17-May	10-Sept.
SFZ92	K	Calloway silt loam	Terral 28BHR18	30	17-May	06-May	13-Sept.
SFZ94	K	Calloway silt loam	Terral 28BHR18	30	17-May	06-May	13-Sept.
SFZ97	P	Calhoun silt loam	Terral 28BHR18	30	17-May	07-May	13-Sept.
SFZX91	P	Calloway silt loam	Terral 28BHR18	30	17-May	06-May	17-Sept.
SFZX95	P	Calloway silt loam	Terral 28BHR18	30	17-May	06-May	17-Sept.

Table 2. Selected chemical property means of soil samples collected from the 0- to 6-inch depth before P-fertilizer application for seven P-fertilization trials established in Cross (CRZ91), Lee (LEZ97), Lonoke (LOZ91), Monroe (MOZ91), and St. Francis (SFZ97, SFZX91, SFZX95) counties during 2019.

Site ID	Soil pH†	Mehlich-3-extractable nutrients							SOM§	Sand	Silt	Clay	Soil texture
		P	SD P‡	K	Ca	Mg	Cu	Zn					
		(ppm)							(%)				
CRZ91	6.3	30	±1	131	810	134	1.7	7.1	1.6	18	75	7	Silt loam
LEZ97	7.3	54	±4	127	1255	365	1.7	1.6	1.7	29	56	15	Silt loam
LOZ91	6.1	13	±4	68	866	121	1.3	1.0	2.0	24	59	17	Silt loam
MOZ91	6.9	25	±5	66	1401	162	1.5	2.3	2.3	14	73	13	Silt loam
SFZ97	6.9	10	±1	65	1620	301	1.4	2.5	2.5	25	58	17	Silt loam
SFZX91	6.9	12	±2	65	1264	216	1.3	1.7	1.2	13	71	16	Silt loam
SFZX95	7.2	15	±4	111	1292	319	1.7	1.3	2.0	16	72	12	Silt loam

† Soil pH was measured in a 1:2 (weight: volume) soil-water mixture.
‡ SD = Standard deviation of Mehlich-3 extractable soil-test P means.
§ Soil organic matter as measured by loss on ignition.

Table 3. Selected chemical property means of soil samples taken from the 0- to 6-inch depth before K-fertilizer application for seven trials conducted in Cross (CRZ92), Lee (LEZ92 and LEZ94), Lonoke (LOZ92), Monroe (MOZ92), and St. Francis (SFZ92, SFZ94) counties during 2019.

Site ID	Soil pH†	Mehlich-3-extractable nutrients							SOM§	Sand	Silt	Clay	Soil texture
		P	K	SD K‡	Ca	Mg	Cu	Zn					
		(ppm)							(%)				
CRZ92	7.2	32	109	±5	812	133	1.7	6.6	1.6	24	67	10	Silt loam
LEZ92	6.4	19	64	±8	1069	246	1.4	1.7	1.5	18	66	16	Silt loam
LEZ94	6.1	24	97	±9	1057	415	1.8	1.1	1.4	12	71	17	Silt loam
LOZ92	6.0	7	71	±8	966	143	1.1	1.0	2.1	14	71	15	Silt loam
MOZ92	7.1	34	90	±21	1440	162	1.8	2.5	2.5	14	75	11	Silt loam
SFZ92	7.1	25	64	±12	1373	238	1.6	4.7	2.3	16	72	12	Silt loam
SFZ94	6.9	20	72	±16	1276	235	1.1	5.9	2.7	16	70	14	Silt loam
SFZ94	6.9	20	72	±16	1276	235	1.1	5.9	2.7	16	70	14	Silt loam

† Soil pH was measured in a 1:2 (weight: volume) soil-water mixture.
‡ SD = Standard deviation of Mehlich-3 extractable soil-test P means.
§ Soil organic matter as measured by loss on ignition.

Table 4. Effect of P-fertilization rate on corn grain yield for seven trials conducted in Cross (CRZ91), Lee (LEZ97), Lonoke (LOZ91), Monroe (MOZ91), and St. Francis (SFZ97, SFZX91, and SFZX95) counties during 2019.

P rate	Grain yield						
	CRZ91	LEZ97	LOZ91	MOZ91	SFZ97	SFZ91	SFZ95
(lb P_2O_5/acre)	(lb/acre)						
0	280	123	204	185	140 b†	176	182 c
40	293	119	207	211	167 a	177	191 bc
80	270	121	200	201	167 a	181	192 bc
120	290	125	206	194	177 a	199	205 b
160	285	120	210	212	167 a	195	221 a
C.V., %‡	6.3	9.5	7.0	6.8	7.4	8.3	6.4
P-value	0.41	0.95	0.76	0.13	0.01	0.26	0.0045

† Significance interpreted as *P*-value ≤ 0.10. Means within a column followed by different lowercase letters are significantly different.
‡ CV = Coefficient of variation.

Table 5. Effect of K-fertilization rate on corn grain yield for seven trials conducted in Cross (CRZ92), Lee (LEZ92, LEZ94), Lonoke (LOZ92), Monroe (MOZ92), and St. Francis (SFZ92, SFZX94) counties during 2019.

	Seedcotton yield							Grain yield
K rate	CRZ92	LEZ92	LEZ94	LOZ92	MOZ92	SFZ92	K rate	SFZ94
(lb K_2O/acre)	(lb/acre)						(lb K_2O/acre)	(lb/acre)
0	261	98 b[†]	154	164 b	211 b	140 b	0	120 d
50	278	117 a	147	185 a	213 b	149 b	40	138 c
100	254	126 a	148	197 a	214 b	173 a	80	189 a
150	261	127 a	146	196 a	215 b	185 a	120	190 a
200	264	129 a	148	191 a	227 a	176 a	160	155 b
C.V., %[‡]	7.9	7.4	4.5	7.2	3.7	9.6	200	183 a
P-value	0.58	0.003	0.55	0.09	0.09	0.009	C.V., %	4.9
							P-value	<0.0001

[†] Significance interpreted as *P*-value ≤ 0.10. Means within a column followed by different lowercase letters are significantly different.
[‡] CV = Coefficient of variation.

Preliminary Characterization of Selected Nutrient Concentrations in Corn Grain and Cotton Seed in Arkansas

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Abstract

The nutrient concentrations in corn grain and cotton seed are important components of calculating the nutrient removal rates by crops and reliable soil-test-based fertilizer recommendations that account for crop nutrient removal at different yield goals. The objective of this study was to characterize the nutrient concentrations in corn grain and cotton seed samples from fertilizer-phosphorus (P) and -potassium (K) rate trials. Averaged across 11 fertilizer-P trials, corn grain had mean concentrations of 1.32% nitrogen (N), 0.29% P, 0.36% K, and 0.10% sulfur (S). Corn grain boron (B) and zinc (Zn) concentrations averaged 2.0 ppm and 24.5 ppm, respectively. Based on the median P and K concentrations, a corn yield of 225 bu./acre will remove 163 lb N, 38 lb P (87 lb P_2O_5), and 47 lb K (56 lb K_2O). Averaged across 6 cotton fertilizer-P rate trials, cotton seed had mean concentrations of 3.71% N, 0.79% P, 1.19% K, and 0.46% magnesium (Mg). These results indicate that the seed associated with the production of one 480-lb bale of cotton lint removes 27 lb N, 5.5 lb P (12.6 lb P_2O_5) and 8.7 lb K (10.5 lb K_2O; not including lint).

Introduction

In 2018, approximately 645,000 and 480,000 acres of corn (*Zea mays* L.) and cotton (*Gossypium hirsutum* L.), respectively, were harvested in Arkansas. Phosphorus (P) and potassium (K) play important roles in many plant physiological processes such as energy transfer, carbohydrate transport, and others. The deficiency of either nutrient will limit crop yield and reduce the growers' profits. Technological advances and market forces had significantly increased corn and cotton yield in Arkansas in the past three decades. Between 1992 and 2018, the average corn grain yield in Arkansas increased from 130 to 181 bu./acre. From 1995 to 2015, the average Arkansas cotton lint yield increased from 635 to 1100 lb/acre. These achievements have increased the nutrient removal rates from the agricultural soils. Economically sensible nutrient management requires the replacement of the nutrients removed by the harvested corn grain and cotton seed with adequate fertilizer rates. Information on the nutrient concentrations and the removal rates by corn grain and cotton seed are needed to develop soil-test-based fertilizer-P and -K recommendations that supply adequate nutrients for optimal crop yield and assist the grower with nutrient management. The specific objectives of this research were to characterize the nutrient concentrations in corn grain and cotton seed and to calculate nutrient removal rates.

Procedures

Corn Experiments

From 2017 to 2019, irrigated-corn response to fertilizer-P or -K rates was evaluated in two separate series of replicated trials on soils typically used for corn production in Arkansas. The detailed experimental procedures are published elsewhere (Mozaffari et al., 2018, 2019, 2020a). Briefly, the fertilizer-P application rates ranged from 0 to 160 lb P_2O_5/acre in 40 lb P_2O_5/acre increments and fertilizer-K application rates ranged from 0 to 200 lb K_2O/acre in 50 lb K_2O/acre increments. Other nutrients were blanket applied to ensure that P (or K) was the only yield-limiting nutrient. The experimental design was a randomized complete block where each treatment was replicated 4 to 5 times depending on the locations. Corn management closely followed the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations. The middle two rows of each plot were harvested with a plot combine for sites at research stations. For trials located in commercial fields, one 12-ft section in each of the two center rows was hand-harvested and placed through a combine. Corn grain samples were collected from the combine at threshing from 11 P and 11 K experiments. The Mehlich-3 extractable P in the 0- to 6-inch depth of those sites ranged from Very Low (P sites) or Low (K sites) to Above Optimum. The soil texture in field trials was predominantly silt loam and 11 corn hybrids were represented. Corn grain samples were dried overnight in an oven at 65 °C. Oven-dried corn grain samples were ground in a coffee grinder to pass a 20-mesh sieve. Nitrogen in the grain samples was measured by combustion. Other nutrients were determined by wet digestion and the concentrations of nutrients in the digest were measured by inductively coupled atomic emission spectroscopy. Nutrient concentrations in this paper are presented on "as is" basis for oven-dried samples.

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Cotton Experiments

Detailed procedures for cotton fertilizer-P and -K rate trials are given in Wilson et al. (2018) and Mozaffari et al. (2020b). Experimental procedures for cotton fertilizer-P or -K rate trials (including P and K rates) were similar to the corn experiments, except that cotton seed samples were collected from 6 trials of each nutrient. Cotton boll samples were collected after boll opening, but before harvest, from 10 plants in each of the 2 center rows of each plot. A total of 20 boll samples were collected from the bottom (5), middle (10), and top (5) of each plant. The boll samples were placed in a 10-saw laboratory gin and separated into lint, fuzzy seeds, and gin trash. The seeds were rinsed in concentrated sulfuric acid for 30 seconds then rinsed for 30 seconds in pH 14 sodium hydroxide to neutralize the acidity. The delinted-neutralized seeds were rinsed 4 times in tap water and 4 times in distilled water and dried overnight in an oven at 65 °C. Oven-dried seed samples were ground to fineness in a FOSS KN 295 Knifech sample grinding mill equipped with hydro-cooling system. Ground cotton seed samples were analyzed for N and mineral nutrients using the same methods described for corn grain.

Results and Discussions

Corn Experiments

Nitrogen and K were present in the greatest elemental concentrations in corn grain harvested from the fertilizer-P trials (Table 1). Averaged across all sites and P rates, the mean concentrations were 1.32% N (± 0.13 standard deviation), 0.29 %P (± 0.04), 0.36% K (± 0.04), and 0.10% S (± 0.01). Calcium (Ca) and magnesium (Mg) concentrations averaged 0.03% and 0.14% (data not presented). Within each site the mean and median concentrations of each nutrient were similar. The concentrations of N, P, and K among the sites fluctuated by almost 50% as indicated by the range values. Boron (B) and zinc (Zn) concentrations averaged 2.0 ppm B (± 0.95) and 24.5 ppm Zn (± 6.4). The nutrient concentrations in grain samples from the fertilizer-K trials were similar to the fertilizer-P trials (Table 2). We used the median grain N, P (from P tests), and K (from the K tests) and calculated that a 225 bu./acre corn yield will remove the equivalent of 163 lb N, 38 lb P (87 lb P_22O_5), and 47 lb K (56 lb K_2O), which compares with 174 lb N/acre, 33 lb P/acre, and 37 lb K/acre, respectively, for corn at 15.5% moisture content using values calculated by the USDA-NRCS Crop Nutrient Tool (USDA, NRCS 2020).

Cotton Experiments

Analysis of cotton seed from the fertilizer-P rate trials showed that N was present in the greatest concentration followed by K and P (Table 3). Averaged across all sites and P rates, the mean concentrations were 3.71% N (± 0.41), 0.79% P (± 0.08), 1.19% K (± 0.10), and 0.46% Mg (± 0.04 %). The median concentrations of B and Zn were 14 and 37.5 mg/kg, respectively. Averaged across the fertilizer-P rates, the range of nutrient concentrations indicated some fluctuation in the concentrations of each nutrient among trials. Nutrient concentrations in seed from the fertilizer-K rate trials were numerically similar to the P trials (Table 4). Assuming 40% gin turnout, the production of a 480-lb bale of cotton lint will result in the removal of 27 lb N, 5.5 lb P, and 8.7 K in the cotton seed. These values compare with calculations of 25 lb N/acre, 4.9 lb P/acre, and 7.8 lb K/acre estimates from USDA-NRCS Crop Nutrient Tool (USDA-NRCS 2020).

Practical Applications

Chemical analysis of corn grain samples indicates that on average one bushel of corn removes the equivalent of 0.73 lb N, 0.39 lb P_2O_5, 0.25 lb K_2O, and 0.056 lb S on an "as is" basis following oven drying. Based on these data, irrigated corn grown in Arkansas appears to contain similar amounts of nutrients as estimated by the USDA-NRCS. Averaged across the cotton fertilizer-P rate trials, the seed content associated with one bale of cotton lint removes the equivalent of 27 lb N, 5.5 lb P, and 8.7 K/bale lint assuming a gin turnout of 40% lint and the remaining 60% as seed. The corn grain and cotton seed nutrient concentrations did show considerable fluctuation among locations and perhaps fertilization treatments, which should be evaluated with additional statistical analysis. The information from these studies can be incorporated into our current soil-test-based fertilizer-P and -K recommendations algorithm. Growers and crop consultants can use this new information (in conjunction with routine soil test data) to manage their crop nutrients more efficiently and avoid under- or over-fertilization.

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Table 1. Descriptive statistics for the concentrations of N, P, K, S, B, and Zn in corn grain samples collected from eleven fertilizer-P rate trials (averaged across fertilizer-P rates) conducted in Arkansas during 2017, 2018, and 2019.

		Nutrient concentration					
Site ID	**Statistic**	**N**	**P**	**K**	**S**	**B**	**Zn**
		---------- (%) ----------				------- (mg/kg) -------	
ARZ71	Mean	1.26	0.29	0.35	0.10	3.0	38.7
	Median	1.26	0.28	0.34	0.09	3.0	38.0
	Range	1.19-1.36	0.22-0.39	0.27-0.45	0.08-0.12	2.1-3.8	31.7-43.4
CLZ75	Mean	1.22	0.27	0.35	0.10	1.4	24.7
	Median	1.22	0.26	0.34	0.10	1.4	22.0
	Range	1.14-1.38	0.22-0.39	0.29-0.48	0.08-0.13	0.9-2.0	16.1-38.8
LEZ81	Mean	1.46	0.31	0.36	0.12	2.1	25.6
	Median	1.44	0.31	0.36	0.12	2.1	25.4
	Range	1.33-1.63	0.28-0.34	0.32-0.39	0.11-0.13	1.1-4.3	22.8-29.5
LEZ85	Mean	1.26	0.32	0.39	0.11	1.8	20.7
	Median	1.26	0.31	0.39	0.11	1.8	20.6
	Range	1.15-1.36	0.29-0.36	0.35-0.44	0.10-0.11	1.5-2.4	18.7-23.2
LOZ81	Mean	1.23	0.25	0.33	0.09	1.1	19.0
	Median	1.21	0.25	0.33	0.09	1.1	19.0
	Range	1.14-1.34	0.21-0.29	0.29-0.37	0.09-0.10	0.8-1.8	17.1-20.9
MOZ91	Mean	1.14	0.27	0.33	0.10	0.8	18.4
	Median	1.11	0.28	0.33	0.10	1.0	18.0
	Range	1.00-1.34	0.25-0.31	0.31-0.38	0.09-0.10	0.0-1.0	17.0-21.0
MSZ71	Mean	1.21	0.31	0.40	0.10	3.0	26.0
	Median	1.21	0.30	0.39	0.10	3.0	25.5
	Range	1.10-1.29	0.22-0.41	0.29-0.51	0.08-0.13	2.0-4.0	19.5-33.4
PRZ71	Mean	1.30	0.30	0.35	0.11	1.9	24.1
	Median	1.31	0.30	0.34	0.10	1.8	22.7
	Range	1.13-1.42	0.26-0.41	0.29-0.46	0.08-0.14	1.2-4.5	19.9-32.2
SFZ71	Mean	1.42	0.31	0.35	0.10	2.8	23.3
	Median	1.42	0.31	0.35	0.10	2.4	23.0
	Range	1.31-1.52	0.26-0.36	0.30-0.41	0.09-0.12	1.8-8.0	19.8-27.6
SFZ87	Mean	1.57	0.32	0.41	0.11	1.5	24.0
	Median	1.57	0.32	0.40	0.11	1.5	21.9
	Range	1.51-1.66	0.29-0.36	0.37-0.46	0.10-0.12	1.1-2.4	18.6-36.8
SFZ97	Mean	1.35	0.26	0.39	0.12	1.0	18.2
	Median	1.35	0.26	0.38	0.12	1.0	18.0
	Range	1.31-1.43	0.24-0.28	0.36-0.42	0.12-0.13	1.0-1.0	17.0-20.0
All sites	Mean	1.32±0.13[a]	0.29±0.04	0.36±0.04	0.10±0.01	2.0±0.95	24.5±6.4
	Median	1.29	0.30	0.36	0.10	1.8	22.5
	Range	1.00-1.66	0.21-0.41	0.27-0.51	0.08-0.14	0.00-8.0	16.1-43.4

[a] Mean ± standard deviation.

Table 2. Descriptive statistics for the concentrations of N, P, K, S, B, and Zn in corn grain samples collected from eleven fertilizer-K rate trials (averaged across fertilizer-K rates) conducted in Arkansas during 2017, 2018, and 2019.

		Nutrient concentration					
Site ID	**Statistic**	**N**	**P**	**K**	**S**	**B**	**Zn**
		---------- (%) ----------				------- (mg/kg) -------	
ARZ72	Mean	1.26	0.28	0.34	0.09	2.6	22.8
	Median	1.26	0.27	0.33	0.09	2.7	22.2
	Range	1.19-1.37	0.23-0.33	0.30-0.40	0.08-0.11	1.9-3.1	17.1-28.1
CLZ76	Mean	1.20	0.36	0.39	0.18	8.7	20.0
	Median	1.16	0.35	0.40	0.12	2.1	19.7
	Range	0.97-1.51	0.21-0.49	0.25-0.46	0.07-0.31	1.2-22.8	14.6-32.1
CLZ82	Mean	1.17	0.28	0.39	0.09	2.4	17.7
	Median	1.17	0.28	0.40	0.09	2.4	17.8
	Range	1.05-1.31	0.23-0.33	0.34-0.45	0.09-0.10	1.7-2.9	14.5-21.2
LEZ86	Mean	1.23	0.35	0.43	0.10	2.2	24.0
	Median	1.23	0.33	0.42	0.10	2.2	23.3
	Range	1.10-1.37	0.28-0.49	0.35-0.56	0.10-0.11	1.6-2.9	19.7-31.8
LOZ82	Mean	1.21	0.24	0.33	0.09	1.6	19.3
	Median	1.18	0.24	0.34	0.09	1.1	19.3
	Range	1.07-1.37	0.19-0.28	0.29-0.37	0.09-0.10	0.9-10.5	17.1-22.0
LOZ92	Mean	1.16	0.22	0.33	0.10	1.1	18.6
	Median	1.16	0.22	0.33	0.10	1.0	18.5
	Range	1.11-1.18	0.19-0.24	0.31-0.34	0.10-0.10	1.0-2.0	17.0-20.0
MOZ92	Mean	1.23	0.27	0.32	0.10	0.9	18.5
	Median	1.21	0.27	0.32	0.10	1.0	18.0
	Range	1.15-1.34	0.24-0.30	0.29-0.36	0.09-0.10	0.0-1.0	16.0-21.0
MSZ72	Mean	1.39	0.30	0.39	0.10	3.1	26.9
	Median	1.37	0.31	0.40	0.11	3.1	26.3
	Range	0.86-1.86	0.23-0.39	0.31-0.49	0.08-0.14	2.3-3.7	21.1-36.9
PRZ72	Mean	1.33	0.28	0.35	0.11	2.2	25.2
	Median	1.34	0.27	0.34	0.11	2.1	24.6
	Range	1.22-1.46	0.23-0.36	0.30-0.44	0.09-0.12	1.2-4.7	20.7-31.8
SFZ72	Mean	1.29	0.33	0.38	0.10	1.9	18.7
	Median	1.30	0.33	0.38	0.10	1.8	18.5
	Range	1.19-1.39	0.27-0.41	0.33-0.47	0.08-0.12	1.1-2.7	15.5-21.9
SFZ92	Mean	1.23	0.29	0.41	0.12	1.3	19.1
	Median	1.23	0.29	0.41	0.11	1.0	19.0
	Range	1.16-1.29	0.26-0.31	0.38-0.43	0.10-0.14	1.0-2.0	18.0-20.0
All sites	Mean	1.28±0.14[a]	0.30±0.05	0.37±0.05	0.11±0.04	2.6±3.2	21.6±4.1
	Median	1.26	0.29	0.37	0.10	2.0	20.7
	Range	0.86-1.86	0.19-0.49	0.25-0.56	0.07-0.31	0.0-22.8	14.5-36.9

[a] Mean ± standard deviation.

Table 3. Descriptive statistics for the concentrations of N, P, K, Mg, Ca, S, B, and Zn in cotton seed samples collected from six fertilizer-P rate trials (averaged across fertilizer-P rates) conducted in Arkansas during 2017, 2018, and 2019.

		Nutrient concentration							
Site ID	**Statistic**	**N**	**P**	**K**	**Mg**	**Ca**	**S**	**B**	**Zn**
		(%)						(mg/kg)	
LEG71	Mean	3.93	0.83	1.17	0.47	0.17	0.32	15.4	36.8
	Median	3.93	0.86	1.15	0.47	0.17	0.32	15.0	36.9
	Range	3.49-4.56	0.73-0.93	1.06-1.33	0.42-0.53	0.14-0.20	0.27-0.37	13.8-17.4	32.1-40.9
LEG83	Mean	3.35	0.76	1.13	1.44	2.93	1.86	15.5	31.4
	Median	3.35	0.77	1.18	0.49	0.13	0.33	13.1	34.9
	Range	2.87-3.93	0.52-0.88	0.35-1.34	0.32-13.06	0.09-36.50	0.17-20.33	9.8-46.1	7.4-39.0
LEG85	Mean	3.56	0.80	1.20	0.47	0.13	0.32	13.0	33.4
	Median	3.58	0.83	1.20	0.48	0.13	0.33	13.8	35.0
	Range	3.14-4.01	0.65-0.93	0.81-1.34	0.32-0.53	0.09-0.15	0.17-0.39	9.8-16.2	20.8-39.4
LEG91	Mean	3.47	0.74	1.19	0.43	0.14	0.29	12.6	40.7
	Median	3.41	0.75	1.18	0.42	0.14	0.30	13.0	41.0
	Range	3.33-3.84	0.66-0.81	1.08-1.28	0.38-0.47	0.12-0.16	0.24-0.33	11.0-14.0	34.0-46.0
LEG95	Mean	3.86	0.79	1.17	0.46	0.15	0.31	13.9	48.3
	Median	3.86	0.79	1.18	0.46	0.15	0.31	14.0	47.5
	Range	3.38-4.38	0.71-0.83	1.11-1.23	0.44-0.48	0.11-0.17	0.29-0.33	12.0-15.0	42.0-60.0
POG71	Mean	4.32	0.81	1.18	0.46	0.20	0.35	15.4	35.0
	Median	4.34	0.82	1.17	0.45	0.20	0.34	15.0	34.8
	Range	4.10-4.48	0.71-0.92	1.05-1.40	0.40-0.52	0.13-0.22	0.30-0.44	13.7-17.3	32.3-39.0
All sites	Mean	3.71±0.41[a]	0.79±0.08	1.19±0.10	0.46±0.04	0.16±0.03	0.32±0.04	13.9±1.7	38.3±6.3
	Median	3.73	0.78	1.18	0.46	0.15	0.32	14.0	37.5
	Range	2.87-4.56	0.52-0.93	0.81-1.42	0.32-0.55	0.09-0.22	0.17-0.44	9.8-17.4	20.8-60.0

[a] Mean ± standard deviation.

Table 4. Descriptive statistics for the concentrations of N, P, K, Mg, Ca, S, B, and Zn in cotton seed samples collected from six fertilizer-K rate trials (averaged across fertilizer-K rates) conducted in Arkansas during 2017, 2018, and 2019.

		Nutrient concentration							
Site ID	**Statistic**	**N**	**P**	**K**	**Mg**	**Ca**	**S**	**B**	**Zn**
		(%)						(mg/kg)	
LEG72	Mean	4.27	0.84	1.22	0.50	0.20	0.33	14.1	34.1
	Median	4.24	0.86	1.20	0.49	0.19	0.33	14.1	33.6
	Range	4.03-4.63	0.71-0.99	1.12-1.42	0.45-0.59	0.16-0.23	0.29-0.45	12.3-16.0	29.4-38.3
LEG84	Mean	3.82	0.72	1.16	0.45	0.12	0.33	12.7	35.7
	Median	3.78	0.73	1.16	0.46	0.12	0.33	13.1	36.6
	Range	3.57-4.19	0.61-0.79	1.07-1.26	0.41-0.48	0.11-0.15	0.31-0.38	11.4-13.9	30.4-37.6
LEG96	Mean	3.92	0.78	1.19	0.45	0.16	0.31	14.4	45.2
	Median	3.87	0.77	1.19	0.46	0.16	0.31	15.0	45.5
	Range	3.56-4.52	0.73-0.85	1.15-1.24	0.42-0.47	0.13-0.19	0.27-0.34	12.0-15.0	43.0-47.0
MSG72	Mean	3.77	0.88	1.26	0.46	0.16	0.34	17.3	34.4
	Median	3.74	0.85	1.25	0.45	0.16	0.34	17.0	34.2
	Range	3.51-4.12	0.74-1.04	1.07-1.53	0.39-0.56	0.14-0.19	0.26-0.43	14.4-20.9	27.7-39.9
MSG82	Mean	3.56	0.68	1.22	0.40	0.13	0.34	11.8	31.8
	Median	3.52	0.69	1.22	0.40	0.13	0.34	11.6	31.6
	Range	3.19-3.99	0.57-0.77	1.10-1.43	0.34-0.45	0.10-0.15	0.29-0.42	10.5-14.2	27.0-36.0
POG92	Mean	4.41	0.76	1.19	0.47	0.16	0.38	12.1	51.7
	Median	4.46	0.76	1.20	0.47	0.16	0.37	12.0	50.5
	Range	3.90-4.83	0.71-0.83	1.07-1.29	0.43-0.49	0.14-0.19	0.35-0.42	11.0-13.0	46.0-65.0
All sites	Mean	3.92±0.38[a]	0.77±0.09	1.21±0.08	0.45±0.05	0.15±0.03	0.34±0.04	13.5±2.2	37.5±7.7
	Median	3.86	0.76	1.20	0.45	0.15	0.34	13.0	35.2
	Range	3.19-4.83	0.57-1.04	1.07-1.53	0.35-0.59	0.10-0.23	0.26-0.45	10.5-20.9	27.0-65.0

[a] Mean ± standard deviation.

Profit-Maximizing Potash Fertilizer Recommendations for Rice

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Abstract

Potassium (K) fertilizer recommendations for rice (*Oryza sativa* L) decrease as the amount of initial soil-test K increases until a point where no fertilizer K is recommended. These recommendations are primarily based on observed agronomic yield response trials conducted across time. Since rice price, fertilizer cost, and initial soil-test K values play roles in developing profit-maximizing fertilizer use, this analysis compares current K_2O fertilizer rate recommendations to rates estimated by maximizing profit and yield-maximizing rates. Using the last ten years of rice and fertilizer prices, we conclude that application recommendations should be revised to lower fertilizer-K application rates.

Introduction

Managing input use to maximize profit is an ever-changing target for crop producers as input cost, output price, as well as production factors like rice cultivars and initial soil-test K values that can vary over time affect the profit-maximizing fertilizer application rate. With muriate of potash fertilizer resources finite (USGS, 2019), we compare current fertilizer rate recommendations to profit-maximizing rates which occur when the marginal cost of an added unit of fertilizer becomes equal to the value of rice the added fertilizer creates (Debertin, 1986). In rice, K_2O rate recommendations are typically developed by taking a number of factors into consideration. They include existing soil-test potassium (K) values to reflect supplemental K needs to ensure adequate nutrition for plant growth (Slaton et al., 2011) and rice yield response to added K (Slaton et al., 2009; Maschmann et al., 2010). While output price for the crop produced, the cost of muriate of potash fertilizer, charges for application, and the potential to transfer K from one production season to the next, are considered, their role is not quantified.

Potassium affects photosynthesis, photosynthate translocation, enzyme activation, protein synthesis, disease resistance, and plant water relations. The tip of the oldest leaves begin to turn yellow when K is deficient. If not fertilized at the appropriate rate, yield losses can result (Dobermann et al., 1998; Maschmann et al., 2010). Increased research and education efforts thus have led to more aggressive K_2O fertilization programs (Maschmann et al., 2010) that also require an initial assessment of nutrient availability to ensure near-maximum yield, to maintain soil productivity, and to maximize profits (Slaton et al., 2009). The objective of this study was to develop profit-maximizing K_2O rate recommendations for Arkansas rice producers. Factors included are initial soil-test K information, rice yield potential, rice price, fertilizer cost, and fertilizer application charges.

Procedures

Yield responses to K_2O fertilizer rate were collected from field trials conducted in Arkansas from 2001 to 2018 using a zero K_2O rate control and increments of 30 to 60 lb/acre of K_2O leading to 414 treatment observations over 91 site-years (Table 1A). Trials were randomized complete block designs with 4 to 6 replications per treatment to examine the effect of added K_2O fertilizer rate on rice grain yield on different soil series and initial soil-test K values.

Rice cultivars chosen for experiments were similar to what producers grew over the period analyzed and included conventional cultivars ('Wells' 34 trials, 'Francis' 7 trials, 'Roy J' 6 trials, -'Diamond' 5 trials, and 6 other cultivars with less than 4 trials each), 24 trials with Clearfield® cultivars, and 3 trials planted with a hybrid cultivar. The observed yields ranged from 83 to 259 bu./acre (Table 1B). Since observed yields vary across fields, rough rice yields (Y) were converted to a relative yield index (RY), so that producers with different yield potentials could calculate yield change as a function of K_2O rate on the basis of relative yield (RY), which was calculated as a particular treatment's replicate yield average divided by the maximum yield of the treatments where K_2O fertilizer was applied and multiplied by 100 so that an index value of 100 implied the maximum yield for a particular trial with the lowest index value expected for the zero K_2O control. This calculation allowed for a negative yield response to added fertilizer K, which appears as a RY index greater than 100. Table 1C summarizes RY indexes observed over the 91 site-years with 414 individual treatment observations. Further, since RY was used, cultivar selection, yield trend, and weather effects on yield response to K_2O fertilizer play a minimal role.

Table 1D summarizes the range of initial soil-test K information observed across the 91 site-years and treatments. Note that other nutrients (N, P, and Zn) were supplied when needed

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and were assumed to not limit rice yields. Hence, RY was estimated using a square root response function to initial soil-test K, a quadratic response function to K_2O fertilizer applied, and their two-way interactions. Production year was treated as a random effect rather than a fixed effect on the basis of a Hausman test (Green, 2008). The equation was estimated in EViews v. 9.0 (Lilien et al., 2015) using generalized least squares.

Given the large number of site-years, we were able to estimate a long-term average effect of K_2O fertilizer on RY that would fluctuate on the basis of initial soil-test K. Using that RY response curve further allowed estimates of the marginal revenue associated with an added pound of K_2O fertilizer/acre at varying K_2O rates by multiplying the RY index by the yield potential and the price of rice. That estimate of marginal revenue at different points along the RY response curve could now be compared against the cost of the added fertilizer-K per acre. Starting with zero fertilizer-K use, the profit-maximizing K_2O rate (K*) could be obtained by continually adding more fertilizer-K until the marginal revenue of an added pound of fertilizer-K no longer exceeded its cost. As such, a higher rice price and rice yield potential, as well as lower fertilizer-K cost, would lead to greater K* with the opposite being true with lower rice prices, yield potential and/or higher fertilizer-K cost. Further, K* varies by the field's initial soil-test K as changes in initial soil-test K led to changes in the amount of rice yield to expect without fertilizer-K as well as the slope and shape of the rice RY response curve to K_2O fertilizer.

To examine whether a producer would benefit from calculating K*, the profit differential between applying fertilizer-K at current recommended rates (K_c) and the K* rate was estimated for each of the last ten years using historical price and yield information for rice and fertilizer-K as well as a range of initial soil-test K values. Added to the profit differential is a fertilizer application charge of $7.00/acre if one of the rate recommendations was zero and the other was positive. The analysis was conducted using current boundaries and mid-points of fertilizer-K recommendations that are based on initial soil-test K and are 120, 90, and 60 lb K_2O/acre at <61 ppm, 61 to 90 ppm, and 91 to 130 ppm initial soil-test K, respectively. If the initial soil-test K exceeds 131 ppm, no fertilizer K is recommended. Finally, we also calculated the yield-maximizing K_2O fertilizer rate (K_{max}), to determine changes in profit and yield between the K* and K_{max} rates.

Results and Discussion

All explanatory model variables were statistically significant ($P = 0.05$) except for the interaction of initial soil-test K and the quadratic K_2O application rate ($P = 0.06$) and the constant term ($P = 0.28$). Figures 1–6 show the relative yield response curves at six initial soil-test K values over the range of initial soil-test K values currently used to form K_2O fertilizer rate recommendations. Note that the response curves in Figures 1–6 get flatter and straighter as the initial soil-test K increases. This indicates that at low levels of initial soil-test K, a yield response from fertilizer application can be expected (Figs. 1 to 4) while crop yields are no longer affected at higher initial soil-test K values (Figs. 5 and 6). Goodness of fit, judged by the R^2 was 0.50. Economic results are presented in Table 2, showing two extreme historical observations with rice price and fertilizer cost at relative highs and lows for 2009 and 2017, respectively. A summary across all ten-years is provided in the bottom rows to show implications of current, profit-maximizing and yield-maximizing K_2O fertilizer rates on profit and yield.

At an initial soil-test K of 60 ppm or below, the profit-maximizing potash fertilizer rate was less than the current recommendation, and more so in 2009 when the cost of fertilizer K was relatively high (Table 2). Over the ten-year period, $2.11/acre of added profit would have occurred using the profit-maximizing potash fertilizer rate. This led to an estimated lower yield average of 1.1 bu./acre that was more pronounced in 2009 than in 2017. Further, on average, following the profit-maximizing potash fertilizer rate reduced the current recommended fertilizer rate by 18 lb K_2O/acre. The fertilizer savings from applying the profit-maximizing K rate nearly doubled to 38 lb K_2O/acre, on average, in comparison to the yield-maximizing fertilizer rate solution at the cost of 1.5 bu./acre.

At 75 ppm soil-test K, the gap between the current and profit-maximizing potash fertilizer rates is smaller on average and thereby has less fertilizer savings and yield change implications resulting in only a $0.67/acre difference in profit. However, the gap in comparison to yield-maximizing fertilizer rate increased. At 90 ppm initial soil-test K, the profit-difference is now larger than at 60 ppm, on average and for both of the selected years. Profit-maximizing fertilizer application rates are less than half of current recommendations on average leading to a more substantial reduction in yield of 3.2 bu./acre when following profit-maximizing rather than current recommendations. The estimated yield-maximizing fertilizer rate continues to increase resulting in a substantial change in profit of $30.47/acre on average. Losing nearly 5 bu./acre by applying 130 lb K_2O less fertilizer is more profitable than the yield-maximizing solution.

At a soil-test K of 105 ppm, the estimated profit-maximizing potash fertilizer rate is zero for all of the ten years of historical price, yield and cost scenarios evaluated. Fertilizer savings between current and profit-maximizing potash fertilizer rates of 60 lb K_2O/acre grow even larger in comparison to the yield-maximizing fertilizer rate. The yield ramifications of following profit-maximizing rather than current recommendations, averaged over the ten years, decreased to 2.1 bu./acre when compared to the same yield difference at 90 ppm initial soil-test K. This is a direct result of the yield response curve changes as the positive slope in Fig. 4 is already insufficient to support fertilizer application. As a result, profitability changes by $21.13/acre on average over the last ten years between the profit-maximizing potash fertilizer rate and current rate recommendations at 105 ppm initial soil-test K. An even larger profit-difference occurred between the profit-maximizing and yield-maximizing fertilizer rates.

Practical Applications

Overall, this analysis suggests that fertilizer-K rate recommendations need to be lowered leading to less fertilizer use that would conserve this limited resource for a longer period. The current recommendations tend to be intermediate between the predicted profit-maximizing and yield-maximizing fertilizer-K rates. Also, the rice yields produced with the profit-maximizing fertilizer-K rates would be slightly lower than those estimated to occur at current rate recommendations or at the yield-maximizing fertilizer rate. Excluded are the potential ramifications on rice price and fertilizer cost given changes in yield and fertilizer use as those are expected to be minimal as producers may already be applying fertilizer K at less than recommended rates. A producer, reacting to this report and applying the profit-maximizing fertilizer-K rate rather than a yield-maximizing, fertilizer-K rate would be unlikely to observe symptoms of K deficiency. Further research is needed to examine the effect of applying K fertilizer at slightly higher than profit-maximizing rates to ensure meeting yield target while creating the potential to provide nutrition needs for the next crop and/or account for spatial initial soil-test K differences in a field while avoiding runoff and potential yield penalties with added K.

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Table 1. Frequency distribution of K_2O fertilizer application rates (A), rough rice yields (B), relative yield index (C), and initial soil-test K (D) across 91 site-years of Arkansas field and plot trials conducted from 2001 to 2018.

A	Fertilizer-K Rates Applied, lb K_2O/acre (Avg. = 75.3)					
	Zero Control	30–60	61–90	91–120	121–150	151–180
# of obs.	91	95	79	88	5	56

B	Rough Rice Yields, bu./acre (Avg. = 177.3)						
	83–140	141–160	161–180	181–200	201–220	221–240	241–259
# of obs.	44	92	90	84	68	26	10

C	Relative Yield Index,- 100[a] = Max. of Treatments with K_2O applied (Avg. = 95.9)				
	61.5–75	76–85	86–95	96–100	101–103.4
# of obs.	6	17	98	289	4

D	Initial Soil-Test K, ppm (Avg. = 95.2)						
	35–40	41–60	61–90	91–120	121–150	151–180	181–223
# of obs.	7	34	155	143	51	20	4

[a] 100 represents the maximum yield of observations excluding the control. If the control had higher yield, then RY > 100 was possible and represents a negative yield response to K.

Table 2. Profit differential between current recommendation (Current), profit-maximizing, and yield-maximizing K_2O rates using two years (2009 and 2017) with a relatively high and low rice price and muriate of potash fertilizer cost, respectively, as well as a ten-year summary.

	Rough rice[a]				Initial Soil-Test K in ppm							
Year	Price	Cost	Yield	Scenario[b]	60	75	90	105	60	75	90	105
	($/cwt)	(%/ton)	(bu./acre)		----- (lb K_2O/acre and $/acre) -----				--- (Estimated yield in bu./acre)--			
2009	$15.00	$880.00	157.4	Current	120	90	90	60	154.5	153.2	153.7	153.2
				Profit-maximizing	85	52	0	0	151.9	149.9	147.6	151.2
				Change in Profit	$8.36	$5.35	$32.46	$37.40	-2.6	-3.3	-6.0	-2.0
				Profit-maximizing	85	52	0	0	151.9	149.9	147.6	151.2
				Yield-maximizing	140	149	166	214	154.9	155.1	155.2	155.4
				Change in Profit	$20.26	$35.40	$77.31	$135.45	-3.0	-5.2	-7.6	-4.2
2017	$9.39	$339.00	166.8	Current	120	90	90	60	163.7	162.3	162.8	162.4
				Profit-maximizing	108	93	52	0	163.1	162.5	160.7	160.2
				Change in Profit	$0.67	$0.02	$1.82	$14.93	-0.7	0.2	-2.1	-2.1
				Profit-maximizing	108	93	52	0	163.1	162.5	160.7	160.2
				Yield-maximizing	140	149	166	214	164.1	164.4	164.5	164.7
				Change in Profit	$4.53	$7.92	$16.13	$48.65	-1.1	-1.9	-3.8	-4.4
Avg.[c]	$12.60	$519.70	163.4	Current	120	90	90	60	160.3	158.9	159.5	159.0
				Profit-maximizing	102	84	36	0	159	158	156	157
				Change in Profit	$2.11	$0.67	$6.98	$21.13	-1.1	-0.5	-3.2	-2.1
				Profit-maximizing	102	84	36	0	159.3	158.4	156.2	156.9
				Yield-maximizing	140	149	166	214	161	161	161	161
				Change in Profit	$8.42	$14.70	$30.47	$74.95	-1.5	-2.5	-4.9	-4.3

[a] Rice yield and price data are Arkansas averages for long-grain rice (USDA-Rice Yearbook, 2019). Muriate of potash fertilizer prices are those reported by the Department of Agricultural and Applied Economics (Mississippi State University, 2019) and can be converted to $/lb of K_2O by dividing the price per ton by 1,200.

[b] Current, profit-maximizing, and yield-maximizing fertilizer rate recommendations are presented and compared in terms of change in profitability as well as yield implications.

[c] Averages are the 10-year average rice price, fertilizer cost, and Arkansas yields. For evaluation of scenarios, the average is the average of application rates, change in profit, and yields evaluated using the 10 different annual observations. The remaining 8 scenario outcomes by year are available from the authors upon request.

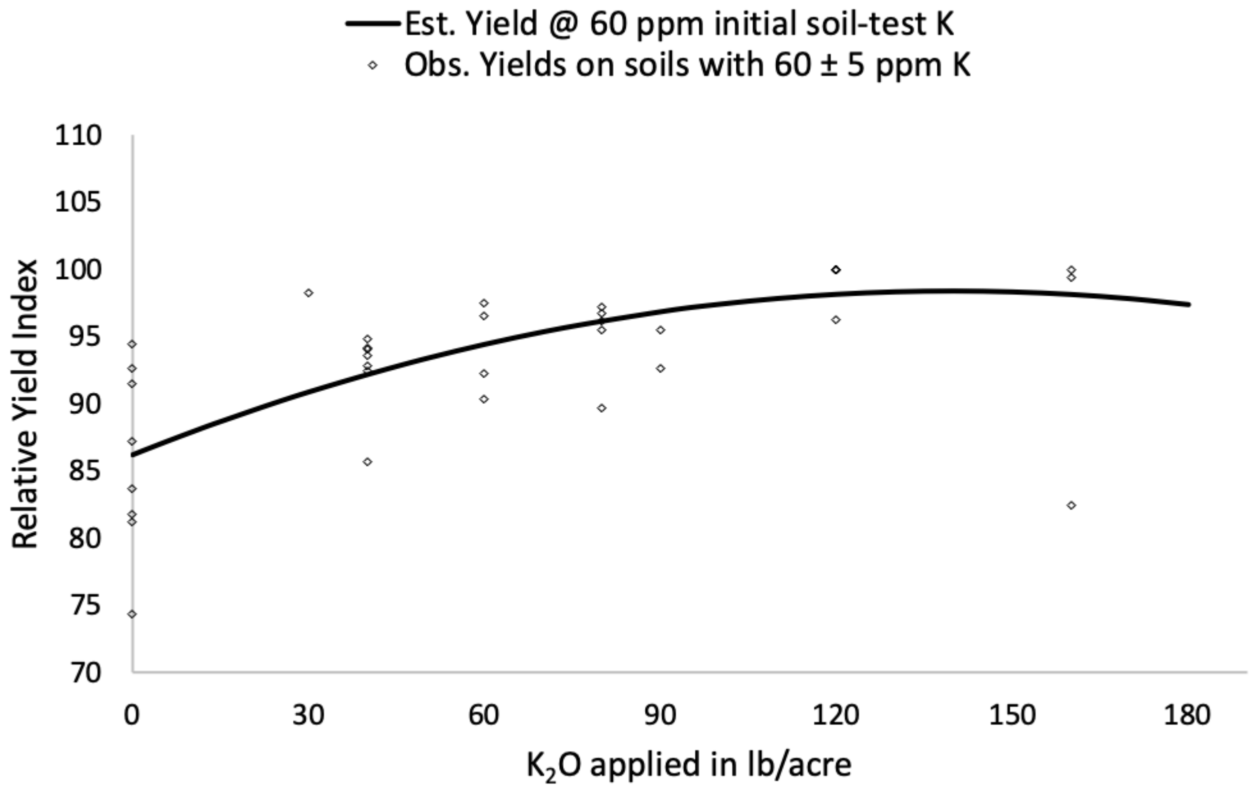

Fig. 1. Estimated relative rice yield response curves to K_2O fertilizer rate at an initial soil-test K value of 60 ppm.

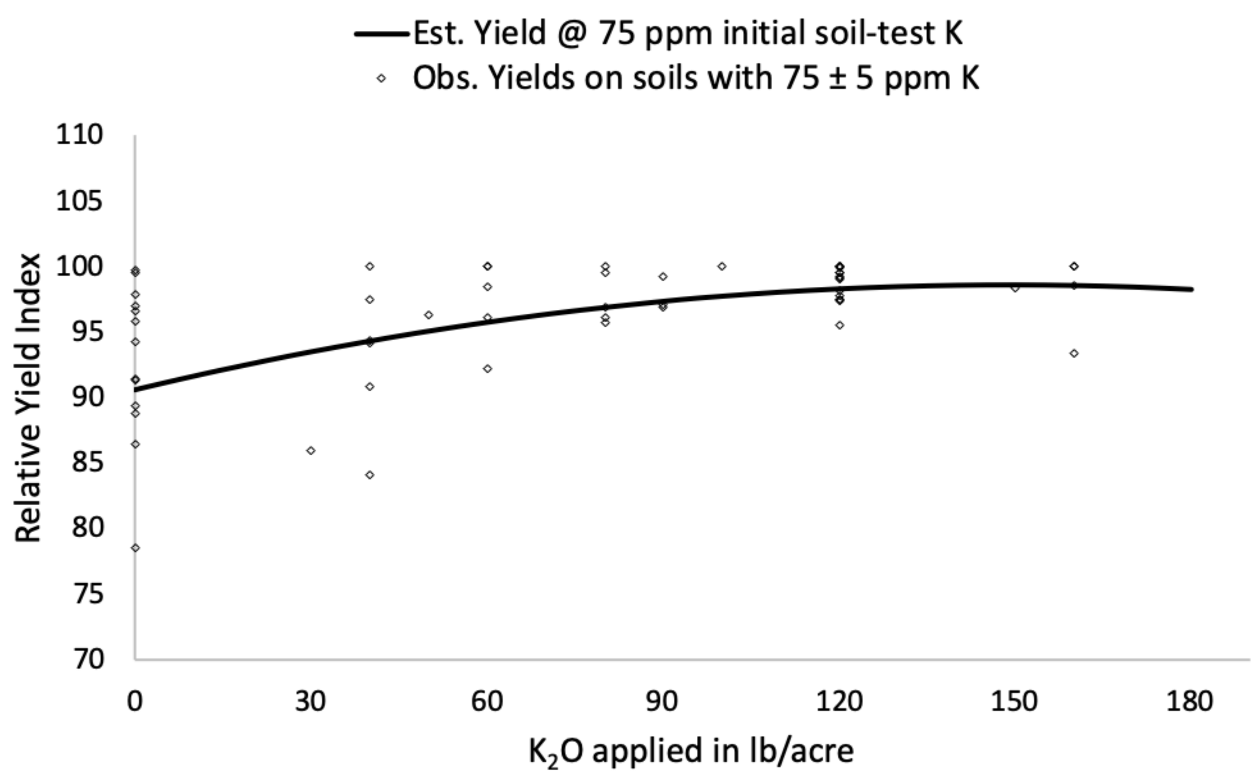

Fig. 2. Estimated relative rice yield response curves to K_2O fertilizer rate at an initial soil-test K value of 75 ppm.

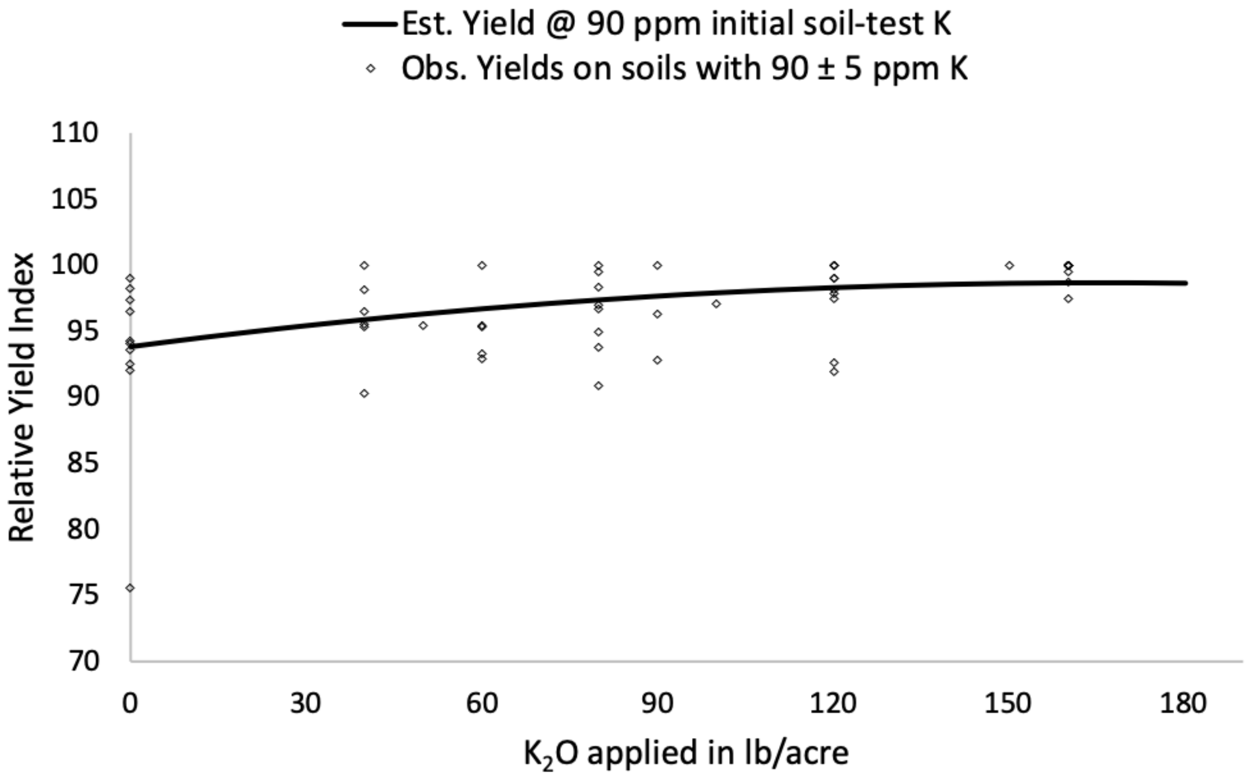

Fig. 3. Estimated relative rice yield response curves to K_2O fertilizer rate at an initial soil-test K value of 90 ppm.

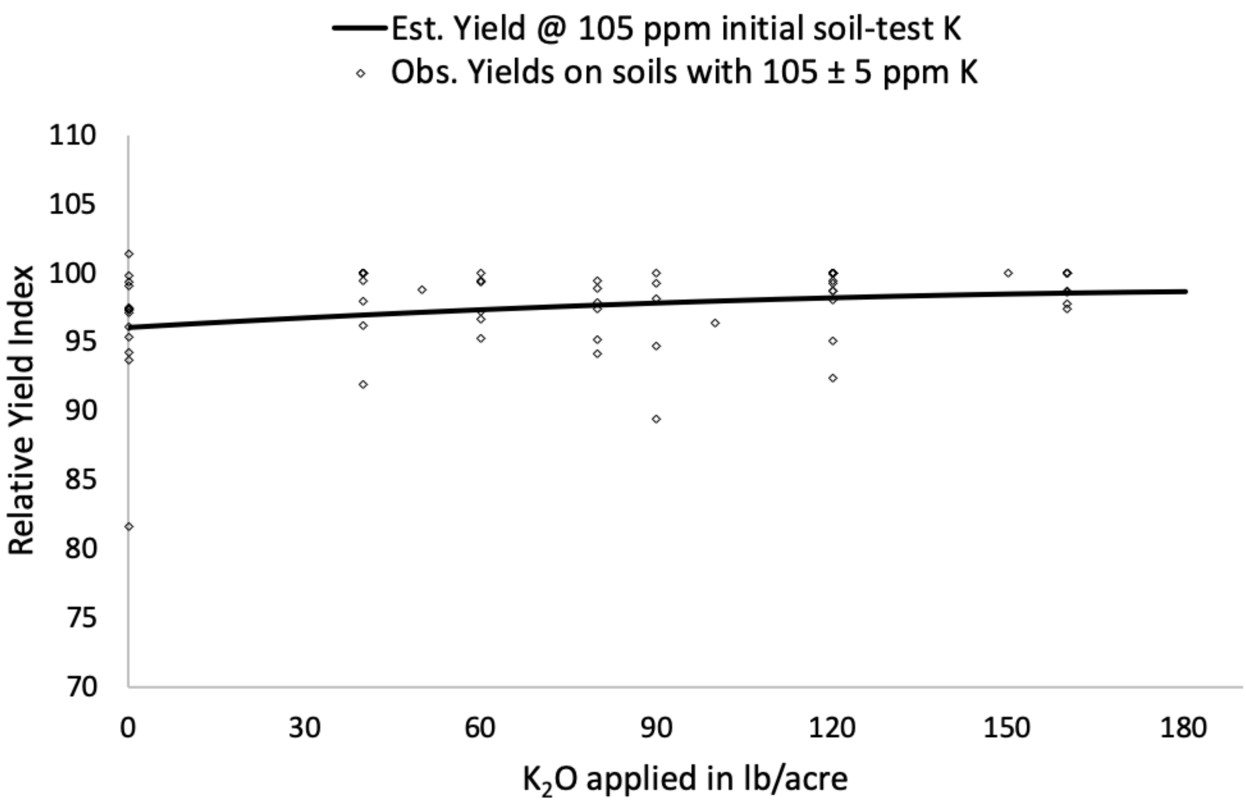

Fig. 4. Estimated relative rice yield response curves to K_2O fertilizer rate at an initial soil-test K value of 105 ppm.

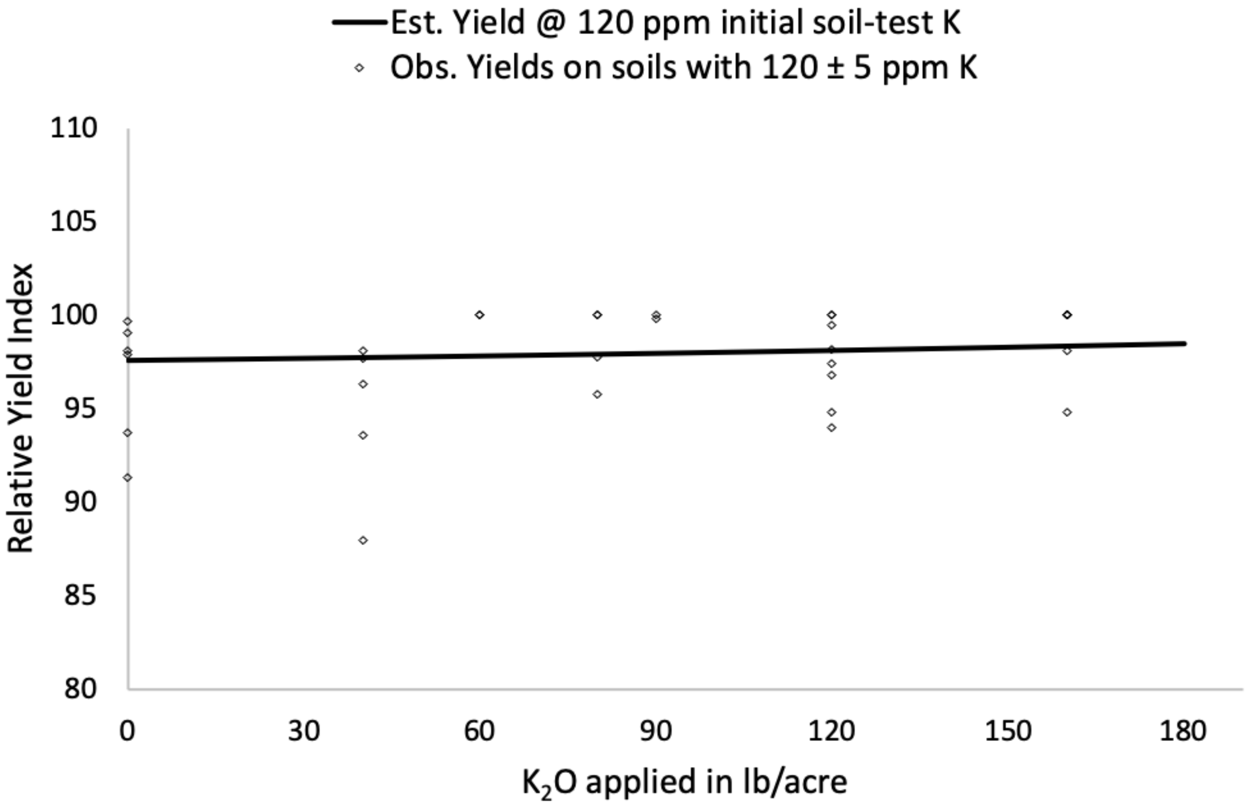

Fig. 5. Estimated relative rice yield response curves to K_2O fertilizer rate at an initial soil-test K value of 120 ppm.

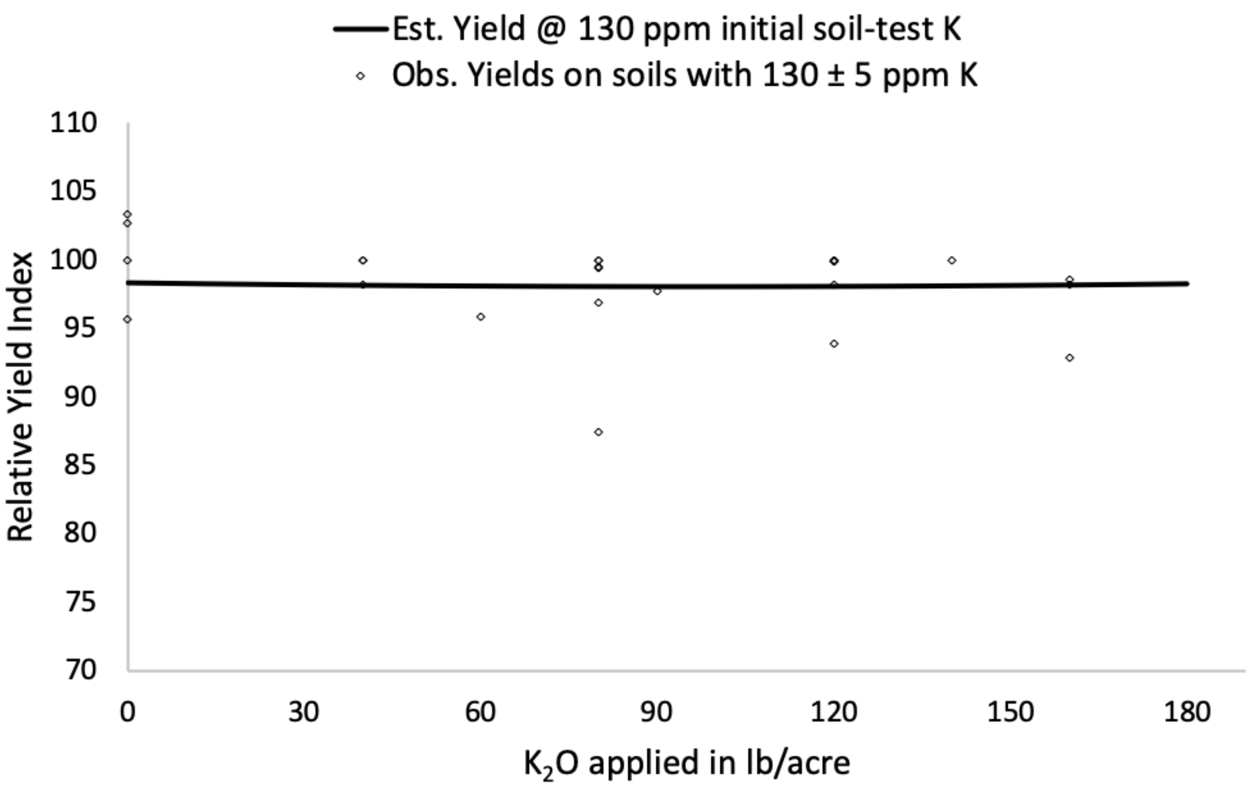

Fig. 6. Estimated relative rice yield response curves to K_2O fertilizer rate at an initial soil-test K value of 130 ppm.

Cover Crop and Phosphorus and Potassium Application Rate Effects on Soil-Test Values and Soybean Yield

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Abstract

Cover crops may affect soil-test phosphorus (P) and potassium (K) levels and yield response of the following crop to fertilization by influencing soil nutrient cycling. This report summarizes year 3 results of a field trial examining the influence of cover crop and fertilizer-P and -K rates on soybean yield response and soil-test P and K. Research was conducted at two locations with soil samples collected from the 0- to 6-inch depth in late winter prior to the 2019 growing season. The second annual P and K applications were made to subplot fertilizer treatments and soybean was planted following cover crop termination. Late planting and poor cover crop growth likely reduced the direct impact on soil-test properties and yield of the following soybean crop, but combined with the residual effects of the previous season's cover crop, cover crop influenced several soil-test properties at both locations and soybean grain yields at the site with lower initial soil-test P and K values. The effect of cover crop on soil-test properties was inconsistent, with the cover crop generally increasing soil-test nutrients and soil organic matter (SOM), relative to the winter fallow treatment, in the K trial at one site and P trial at the other site, while the other trials indicated no difference in SOM and lower values of some soil-test nutrients following the cover crop. Where the effect was significant on grain yield, however, soybean following the cover crop produced 3% to 5% greater yields than following fallow. Fertilizer rate had a limited influence on grain yields.

Introduction

When properly managed in rotation with row crops, winter cover crops have the potential to enhance nutrient availability and cycling, increase soil organic matter (SOM) content, reduce soil erosion and weed pressure, increase infiltration, and improve soil moisture retention (Clark, 2007). Extensive research has been conducted to examine how cover crops influence nitrogen (N) availability for the cash crops they are rotated with, but less work has been done to determine the influence of cover crops on soil-test nutrient values and cash crop yield response with respect to phosphorus (P) and potassium (K) management. In a short-term trial in Kansas, cover crop did not influence grain yield or soil-test P and K in samples collected following harvest of the summer crop (Carver et al., 2017). A long-term trial in Brazil, however, reported a significant increase in soil-available P and K under several different cover crop treatments, relative to winter fallow, which was enhanced under no-tillage management compared to conventional tillage (Tiecher et al., 2017). Research in Arkansas indicated that soil-test P remained relatively stable across the fall and winter months following rice (*Oryza sativa*) and soybean (*Glycine max*) harvest (Slaton et al., 2016). Similarly, soil-test K following soybean did not change appreciably over time, but soil-test K increased from rice harvest until December, indicating that high biomass crops like corn (*Zea mays*) and rice, with more recalcitrant residue, can cause soil-test K to change over time as the K from crop residue leaches into the soil with precipitation. Relative to K, the P content is lower in crop residue since most of the P is removed in harvested grain and is released slowly during residue decomposition. Soil-test P across time is less affected by previous crop residue than soil-test K. Research has provided evidence that cover crops can affect soil nutrient dynamics in the short term, as cover crop biomass accumulates and redistributes nutrients, and in the long term as soil-test chemical properties change temporally. Based on the influence of cover crops on various soil properties, it is important to investigate the interaction of cover crops with various fertilizer P and K rates in order to effectively make soil-test-based fertilizer recommendations for cash crops managed in rotation with winter cover crops.

The goal of this research is to continue management of long-term plots rotated between corn, cotton (*Gossypium hirsutum*), and soybean cash crops 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. Slaton et al. (2018, 2019) summarized the establishment and initial soil properties in the first year of this research project, then described the yield response of cotton to cover crop and P and K fertilizer rates as well as the influence on soil-test properties. This report summarizes the year 3 results focused on examining the effect of cover crop in conjunction with various P and K fertilizer rates on soil-test properties and the grain yield of soybean.

Procedures

Trials were established in 2017 at the University of Arkansas System Division of Agriculture's Rohwer Research

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Station (RRS) and Lon Mann Cotton Research Station (LMCRS). The 5.7-acre field used for the trial at RRS has soils mapped as Herbert silt loam (59%), McGehee silt loam (19%), and Sharkey and Desha clay (22%) and the 10-acre field used at LMCRS has Calloway (54%), Loring (28%), and Memphis (1%) silt loam and Marvell fine sandy loam (16%) soils (Slaton et al., 2018). Study plots were 4 rows (38-inch row spacing) wide and extended the length of each field, approximately 220 ft at RRS and 260 ft at LMCRS. Corn was grown in 2017 prior to fertilizer treatment application, followed by a cereal rye cover planted at each location in the fall of 2017, fertilizer treatment application in the spring of 2018, and a cotton crop in the 2018 growing season (Slaton et al., 2019). Due to wet field conditions, cereal rye was not planted until 4 December 2018 at LMCRS and early March 2019 at RRS. Due to the late planting date, winter wheat was substituted for cereal rye at RRS. Two composite soil samples of six, 1.0-inch diameter soil cores (0- to 6-inch depth), representing the east and west sides of each field area, were collected from each plot on 31 January at RRS and 1 February at LMCRS. Soil samples were analyzed for soil pH, Mehlich-3 extractable nutrients, and soil organic matter (loss on ignition, LOI) by the University of Arkansas System Division of Agriculture's Fayetteville Agricultural Diagnostic Laboratory at the Milo J. Shult Agricultural Research and Extension Center, Fayetteville, Ark.

Late planting, wet soils, and cold temperatures limited cover crop growth at both locations, so the plants were small at the time of termination, reducing the potential cover crops benefits, and the decision was made to not collect cover crop biomass samples or additional soil samples prior to termination.

At each location, fertilizer-P treatment rates were 0, 40, 80, and 120 lb P_2O_5/acre (triple superphosphate), and fertilizer K treatment rates were 0, 62, 124, and 186 lb K_2O/acre (muriate of potash). The second annual P and K fertilizer treatment applications were made with a 12-ft wide drop spreader (Gandy Company, Owatonna, Minn.) after calibration for the lowest application rate of each fertilizer. The intermediate and high fertilizer rates were achieved with one or two, respectively, additional passes down the length of the plots. A blanket application of 46 lb P_2O_5/acre was applied to the K trial and 124 lb K_2O/acre was applied to the P trial at each location with the drop spreader. Fertilizer treatment and blanket applications were made on 23 April at RRS and 17 May at LMCRS. No additional fertilizers were applied at either location in 2019. Soybean was planted on 23 April at RRS (Pioneer P47A76L) and on 28 May at LMCRS (Pioneer P48A60X).

The soybean crop at each location was managed for pests based on Cooperative Extension Service recommendations. Soybean was harvested on 12 September at RRS and on 28 September at LMCRS. Grain yield was measured by harvesting the two middle rows of a 125-ft long section in the middle of each plot at RRS and the two middle rows of three, 39-ft long sections in the middle of each plot at LMCRS. Yield was calculated based on harvested area and a 60-lb bushel weight and adjusted to 13% moisture for statistical analysis and reporting. Following soybean harvest, cereal rye was planted on 10 October 2019 at RRS and on 19 November 2019 at LMCRS.

The experimental design of each trial was a three-replicate, randomized complete block with a split-plot treatment structure where cover crop (with or without) was the main-plot factor and fertilizer rate was the subplot factor. Analysis of variance (ANOVA) was performed by location and nutrient on selected soil-test properties and soybean grain yield data using the GLM procedure of SAS v. 9.4 (SAS Institute, Cary, N.C.). Differences were interpreted as significant when $P \leq 0.10$.

Results and Discussion

In the third year of this long-term trial, following two summer cash-crops (corn in 2017 and cotton in 2018), two winter cover crop seasons, and the first annual P and K fertilizer treatment application (applied prior to 2018 cotton crop), soil properties measured prior to 2019 soybean planting were not affected by the cover crop by fertilizer rate interaction in either trial at either location. The cover crop main effect, however, did affect several soil-test properties in all four trials and fertilizer rate subplot effect was significant in all of the trials except the P trial at the LMCRS.

In the P trial at the LMCRS, soil-test P was 4 ppm greater following fallow than following the cereal rye cover crop (Table 1), which is consistent with results in the same trial in 2018, where soil-test P declined by 4 ppm in the cover crop treatment and <1 ppm in the fallow treatment over the course of the cover crop growing season (Slaton et al., 2019). Without plant tissue analysis and soil property measurements at the beginning and end of the cover crop season, it is not possible to determine whether the difference in soil-test P observed in 2019 is a direct result of the recent cover crop, which was not well developed at the time of termination, or an additive effect of two years of cover cropping, but there was no difference in soil-test P based on assigned cover crop treatments at the initiation of this trial in 2017 (Slaton et al., 2018). Additionally, soil-test Cu and B were influenced by cover crop in the P trial at the LMCRS, where soil-test Cu was less and B was greater following the cover crop than following winter fallow, while other soil-test properties were not affected by cover crop. Fertilizer rate did not significantly affect any soil-test properties in the P trial at the LMCRS, although a general numerical increase in soil-test P was observed as fertilizer-P rate increased.

In the K trial at the LMCRS, cover crop did not significantly affect soil-test P, K, S, Mg, Zn, or B, but SOM, pH, Ca, Fe, Mn, and Cu were all greater following the cover crop than following fallow (Table 2). While the magnitude of difference in these soil properties based on cover crop treatment is small, and may be partially attributed to natural variability, the trend of increasing SOM and nutrient availability with the use of cover crops is expected and commonly reported in the literature. As this research continues into the future, a greater understanding of the long-term influence of cover crops on soil-test properties will be gained and it will clarify which properties are actually influenced by the cover crop in this location and production system. After one treatment application prior to the 2018 growing season, fertilizer-K rate differences were reflected in soil-test K values measured prior to treatment application and planting in 2019. While soil-test K did not differ between the no-K fertilized control and low K rate treatments at the LMCRS, 11 ppm increases in soil-test K were observed when increasing from the low to intermediate and from the intermediate to high K rate treatments. The stepwise increase in soil-test K was expected based on increasing application rates of the treatments. No other soil-test properties were affected by K application rate at the LMCRS.

In the P trial at the RRS in 2019, SOM was greater and soil pH was lower following the cover crop than following winter fallow (Table 3). The late-planted cover crop was only 2- to 3-inches tall at termination in the spring of 2019, so observed differences in SOM and pH may be a lasting effect of the previous cover crop planted in the fall of 2017. The difference in the two soil properties based on cover crop is small and has limited practical significance at this point. At the initiation of this trial in 2017, there were no differences in SOM or soil pH based on cover crop treatment assignments (Slaton et al., 2018). Soil-test P, K, S, Mg, Ca, Cu, and Zn were not affected by cover crop, but Fe, Mn, and B were all greater following the cover crop than following winter fallow. When averaged across cover crop treatments, soil-test P was affected by fertilizer-P rate with the control having the lowest value (38 ppm) and the highest application rate (120 lb P_2O_5/acre) resulting in the greatest soil-test P value (49 ppm). Soil-test P in this trial did not differ based on fertilizer-P rate treatment assignment prior to the first annual application and averaged 44 ppm in the spring of 2018 (Slaton et al., 2019). The low P application rate (40 lb P_2O_5/acre) resulted in a 1 ppm decrease in soil-test P over the previous year, while the intermediate (80 lb P_2O_5/acre) and high (120 lb P_2O_5/acre) rates increased soil-test P by 3 and 5 ppm, respectively. After one annual fertilizer-P application, all P treatments remained in the Optimum soil-test P category (36 to 50 ppm), but treatment means were close to the lower and upper boundaries.

In the K trial at the RRS in 2019, soil-test Ca, Mg, and B were all greater following fallow than following the cover crop, while Fe was greater following the cover crop (Table 4). These differences were minor after the first annual application, but, as this trial continues, further sampling should clarify the influence of the cover crop on these soil properties. No other soil-test properties were affected by cover crop in the RRS K trial in 2019. Soil-test K, Ca, and Mg were the only soil-test properties influenced by the fertilizer-K rate at the RRS in 2019. Following the 2017 growing season and prior to the first annual application, soil-test K at this site averaged 180 ppm (results not shown), which was maintained through the 2018 growing season following the first annual low rate treatment application of 62 lb K_2O/acre (183 ppm; Table 4). Soil-test K dropped to 153 ppm, which was significantly less than the low application rate, where no K was applied and increased to an average of 221 ppm at the intermediate and high application rates, which did not differ from each other. Conversely, soil-test Mg was lower in the intermediate and high K rate treatments than in the no-K fertilized control, while the low K rate treatment resulted in a soil-test Mg value that did not differ from the higher K rate treatments or the control.

Soybean grain yield in 2019 was not affected by cover crop treatment, P rate, or their interaction at the RRS, where treatment average yields ranged from 74.5 to 82.6 bu./acre (Table 5). Soybean yield at the LMCRS was affected only by cover crop treatment. Soybean following the cover crop at the LMCRS produced a greater yield than following winter fallow. The lack of a yield response to P rate at the RRS was expected as all treatments were in the Optimum soil-test P category. At the LMCRS, soil-test P values ranged from 24 to 27 ppm, which are within the Low (16 to 25 ppm) or Medium (26 to 35 ppm) soil-test categories.

The K-rate trial at the RRS was not affected by cover crop, K rate, or their interaction in 2019 (Table 6). Again, the lack of response to K was expected since soil-test K was at the Optimum or Above Optimum levels. Soybean grain yield at the LMCRS was affected by cover crop treatment and K rate main effects, but the interaction was not significant. The three treatments where K was applied resulted in similar yields, which averaged 2 bu./acre greater than the no-K control. Soil-test K of the no-K control was in the Low category at 83 ppm, which supports the increase in grain yield from K fertilization. Similar to the P trial at the LMCRS, grain yields in the K trial were greater following the cover crop than following fallow (1.4 bu./acre difference).

Practical Applications

Soybean grain yield was not affected by P fertilization rate at the RRS, where soil-test P was in the High category, or at the LMCRS, which is not surprising based on the fact that soybean is not highly responsive to P fertilization and the near optimal or optimal soil-test P levels present at both sites. Potassium fertilization, regardless of rate, did produce a slight increase in soybean grain yield, relative to the control, at the LMCRS where soil-test K was in the Low category, while K fertilization did not influence soybean yield at the RRS where soil-test K was Optimum to Above Optimum.

The cumulative effect of the two cover crop treatments measured by soil samples collected in early 2019 generally suggested that cover crop had little or no significant effect on soil-test P and K. The excessive rainfall and wet field conditions from fall 2018 through spring 2019 prevented timely establishment and subsequent growth of cover crops at both locations and we could not examine the seasonal (fall vs spring) effect of cover crop growth on soil-test P and K. Soil samples did show that fertilizer-P and -K rates applied in 2018 generally resulted in significant increases in soil-test P and K values as fertilizer rate increased. In two of the four trials, SOM was significantly, albeit nominally higher (0.04% to 0.07%) in soil collected from plots that included a cover crop suggesting that cover crops may help slowly build SOM in Arkansas soils. As these trials proceed into the future, the effects of a winter cover crop and fertilization rate on soil-test properties and crop yields will likely become more evident.

Acknowledgments

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Table 1. Influence of the cover crop (CC) main-plot effect, the fertilizer rate (FR) subplot effect, and their interaction on selected soil properties, prior to annual fertilizer treatment application in the third year of a trial in the North Research Area of Field B-1-N (Phosphorus Trial) at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station.

Soil property	Cover crop effect				Fertilizer rate (lb P_2O_5/acre) effect						CC×FR.	
	Cover	Fallow	*P*-value	$LSD_{0.1}$	0	40	80	120	*P*-value	$LSD_{0.1}$	*P*-value	C.V.
												(%)
SOM[†] (%)	1.20	1.23	0.4324	NS	1.24	1.20	1.20	1.18	0.7756	NS	0.9495	10.6
pH	7.14	7.22	0.2070	NS	7.20	7.17	7.15	7.19	0.9298	NS	0.9453	2.2
P (ppm)	23 b[‡]	27 a	0.0042	1.8	24	24	26	27	0.1788	NS	0.4302	11.7
K (ppm)	80	77	0.6232	NS	81	76	80	76	0.8328	NS	0.6569	16.1
Ca (ppm)	939	1022	0.2125	NS	1029	944	964	938	0.5533	NS	0.9175	15.2
Mg (ppm)	283	305	0.2664	NS	295	293	298	289	0.9950	NS	0.8758	21.5
S (ppm)	4.4	4.9	0.1926	NS	4.6	4.3	4.9	5.0	0.7567	NS	0.1278	25.4
Fe (ppm)	158	155	0.2317	NS	157	155	158	155	0.7016	NS	0.8051	3.7
Mn (ppm)	99	96	0.5460	NS	101	97	98	92	0.4741	NS	0.7834	11.3
Cu (ppm)	0.67 b	0.77 a	0.0394	0.08	0.74	0.70	0.74	0.68	0.7860	NS	0.9904	17.9
Zn (ppm)	0.93	0.98	0.1087	NS	0.98	0.94	0.95	0.92	0.5796	NS	0.9914	9.4
B (ppm)	0.14 a	0.07 b	0.0892	0.07	0.12	0.06	0.12	0.11	0.6624	NS	0.7797	98.5

† SOM = soil organic matter

‡ Different lowercase letters next to means within each effect indicate significant differences ($P \leq 0.10$).

Table 2. Influence of the cover crop (CC) main-plot effect, the fertilizer rate (FR) subplot effect, and their interaction on selected soil properties, prior to annual fertilizer treatment application in the third year of a trial in the South Research Area of Field B-1-N (Potassium Trial) at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station.

Soil property	Cover crop effect				Fertilizer rate (lb K_2O/acre) effect						CC×FR.	
	Cover	Fallow	*P*-value	$LSD_{0.1}$	0	62	124	186	*P*-value	$LSD_{0.1}$	*P*-value	C.V.
												(%)
SOM[†] (%)	1.56 a[‡]	1.52 b	0.1003	0.04	1.55	1.50	1.57	1.53	0.2299	NS	0.8240	4.0
pH	7.28 a	7.21 b	0.0847	0.05	7.22	7.23	7.30	7.24	0.3532	NS	0.5613	1.2
P (ppm)	32	33	0.1624	NS	32	32	33	32	0.9413	NS	0.8001	8.3
K (ppm)	98	95	0.3070	NS	83 c	88 c	109 b	120 a	<0.0001	7.3	0.7306	8.1
Ca (ppm)	1263 a	1196 b	0.0553	43	1229	1222	1246	1221	0.9163	NS	0.3492	5.6
Mg (ppm)	298	297	0.9332	NS	299	297	293	298	0.9561	NS	0.9750	6.9
S (ppm)	4.5	4.5	0.7694	NS	4.5	4.4	4.6	4.3	0.6388	NS	0.7483	8.2
Fe (ppm)	172 a	168 b	0.0987	3.4	170	169	167	173	0.2999	NS	0.9090	3.2
Mn (ppm)	128 a	120 b	0.0069	3.5	125	121	123	126	0.4163	NS	0.5196	4.5
Cu (ppm)	2.17 a	1.73 b	0.0480	0.33	1.98	1.96	1.94	1.89	0.9875	NS	0.9142	27.1
Zn (ppm)	1.23	1.19	0.1344	NS	1.21	1.21	1.22	1.20	0.9682	NS	0.3966	4.5
B (ppm)	0.32	0.30	0.9055	NS	0.27	0.35	0.30	0.35	0.1877	NS	0.8308	26.4

† SOM = soil organic matter
‡ Different lowercase letters next to means within each effect indicate significant differences ($P \leq 0.10$).

Table 3. Influence of the cover crop (CC) main-plot effect, the fertilizer rate (FR) subplot effect, and their interaction on selected soil properties, prior to annual fertilizer treatment application in the third year of a trial in the North Research Area of Field 1-D (Phosphorus Trial) at the University of Arkansas System Division of Agriculture's Rohwer Research Station.

Soil property	Cover crop effect				Fertilizer rate (lb P_2O_5/acre) effect						CC×FR.	
	Cover	Fallow	*P*-value	$LSD_{0.1}$	0	40	80	120	*P*-value	$LSD_{0.1}$	*P*-value	C.V.
												(%)
SOM[†] (%)	1.26 a[‡]	1.19 b	0.0206	0.04	1.22	1.22	1.21	1.25	0.7056	NS	0.4124	5.7
pH	6.38 b	6.43 a	0.0915	0.05	6.41	6.41	6.40	6.40	0.9983	NS	0.4775	1.4
P (ppm)	44	42	0.4384	NS	38 c	43 bc	47 ab	49 a	0.0028	5.1	0.8830	12.7
K (ppm)	104	113	0.1381	NS	110	111	107	106	0.9156	NS	0.7760	14.9
Ca (ppm)	812	790	0.4000	NS	794	819	779	818	0.5008	NS	0.2658	6.7
Mg (ppm)	130	134	0.5744	NS	135	133	125	132	0.6166	NS	0.3254	10.4
S (ppm)	5.7	5.8	0.4903	NS	5.6	5.6	6.4	5.8	0.3768	NS	0.4520	17.7
Fe (ppm)	345 a	257 b	<0.0001	13.5	288 b	305 ab	320 a	304 ab	0.0486	20	0.8494	7.1
Mn (ppm)	116 a	96 b	0.0031	8.5	104	108	110	105	0.8219	NS	0.5386	12.8
Cu (ppm)	2.08	2.06	0.8221	NS	2.01	2.10	2.03	2.21	0.5305	NS	0.4571	13.6
Zn (ppm)	0.70	0.71	0.4440	NS	0.70	0.71	0.70	0.71	0.9895	NS	0.7690	10.5
B (ppm)	0.44 a	0.40 b	<0.0001	0.01	0.41	0.43	0.43	0.42	0.1496	NS	0.9844	5.5

† SOM = soil organic matter
‡ Different lowercase letters next to means within each effect indicate significant differences ($P \leq 0.10$).

Table 4. Influence of the cover crop (CC) main-plot effect, the fertilizer rate (FR) subplot effect, and their interaction on selected soil properties, prior to annual fertilizer treatment application in the third year of a trial in the South Research Area of Field 1-D (Potassium Trial) at the University of Arkansas System Division of Agriculture's Rohwer Research Station.

Soil property	Cover crop effect				Fertilizer rate (lb K_2O/acre) effect						CC×FR.	
	Cover	Fallow	*P*-value	$LSD_{0.1}$	0	62	124	186	*P*-value	$LSD_{0.1}$	*P*-value	C.V.
												(%)
SOM[†] (%)	1.40	1.37	0.7705	NS	1.41	1.34	1.42	1.36	0.3131	NS	0.1015	6.1
pH	6.67	6.70	0.0897	NS	6.65	6.72	6.69	6.70	0.1514	NS	0.2518	1.0
P (ppm)	34	32	0.4371	NS	33	31	36	32	0.5886	NS	0.8668	20.2
K (ppm)	189	183	0.7254	NS	153 c	183 b	223 a	219 a	<0.0001	18.5	0.3849	10.7
Ca (ppm)	666 b[‡]	699 a	0.0044	18	705 a	688 a	659 b	653 b	0.0042	26	0.8825	4.2
Mg (ppm)	102 b	115 a	0.0033	6.7	116 a	107 ab	102 b	102 b	0.0365	9.8	0.7699	9.7
S (ppm)	5.7	5.7	0.9124	NS	5.7	5.3	5.8	5.8	0.3904	NS	0.5183	10.4
Fe (ppm)	247 a	211 b	0.0040	18	226	222	241	231	0.7037	NS	0.9807	12.5
Mn (ppm)	103	97	0.3107	NS	98	98	102	103	0.8296	NS	0.6465	11.9
Cu (ppm)	2.08	2.07	0.9964	NS	2.09	2.02	2.15	2.04	0.7861	NS	0.9447	11.5
Zn (ppm)	0.60	0.60	0.7903	NS	0.61	0.61	0.59	0.61	0.7622	NS	0.5736	6.7
B (ppm)	0.37 b	0.39 a	0.0978	0.02	0.38	0.37	0.39	0.39	0.5679	NS	0.1195	8.6

† SOM = soil organic matter
‡ Different lowercase letters next to means within each effect indicate significant differences ($P \leq 0.10$).

Table 5. Soybean grain yield as affected by annual P rate, cover crop (CC), and their interaction during the third year of long-term trials at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) and Rohwer Research Station (RRS) in 2019.

	LMCRS			RRS		
Annual P rate†	Fallow	Cereal rye	Rate mean	Fallow	Cereal rye	Rate mean
(lb P_2O_5/acre)	(bu./acre)					
0	48.6	50.8	49.7	74.5	78.6	76.5
40	48.8	51.5	50.1	80.5	80.5	80.5
80	49.6	52.4	51.0	76.6	80.2	78.4
120	49.1	51.1	50.1	77.0	82.6	79.8
CC Mean	48.9 b‡	51.3 a	--	76.6	79.8	--
P rate	0.2066			0.4629		
Cover crop	<0.0001			0.1270		
Interaction	0.9243			0.8381		
C.V. (%)	2.4			7.0		

† Fertilizer rate treatments were applied for the first time in 2018, this data reflects two annual applications.
‡ Different lowercase letters next to means within a site indicate significant differences ($P \leq 0.10$).

Table 6. Soybean grain yield as affected by annual K rate, cover crop (CC), and their interaction during the third year of long-term trials at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) and Rohwer Research Station (RRS) in 2019.

	LMCRS			RRS		
Annual K rate†	Fallow	Cereal rye	Rate mean	Fallow	Cereal rye	Rate mean
(lb K_2O/acre)	(bu./acre)					
0	43.3	45.8	44.6 b	82.4	84.0	83.2
62	45.6	47.7	46.7 a	86.5	80.2	83.4
124	46.3	47.1	46.7 a	85.3	83.3	84.3
186	46.8	46.1	46.4 a	80.4	79.5	80.0
CC Mean	45.1 b‡	46.5 a	--	83.4	82.2	--
K rate	0.0061			0.6568		
Cover crop	0.0352			0.4432		
Interaction	0.1221			0.6655		
C.V. (%)	2.9			7.6		

† Fertilizer rate treatments were applied for the first time in 2018, this data reflects two annual applications.
‡ Different lowercase letters next to means within a site indicate significant differences ($P \leq 0.10$).

Appendix: Soil Testing Research Proposals

2019-2020 Soil Testing Research Proposals

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
Matt Bertucci	John Jennings, Dirk Philipp	Assessment of Bermudagrass Forage Yield and Nutrient Uptake in Response to Phosphorus and Potassium Fertilization	1 of 3	28,186.00
Michael Popp	Kelly Bryant	Economics of Potassium Use in Soybean and Rice	3 of 3	17,632.34
Mary Hightower	Mike Daniels, Andrew Sharpley, Trent Roberts, Nathan Slaton	Creating Awareness for Nutrient Management, Potassium Research Projects	1 of 1	10,700.00
Morteza Mozaffari	Chuck Wilson	Improving Potassium and Phosphorus Soil Test Correlation and Calibration for Cotton and Corn in Arkansas	3 of 3	67,641.00
Andrew Sharpley	Mike Daniels	Monitoring Potassium Losses in Runoff on Arkansas Discovery Farms	3 of 3	31,740.00
Nathan Slaton	Trent Roberts	Post Doctorate and Graduate Student Assistantships	1 of 3	141,285.00
Nathan Slaton	Trent Roberts	Long-Term Phosphorus and Potassium Fertilization Plots	3 of 3	49,404.00
Leo Espinoza	John Jennings, Dirk Philipp	Validation of Phosphorus and Potassium Recommendations for Warm-Season Grasses	1 of 3	20,000.00
			Total Funding:	**366,588.34**

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