Wayne E. Sabbe

Arkansas Soil Fertility Studies 2023

Nathan A. Slaton, Editor

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Cover: Wesley France, Program Associate, collects soil samples for an ongoing soil-test research project in a farmer field near Tillar, Ark. Soil samples were collected at the 4- and 6-in. depths in 100 locations across the field, and the results were correlated with high spatial resolution gamma-ray spectrometer data to assess sensor performance and map in-field changes in soil pH and potassium. U of A System Division of Agriculture photo by Niyi Omidire, former post-doc.

Layout and editing by Gail Halleck

Arkansas Agricultural Experiment Station (AAES), University of Arkansas System Division of Agriculture, Fayetteville. Deacue Fields, Vice President for Agriculture; Jean-François Meullenet, AAES Director and Senior Associate Vice-President for Agriculture–Research. WWW/InddCC2023.

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WAYNE E. SABBE ARKANSAS SOIL FERTILITY STUDIES – 2023 –

Nathan A. Slaton, Editor
Department of Crop, Soil, and Environmental Sciences

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 an 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 the 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 2023 edition of the Arkansas Soil Fertility Studies includes a summary of soil-test data from soil samples submitted to the Marianna Soil Test Laboratory in 2022 plus ten research reports from projects evaluating potassium and sulfur loss in field runoff, gamma-ray spectroscopy for measuring soil pH, comparing the economics and logistics of variable and uniform rate potassium fertilization strategies, and examining crop and soil test responses to N, P and K fertilization in cropping systems involving bermudagrass forage, blackberry, corn, cotton, cover crops, and soybean production. Monitoring the short- and long-term soil fertility trends in Arkansas production systems and continual evaluation of new technologies and crop and soil nutrient management practices are important to ensure that our production systems are relevant and agronomically efficient, profitable, and environmentally sound.

Fertilizer tonnage fees fund the soil testing program and research projects that support the development and validation of soil and crop nutrient management practices along with funding from commodity check-off funds, state and federal sources, various fertilizer industry institutes, lime vendors, and the University of Arkansas System Division of Agriculture. The fertilizer tonnage fee provided funds not only for soil testing and research but also for the publication of this research series.

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

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

This publication is available as a research series online at:
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Arkansas Soil-Test Summary for Samples Collected in 2022

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

Abstract

Soil-test data from samples submitted to the University of Arkansas System Division of Agriculture's Marianna Soil Testing Laboratory (MSTL) in Marianna, Ark., in 2022 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), and zinc (Zn). In 2022, 180,502 client soil samples submitted by the public were analyzed. Of the total samples, 38,346 were submitted as field-average samples, representing 811,678 acres for an average of 19 ac/sample. Grid soil samples accounted for 141,902, or 79% of all submitted samples. Soil samples from the Southern Mississippi River Alluvium, River Terraces, and Valley Loess, geographic areas with row-crop agriculture, represented 45% of the total field-average samples and 72% of the total acreage. Soil association numbers show that most samples were from soils common to row-crop and pasture production. Crop codes with near complete metadata indicate that land used for i) row-crop production accounted for 70% and 36%, ii) hay and pasture for 17% and 19%, and iii) home lawns and gardens accounted for 2% of sampled acreage and 26% of submitted samples, respectively. This report also includes a 17-year summary of Mehlich-3 extractable soil sulfur (S). The Mehlich-3 extractable soil-test S median annual value declined by -0.2 to 0.4 ppm/year between 2006 to 2022 when examined by the crop grown before soil sample collection.

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 no-cost soil-testing services for nutrient management and research. The Arkansas Soil Testing Program has grown over the years and is 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 and Research Laboratory (MSTL), located in Marianna, Ark. The large number of soil samples analyzed annually by the MSTL creates a large 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 a focus on soil pH and Mehlich-3 extractable soil phosphorus (P), potassium (K), and zinc (Zn) because these properties are used most frequently for soil amendment and crop nutrient management. This report summarizes soil pH and soil P, K, and Zn availability indices from samples submitted during 2022 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 2022 and 31 December 2022 were categorized according to geographic area (GA), county, soil association number (SAN), and selected cropping systems. The GA and SAN were derived from the Arkansas General Soil Map (USDA-NRCS, http://www.arcgis.com/apps/webappviewer/index.html?id=fb6594f5690c4830be19624a8cfeaea9, April 2011).

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 as GA, SAN, and previous crop, is often not provided. 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 some information was not completed at the time of sample submission, which 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 indicate the relative level of soil fertility. The categorical ranges associated with Very Low, Low, Medium, Optimum, and Above Optimum soil-test P levels for some crops have changed across time as research has refined the boundaries associated with

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each soil test level. However, for consistency in evaluating soil test trends across time, the boundaries used in this summary have remained consistent. Soil pH is determined by electrode while stirring in a 1:2 volume-to-volume soil:deionized water mixture (Sikora and Kissel, 2014). The Mehlich-3 extraction process is described by Zhang et al. (2014). The nutrient concentrations in Mehlich-3 extracts are determined using an inductively coupled plasma optical emission spectrophotometer (ICAP, SPECTRO ARCOS model). The MSTL participates in the Agricultural Laboratory 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 for selected crops were also summarized using the annual median value from 17 years of data (2006–2022) to examine trends in soil-test S by previous crop across time. Linear regression of the median annual values was used to determine the linear coefficient and coefficient of determination (r^2) by crop.

Results and Discussion

Between 1 January 2022 and 31 December 2022, there were 196,846 soil samples analyzed by the MSTL. After removing 16,344 standard-solution and check-soil samples measured for quality assurance and quality control, the total number of client (e.g., researchers, growers, and homeowners) samples was 180,502 comprising 263 research and out-of-state samples and 180,239 samples from the public that had complete data for the county, total acres, and soil pH, P, K, and Zn (Table 1). The submitted soil samples represented 1,198,325 acres for an average of 13 ac/sample. 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. Of the 180,239 client samples (Table 1), 141,902 (79%) were submitted as grid samples. The balance of the samples (38,337) was submitted as field- or area-average composites, collected primarily from agricultural fields.

Values listed in Table 1 include the number of grid samples analyzed but may not represent the total acres sampled. The new LIMS software allows grid sample acreage to be included. The most common grid sample size was 2.5 acres on 81% of the submitted samples, followed by grid sizes of 5.0 acres (7.7% of samples), 2.0 acres (7.5%), 1.0 acre (1.8%), 10 acres (1.1%) and 4 acres (0.3%). The five counties with the most grid samples submitted include Poinsett (27,820 samples); Clay (25,730); Mississippi (19,220); Crittenden (10,058); and Lee (8,486). 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 Southern Mississippi River Alluvium and Terraces, and Valley Loess, primarily row-crop areas, represented 45% of the total field-average samples and 72% of the total acreage for samples submitted with a geographical area designation (Table 2). The average number of acres represented by each field-average soil sample from the 11 geographic areas ranged from 6 to 50 ac/sample. Soil association numbers show that most samples were taken from soils common to row-crop and pasture production areas (Table 3). The soil associations having the most samples submitted were Henry-Grenada-Calloway-Calhoun (61; 2,156 ac), Dundee-Dobbs-Bosket-Sharkey (24; 1,889 ac), Ethel-Immanuel-Lagrue-Henry (45; 1,875 ac), Clarksville-Nixa-Captina-Jay (2; 1,727 ac), and Enders-Nella-Steprock-Mountainburg-Linker (10; 1,288 ac). However, the soil associations representing the largest acreage were Ethel-Immanuel-Lagrue-Henry 45; 105,726 ac), Dundee-Dobbs-Bosket-Sharkey (24; 99,193 ac), Henry-Grenada-Calloway-Calhoun (61; 59,737 ac), Dewitt-Stuttgart (44; 49,237 ac), and Clarksville-Nixa-Captina-Jay (2; 17,170 ac), which represented 20%, 19%, 12%, 9%, 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 70% of the sampled acreage and 36% of submitted samples, ii) hay and pasture production accounted for 17% of the sampled acreage and 19% of submitted samples, and iii) home lawns and gardens accounted for 2% of sampled acreage and 26% of submitted samples (Table 4). Among row crops listed in Table 4, 22% of the soil samples were collected following soybean in the crop rotation. The cumulative acreage soil sampled following soybean represented about 12% of the annual soybean acreage, which totaled 3.15 million harvested acres in 2022, respectively (USDA-NASS, 2022). The percentages of acres sampled and soil samples collected for row crop codes are underestimated since a large number of row crop samples are submitted as grid samples without information listing the previous crop grown.

Information in Tables 5, 6, and 7 pertains to the fertility status of Arkansas soils as categorized by GA, county, and the crop grown before 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 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 might 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 6.0 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 following non-irrigated grain sorghum, rice, and soybean in the rotation and the lowest median K concentrations occur in soils following non-irrigated grain sorghum, hay, and turf. Soil collected following cotton and home garden production has the highest median K concentration. The highest median concentrations of P and Zn occur in soils used for home garden and landscape/ornamental plant production and are considered above optimum.

Seventeen-Year Trends for Selected Crops and Soil Test Parameters

Routine and timely soil sampling and testing are used by farmers to determine which fertilizer nutrients and soil amendments are needed to optimize crop growth and yield. The availability of soil sulfur (S) for crop growth is important for its role in plant protein formation. We last reported 13-year trends (DeLong et al., 2020) and extended these trends using data from 2019-2022 (DeLong et al., 2021, 2022, 2023). Table 8 summarizes Mehlich-3 extractable S in Arkansas soils from 2006-2022 for selected previous crops using the median annual concentration. The annual results suggest soil-test S for every row-crop category has gradually declined by 0.2 to 0.4 ppm/year over time, but the 17-year trend (r^2 values range from 0.18 to 0.61) is not as strong as the 13-year trend (r^2 values range from 0.19 to 0.80), suggesting several factors influence soil-test S. For example, soil moisture conditions as affected by rainfall events near the time of sampling may influence soil test S since sulfate-S, a mobile element in the soil profile, moves with the general direction of soil moisture in the soil profile.

Practical Applications

Grid soil samples represent 79% of all soil samples submitted to the MSTL. Of the non-grid soil samples submitted with near complete metadata in 2022, 55% of the samples and 87% of the represented acreage had commercial agricultural/farm crop codes. 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. This report includes a summary of Mehlich-3 extractable soil S, which suggests that additional research on crop response to S fertilization and a thorough evaluation of soil sampling protocols to correlate soil-test S with crop response to S fertilization may be needed.

Acknowledgments

The Soil Testing Program funding is provided by Arkansas Fertilizer Tonnage Fees administered by the Soil Test Review Board and the University of Arkansas System Division of Agriculture. This work was supported, at least in part, by the USDA National Institute of Food and Agriculture, Hatch project ARK 2824.

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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 2022 through 31 December 2022.

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 samples	Acres/ sample
Arkansas	129,948	11	4,571	3	28	Lee	78,773	7	9,243	5	9
Ashley	3,717	0	331	0	11	Lincoln	6,474	1	185	0	35
Baxter	1,995	0	286	0	7	Little River	19,786	2	6,953	4	3
Benton	11,454	1	1,633	1	7	Logan	5,039	0	388	0	13
Boone	6,391	1	485	0	13	Lonoke	77,795	6	2,306	1	34
Bradley	960	0	91	0	11	Madison	4,181	0	318	0	13
Calhoun	215	0	28	0	8	Marion	783	0	121	0	6
Carroll	7,950	1	400	0	20	Miller	7,421	1	314	0	24
Chicot	4,385	0	263	0	17	Mississippi	53,825	4	19,680	11	3
Clark	4,139	0	229	0	18	Monroe	25,308	2	1,982	1	13
Clay	70,969	6	26,072	14	3	Montgomery	2,524	0	164	0	15
Cleburne	2,689	0	301	0	9	Nevada	1,339	0	124	0	11
Cleveland	10,850	1	4,257	2	3	Newton	1,238	0	150	0	8
Columbia	1,635	0	158	0	10	Ouachita	502	0	116	0	4
Conway	8,570	1	836	0	10	Perry	2,654	0	186	0	14
Craighead	43,172	4	9,394	5	5	Phillips	8,644	1	907	1	10
Crawford	6,106	1	453	0	13	Pike	983	0	84	0	12
Crittenden	32,153	3	10,671	6	3	Poinsett	82,415	7	28,539	16	3
Cross	37,689	3	2,405	1	16	Polk	5,312	0	419	0	13
Dallas	720	0	85	0	8	Pope	2,907	0	416	0	7
Desha	10,714	1	4,763	3	2	Prairie	15,913	1	1,100	1	14
Drew	1,752	0	181	0	10	Pulaski	6,285	1	1,225	1	5
Faulkner	21,444	2	737	0	29	Randolph	16,691	1	3,190	2	5
Franklin	4,775	0	273	0	17	Saline	11,031	1	3,577	2	3
Fulton	2,780	0	251	0	11	Scott	1,268	0	113	0	11
Garland	1,682	0	1,355	1	1	Searcy	1,790	0	128	0	14
Grant	821	0	111	0	7	Sebastian	2,524	0	414	0	6
Greene	48,310	4	7,630	4	6	Sevier	8,863	1	316	0	28
Hempstead	2,324	0	192	0	12	Sharp	3,487	0	256	0	14
Hot Spring	2,428	0	156	0	16	St. Francis	46,746	4	1,979	1	24
Howard	5,351	0	337	0	16	Stone	3,034	0	297	0	10
Independence	1,732	0	351	0	5	Union	1,466	0	289	0	5
Izard	4,553	0	210	0	22	Van Buren	3,735	0	285	0	13
Jackson	99,057	8	6,957	4	14	Washington	15,808	1	1,987	1	8
Jefferson	28,544	2	1,663	1	17	White	10,025	1	944	1	11
Johnson	2,524	0	268	0	9	Woodruff	17,574	1	322	0	55
Lafayette	1,519	0	32	0	47	Yell	2,808	0	275	0	10
Lawrence	15,369	1	2,531	1	6	Sum or Avg.	1,198,325		180,239		13

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 2022 through 31 December 2022.

Geographic area	Acres Sampled	% of total acres	No. of samples	% of total samples	Acres/ sample
Ozark Highland	50,931	10	3,682	17	14
Boston Mountains	19,116	4	1,818	8	11
Arkansas Valley and Ridges, Eastern Part	24,593	5	1,898	9	13
Ouachita Mountains	12,041	2	1,875	9	6
Southern Mississippi River Alluvium	142,422	27	3,528	16	40
Arkansas River Alluvium	11,695	2	633	3	18
Red River Alluvium	4,909	1	482	2	10
Southern Mississippi River Terraces	155,226	30	3,104	14	50
Western Coastal Plain	9,583	2	1,141	5	8
Southern Mississippi Valley Loess	77,824	15	3,269	15	24
Cretaceous Western Coastal Plain	13,133	3	625	3	21
Sum or Average	521,472		22,055		20

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 2022 through 31 December 2022.

						Median			
SAN Soil association	Acres sampled	% of total acres	No. of samples	% of total samples	Acres/ sample	pH	P	K	Zn
							----------(ppm)----------		
1. Rueter-Clarksville-Moko	8,820	1.7	535	2.4	16	6.4	112	155	11.2
2. Clarksville-Nixa-Captina-Jay	17,170	3.3	1,727	7.8	10	6.5	70	131	7.7
3. Newnata-Eden-Moko-Summit	5	<0.1	5	<0.1	1	5.4	57	104	5.2
4. Alred-Tonti-Gatewood	13,520	2.6	854	3.9	16	6.3	37	102	4.0
5. Alred-Gatewood-Mano-Ocie	5,478	1.1	273	1.2	20	6.4	65	139	8.3
6. Gatewood-Moko-Ocie	172	<0.1	5	<0.1	34	6.0	88	133	8.5
7. Portia-Estate-Moko	386	0.1	24	0.1	16	6.3	110	100	8.1
8. Brockwell-Boden-Portia	5,381	1.0	259	1.0	21	6.3	47	104	4.2
9. Linker-Enders-Steprock-Mountainburg-Sidon	6,202	1.2	530	2.4	12	6.1	53	100	4.2
10. Enders-Nella-Steprock-Mountainburg-Linker	12,914	2.5	1,288	5.8	10	6.1	63	102	5.8
11. Wrightsville-Sallisaw-Leadvale	8	0.1	2	0.1	4	5.3	39	69	2.3
12. Leadvale-Taft	10,701	2.1	758	3.4	14	6.1	58	98	5.7
13. Enders-Mountainburg-Steprock-Nella-Linker	2,000	0.4	250	1.1	8	6.0	35	92	3.0
14. Spadra-Guthrie-Barling	548	0.1	46	0.2	12	5.9	138	118	10.2
15. Mountainburg-Linker-Enders	10,452	2.0	787	3.6	13	6.0	57	104	4.3
16. Muskogee-Wrightsville-McKamie-Pickwick	884	0.2	55	0.2	16	5.9	78	133	7.5
17. Carnasaw-Clebit-Sherless-Pirum	7,162	1.4	601	2.7	12	5.9	117	96	7.5
18. Ceda-Kenn-Avilla	3,827	0.7	840	3.8	5	6.1	54	106	4.9
19. Leadvale-Cane-Sallisaw	390	0.1	25	0.1	16	5.9	49	87	5.0
20. Yanush-Avant-Bigfork-Carnasaw-Bismarck	663	0.1	409	1.9	2	6.2	60	110	5.2
21. Calhoun-Overcup-Amagon	9,649	1.9	320	1.5	30	6.3	24	109	3.3
22. Kobel-Yancopin	9,681	1.9	308	1.4	31	6.3	28	108	3.0
23. Sharkey-Alligator	6,131	1.2	202	0.9	30	6.5	28	251	3.8

continued

Table 3. Continued.

SAN Soil association	Acres sampled	% of total acres	No. of samples	% of total samples	Acres/ sample	Median pH	Median P	Median K	Median Zn
							---------(ppm)---------		
24. Dundee-Dubbs-Bosket-Sharkey	99,193	19.0	1,889	8.6	53	6.5	30	109	2.9
25. Amagon-Dundee-Sharkey	3,217	0.6	339	1.5	9	6.6	46	188	3.5
26. Commerce-Sharkey-Robinsonville	3,208	0.6	133	0.6	24	6.5	42	217	4.2
27. Sharkey	748	0.1	19	0.1	39	7.2	26	269	4.3
28. Tuckermann-Bosket	22	<0.1	2	<0.1	11	6.6	86	49	16.3
29. Commerce-Robinsonville-Crevasse	7,710	1.5	211	1.0	37	5.9	42	99	3.4
30. Sharkey-Dundee	379	0.1	11	<0.1	34	6.7	35	303	4.8
31. Sharkey-Bowdre-Tunica	2,484	0.5	94	0.4	26	6.4	29	102	2.9
32. Perry-Portland-Rilla	6,502	0.5	312	0.4	21	6.7	27	254	2.9
33. Bruno-Crevasse-Coushatta-Norwood	80	<0.1	17	0.1	5	5.9	113	138	7.1
34. Roxana-Roellen-Dardanelle-Crevasse	1,552	0.3	82	0.4	19	6.1	35	78	3.6
35. Rilla-Hebert-Perry	3,450	0.7	212	1.0	16	6.3	44	129	2.6
36. Severn-Kiomatia-Choska	108	<0.1	7	<0.1	15	6.2	67	58	4.8
37. Perry-Portland	3	<0.1	3	<0.1	1	6.1	5	50	1.7
38. Billyhaw-Perry-Portland	961	0.2	113	0.5	9	6.1	62	92	4.2
39. Severn-Kiomatia	520	0.1	13	0.1	40	6.1	29	198	2.5
40. Severn-Oklared-Billyhaw	58	<0.1	7	<0.1	8	6.0	39	96	2.7
41. Severn-Norwood-Moreland	1,391	0.3	190	0.9	7	6.3	73	78	6.5
42. Armistead-Gallion-Perry	1,965	0.4	148	0.7	13	5.9	58	86	4.3
43. Rilla-Caspiana-Billyhaw-Perry	14	<0.1	11	<0.1	1	6.5	38	83	4.6
44. Dewitt-Stuttgart	49,237	9.4	1,203	5.5	41	6.7	30	107	4.1
45. Ethel-Immanuel-Lagrue-Henry	105,726	20.3	1,875	8.5	56	6.7	28	103	3.8
46. Oaklimeter-Immanuel	263	0.1	26	0.1	10	5.7	43	68	6.4
47. Adaton-Sawyer	340	0.1	13	0.1	26	6.3	66	76	8.8
48. Wrightsville-McKamie-Acadia	529	0.1	20	0.1	26	5.8	49	38	3.2
49. Amy-Stough-Savannah	2,026	0.1	337	1.5	6	6.2	76	83	6.7
50. Sacul-Warnock-Darley-Bibb-Darden	95	<0.1	53	0.2	2	6.5	43	83	3.0
51. Amy-Stough	856	0.2	137	0.6	6	6.1	51	84	4.1

continued

Table 3. Continued.

SAN Soil association	Acres sampled	% of total acres	No. of samples	% of total samples	Acres/ sample	Median pH	Median P	Median K	Median Zn
							----------(ppm)----------		
52. Smithdale-Savannah-Sacul-Amy	3,265	0.6	312	1.4	10	5.9	46	60	4.4
53. Sacul-Sawyer-Savannah	772	0.1	91	0.4	8	5.9	64	75	6.6
54. Guyton-Amy	271	0.1	34	0.2	8	5.8	28	52	2.3
55. Sacul-Kullit-Bowie	179	<0.1	11	<0.1	16	6.0	31	66	10.6
56. Sacul-Eastwood-Darley	27	<0.1	8	<0.1	3	5.5	63	57	5.7
57. Wrightsville-Kolin	44	<0.1	2	<0.1	22	5.5	105	36	4.4
58. Sawyer-Sacul-Kirvin	50	<0.1	3	<0.1	17	5.6	99	82	6.5
59. Gladewater-Kaufman-Texark	0	0	0	0	0	0.0	0	0	0.0
60. Sawyer-Eylau-Sacul-Woodtell	1,129	0.2	120	0.5	9	6.1	44	72	3.9
61. Henry-Grenada-Calloway-Calhoun	59,737	11.5	2,156	9.8	28	6.9	27	92	3.4
62. Loring-Oaklimeter	129	<0.1	37	0.2	3	6.2	40	102	4.0
63. Loring-Memphis-Collins	7,145	1.4	873	4.0	8	6.4	37	116	4.0
64. Brandon-Saffell-Memphis-Collins	1,583	0.3	71	0.3	22	6.2	26	85	3.5
65. Hillemann-Grubbs-Henry	9,231	1.8	132	0.6	70	7.4	25	75	3.8
66. Sumter-BIllstown-Japany	677	0.1	49	0.2	14	6.4	71	157	8.1
67. Peanutrock-Pikecity-Tiak-Antione	11,837	2.3	518	2.3	23	6.0	120	139	10.2
68. Tiak-Antione	58	<0.1	36	0.2	2	6.0	97	113	7.8
69. Guytown-Ocklockonee-Toine-Sardis	361	0.1	5	<0.1	72	6.0	111	164	10.3
70. Blevins-Tiak-Peanutrock	200	<0.1	17	0.1	12	6.2	160	221	20.0
Sum or Average	521,472		22,055		18	6.1	57	110	5.5

Table 4. Sample number and total acreage by previous crop grown for soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory in Marianna from 1 January 2022 through 31 December 2022.

Previous crop	Acres Sampled	% of total acres	No. of samples	% of total samples	Acres/ sample
Corn	81,349	10	2,119	6	38
Cotton	18,077	2	1,023	3	18
Grain sorghum, non-irrigated	133	0	22	0	6
Grain sorghum, irrigated	947	0	25	0	38
Rice	97,889	12	2,198	6	45
Soybean	362,618	45	8,400	22	43
Wheat	5,054	1	142	0	36
Cool-season grass hay	4,058	0	346	1	12
Native warm-season grass hay	2,654	0	182	0	15
Warm-season grass hay	34,772	4	1,565	4	22
Pasture, all categories	95,973	12	5,213	14	18
Home garden	6,647	1	3,708	10	2
Turf	1,507	0	760	2	2
Home lawn	8,406	1	6,215	16	1
Small fruit	999	0	478	1	2
Ornamental	2,023	0	1,009	3	2
Miscellaneous[a]	88,574	11	4,941	13	18
Sum or Average	811,678		38,346		19

[a] 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 2022 through 31 December 2022.

	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)------					(ppm)	------(% of sampled acreage)-----					(ppm)
Ozark Highland	4	9	27	35	25	6.4	8	11	11	13	57	63
Boston Mountains	11	18	27	30	14	6.1	10	11	11	12	57	59
Arkansas Valley and Ridges, Eastern Part	13	21	30	26	9	6.0	8	13	13	12	54	56
Ouachita Mountains	14	20	30	27	9	6.0	5	10	12	14	60	67
Southern Mississippi River Alluvium	4	8	21	46	20	6.5	14	23	21	20	22	31
Arkansas River Alluvium	6	10	23	36	25	6.4	13	18	20	19	30	35
Red River Alluvium	17	17	23	31	12	6.1	11	11	10	12	55	60
Southern Mississippi River Terraces	4	9	18	28	41	6.7	14	26	27	20	13	29
Western Coastal Plain	16	18	25	28	14	6.1	15	11	10	12	52	52
Southern Mississippi Valley Loess	7	8	15	29	41	6.7	16	27	19	19	19	29
Cretaceous Western Coastal Plain	15	21	25	24	14	6.0	8	9	7	7	69	116
Average	10	14	24	31	21	6.3	11	15	15	14	45	54

	Mehlich-3 soil potassium[b] (ppm)						Mehlich-3 soil zinc[b] (ppm)					
Geographic area	**<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)
Ozark Highland	13	18	22	17	29	123	8	16	9	24	44	6.7
Boston Mountains	22	23	19	14	22	102	10	21	11	22	36	5.2
Arkansas Valley and Ridges, Eastern Part	20	22	24	14	21	101	11	21	12	23	33	4.8
Ouachita Mountains	17	22	27	16	18	105	5	20	12	27	36	5.5
Southern Mississippi River Alluvium	11	18	27	17	26	119	9	40	20	24	7	3.1
Arkansas River Alluvium	9	11	21	18	42	147	15	39	18	19	9	2.9
Red River Alluvium	32	21	19	11	17	85	16	20	10	22	32	4.6
Southern Mississippi River Terraces	7	26	42	16	9	104	9	28	15	36	12	3.9
Western Coastal Plain	41	20	16	10	13	71	19	19	9	20	33	4.6
Southern Mississippi Valley Loess	13	31	32	14	11	97	11	31	13	27	17	3.6
Cretaceous Western Coastal Plain	19	12	15	13	40	141	7	11	7	18	56	10.0
Average	19	20	24	15	22	109	11	24	12	24	29	5.0

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

Table 6. The percentage of sampled acres as distributed within five soil-test levels and median soil chemical property values by county for soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory in Marianna from 1 January 2022 through 31 December 2022.

	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)--------					(ppm)	----------(% of sampled acreage)---------					(ppm)
Arkansas	8	15	23	24	30	6.3	14	29	27	19	11	28
Ashley	8	8	19	44	22	6.5	10	16	19	17	38	38
Baxter	3	6	18	27	47	6.9	10	12	11	9	57	63
Benton	8	11	24	36	22	6.4	2	6	10	11	72	90
Boone	4	8	29	34	25	6.4	2	9	9	14	65	77
Bradley	12	12	14	29	33	6.7	11	8	2	8	71	119
Calhoun	29	14	21	25	11	5.9	14	11	11	7	57	54
Carroll	1	6	29	36	29	6.5	0	3	4	6	88	169
Chicot	3	5	13	45	34	6.7	27	34	18	10	11	21
Clark	25	24	28	15	8	5.8	27	18	10	11	34	33
Clay	4	11	27	44	14	6.3	10	20	20	22	29	36
Cleburne	19	14	27	30	10	6.1	10	16	11	10	53	54
Cleveland	12	20	31	30	7	6.0	25	28	16	14	17	24
Columbia	22	15	18	31	14	6.1	34	13	11	8	34	29
Conway	11	17	21	29	22	6.3	7	14	19	19	41	44
Craighead	3	7	24	43	22	6.5	10	16	15	21	38	42
Crawford	11	17	28	30	14	6.1	8	13	11	13	56	58
Crittenden	6	7	18	41	29	6.6	7	21	23	24	25	35
Cross	2	5	13	26	54	7.0	14	25	22	24	15	31
Dallas	21	13	21	34	11	6.1	8	11	12	9	60	60
Desha	6	11	27	36	20	6.3	4	17	17	22	39	43
Drew	18	21	28	24	9	6.0	25	12	10	12	40	37
Faulkner	18	20	20	25	16	6.0	15	14	12	13	45	44
Franklin	10	22	34	27	7	6.0	8	10	14	11	58	69
Fulton	3	13	31	29	25	6.4	12	18	18	15	37	37
Garland	12	18	30	30	11	6.1	5	12	14	17	52	53
Grant	18	21	18	32	12	6.1	9	14	14	11	51	52
Greene	9	13	26	35	17	6.3	22	24	18	14	22	28
Hempstead	18	21	28	26	8	5.9	13	9	14	11	54	61
Hot Spring	19	32	31	12	6	5.7	38	17	10	7	27	22
Howard	15	18	28	22	16	6.0	1	4	3	5	86	176
Independence	9	13	27	30	20	6.3	10	17	15	16	42	42
Izard	5	14	28	34	20	6.3	8	11	13	16	52	52
Jackson	4	10	23	42	22	6.5	20	21	17	18	24	30
Jefferson	13	12	21	32	22	6.3	13	19	19	22	27	35
Johnson	16	24	25	26	9	6.0	10	9	12	13	57	58
Lafayette	9	3	41	44	3	6.2	6	16	6	9	63	55
Lawrence	3	9	23	43	21	6.4	20	28	19	15	18	26
Lee	3	9	25	36	26	6.5	6	15	22	29	27	38
Lincoln	6	15	32	25	23	6.2	8	28	15	16	34	35

continued

Table 6. Continued.

County	Soil pH[a]						Mehlich-3 soil phosphorus[b] (ppm)					
	<5.4	5.4–5.7	5.8–6.2	6.3–6.9	>6.9	Md[c]	<16	16–25	26–35	36–50	>50	Md[c]
	--------(% of sampled acreage)--------					(ppm)	----------(% of sampled acreage)---------					(ppm)
Little River	5	15	34	31	14	6.2	11	23	21	20	24	33
Logan	8	17	37	30	9	6.1	12	16	16	15	40	39
Lonoke	13	20	33	29	6	6.0	18	24	20	17	23	30
Madison	4	19	27	35	15	6.2	3	7	11	11	68	96
Marion	2	7	21	31	39	6.7	9	13	13	8	56	53
Miller	8	17	22	28	25	6.3	14	19	17	20	29	35
Mississippi	2	4	16	40	37	6.7	12	23	21	22	22	33
Monroe	8	8	17	26	41	6.7	28	25	20	14	13	24
Montgomery	20	27	35	15	3	5.8	4	12	6	7	71	110
Nevada	27	23	21	23	6	5.7	9	8	7	10	66	86
Newton	2	14	23	35	26	6.4	5	13	13	8	62	83
Ouachita	17	17	21	40	5	6.2	10	13	5	17	54	55
Perry	23	17	31	19	10	5.9	10	16	19	17	38	38
Phillips	13	10	17	36	25	6.5	4	18	25	24	29	37
Pike	13	14	27	27	18	6.1	1	4	4	12	80	149
Poinsett	2	5	15	36	43	6.8	7	20	22	25	25	36
Polk	20	25	30	21	5	5.8	4	4	6	8	78	125
Pope	19	17	22	25	18	6.1	19	10	10	10	50	52
Prairie	5	8	18	38	31	6.6	26	36	19	12	7	21
Pulaski	15	14	24	31	15	6.2	6	9	10	12	64	70
Randolph	5	12	30	37	16	6.3	20	32	20	16	12	25
Saline	13	18	26	32	11	6.1	6	13	15	20	46	48
Scott	14	25	34	16	12	5.9	4	7	16	11	62	70
Searcy	8	15	30	30	17	6.2	7	11	17	20	45	43
Sebastian	13	18	25	24	21	6.2	13	15	10	9	52	57
Sevier	13	21	27	28	11	6.0	12	13	9	8	58	70
Sharp	9	11	30	32	18	6.2	24	16	10	13	38	36
St. Francis	4	9	18	37	33	6.7	11	19	13	14	42	42
Stone	8	19	28	32	13	6.1	5	8	10	16	60	61
Union	12	12	22	43	11	6.3	12	10	8	19	50	50
Van Buren	5	21	39	27	9	6.1	8	15	13	12	52	54
Washington	4	10	28	35	23	6.4	5	9	9	11	66	72
White	12	15	27	34	12	6.2	7	15	15	10	53	55
Woodruff	2	2	14	32	49	6.9	13	33	22	18	14	27
Yell	7	23	35	23	12	6.0	3	8	8	9	72	117
Average	10	14	25	31	19	6.3	12	16	14	14	45	55

continued

Table 6. Continued.

	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	10	26	37	16	10	104	4	21	16	42	17	4.8
Ashley	15	18	21	20	25	124	24	24	12	25	14	3.1
Baxter	9	17	26	19	30	128	6	17	6	17	55	9.6
Benton	7	12	22	23	36	146	1	8	9	33	49	7.9
Boone	13	15	18	16	38	140	5	14	11	26	44	7.1
Bradley	34	14	31	11	10	93	16	14	3	16	49	7.9
Calhoun	21	29	21	7	21	88	25	25	0	21	29	2.9
Carroll	8	10	13	15	54	190	2	4	2	16	76	17.8
Chicot	3	4	8	6	78	266	13	38	29	14	5	3.0
Clark	33	27	21	11	9	82	36	27	7	14	16	1.9
Clay	8	18	30	24	20	122	7	32	21	33	7	3.5
Cleburne	27	25	17	12	20	88	19	25	7	21	27	3.7
Cleveland	3	9	12	12	63	238	4	26	23	38	7	3.9
Columbia	64	15	8	6	7	44	36	23	8	21	13	2.3
Conway	11	15	33	25	17	120	7	13	6	40	33	6.7
Craighead	8	16	20	23	32	141	8	35	22	27	8	3.4
Crawford	23	21	26	14	16	99	4	16	12	27	41	6.4
Crittenden	1	7	16	19	57	192	7	29	24	36	4	3.6
Cross	12	25	25	12	26	107	9	33	15	34	9	3.6
Dallas	36	24	18	14	8	81	22	25	4	28	21	3.9
Desha	12	21	22	15	30	117	4	29	19	38	11	4.0
Drew	33	24	20	12	10	78	14	25	11	21	28	3.9
Faulkner	19	26	24	14	18	98	14	25	13	23	26	3.9
Franklin	16	19	23	16	26	112	7	21	11	20	41	6.3
Fulton	12	25	26	14	22	102	14	31	12	16	27	3.4
Garland	9	23	34	18	15	109	2	23	16	30	29	4.9
Grant	30	20	22	9	20	93	10	30	13	27	21	3.8
Greene	11	25	31	20	13	107	15	39	16	25	6	2.9
Hempstead	33	20	13	13	21	83	14	16	16	26	29	4.5
Hot Spring	50	26	13	3	9	60	38	29	2	12	18	2.0
Howard	11	12	13	13	52	183	2	7	5	18	67	13.0
Independence	19	24	21	13	23	102	13	29	13	20	25	3.6
Izard	15	18	38	14	15	107	10	26	11	25	28	4.3
Jackson	17	25	29	19	11	100	20	40	15	21	4	2.6
Jefferson	11	21	23	15	29	118	8	33	20	30	10	3.4
Johnson	13	24	29	18	16	104	8	26	12	30	24	4.3
Lafayette	9	16	6	19	50	167	13	13	19	16	41	4.3
Lawrence	9	26	31	17	16	107	6	24	19	36	15	4.1
Lee	3	12	27	21	38	146	11	34	19	29	7	3.3
Lincoln	14	17	22	14	34	123	6	46	16	17	15	3.0

continued

Table 6. Continued.

County	Mehlich-3 soil potassium[b] (ppm)						Mehlich-3 soil zinc[b] (ppm)					
	<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)
Little River	4	19	40	21	16	116	16	40	18	21	4	2.8
Logan	24	24	23	9	20	93	9	27	17	24	23	3.7
Lonoke	12	22	31	18	17	111	24	42	11	16	7	2.4
Madison	15	16	16	15	38	134	2	18	8	20	52	8.7
Marion	11	14	27	26	22	124	4	12	3	19	61	10.1
Miller	24	19	15	15	27	108	26	38	8	14	15	2.3
Mississippi	1	6	15	22	57	190	3	26	32	34	5	3.7
Monroe	14	30	33	14	8	96	9	39	19	26	6	3.1
Montgomery	37	19	18	14	12	82	8	18	7	23	44	6.7
Nevada	39	27	15	9	11	71	16	13	3	19	48	7.9
Newton	20	19	20	12	29	109	11	19	6	18	47	6.9
Ouachita	41	27	16	9	7	70	14	17	11	20	38	5.6
Perry	15	20	34	17	14	108	12	34	17	19	17	3.3
Phillips	3	16	41	26	14	120	24	38	15	18	5	2.5
Pike	25	23	19	15	18	98	2	6	7	23	62	11.9
Poinsett	3	10	19	20	48	172	7	34	27	29	4	3.4
Polk	27	24	16	12	21	87	9	14	7	27	43	6.7
Pope	21	26	19	12	22	97	14	19	13	22	33	4.5
Prairie	12	43	32	9	5	87	20	38	19	21	3	2.8
Pulaski	14	27	28	14	18	102	4	15	8	22	51	8.2
Randolph	16	27	29	14	14	99	4	19	16	42	18	4.7
Saline	7	15	21	20	36	144	7	24	14	34	22	4.5
Scott	24	17	20	13	26	106	3	14	4	20	58	9.4
Searcy	25	16	30	12	17	97	27	22	13	23	16	3.1
Sebastian	19	22	24	15	20	104	5	17	7	24	47	7.4
Sevier	27	11	16	12	34	115	9	12	9	14	56	9.9
Sharp	11	23	29	18	19	109	25	20	10	16	29	3.5
St. Francis	11	15	14	8	52	186	21	47	16	13	3	2.4
Stone	24	24	21	13	19	96	8	20	13	27	31	5.0
Union	30	24	22	17	6	80	15	23	14	14	34	3.7
Van Buren	26	27	17	16	14	88	19	22	13	22	24	3.7
Washington	10	16	23	23	28	133	5	11	8	32	44	7.3
White	24	23	25	13	16	96	12	24	10	28	27	4.6
Woodruff	19	35	32	11	2	86	6	36	23	29	7	3.4
Yell	17	14	21	14	34	126	1	8	7	21	63	10.9
Average	18	20	23	15	24	115	12	24	13	24	27	5.1

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

Table 7. The percentage of sampled acres as distributed within five soil-test levels and median soil chemical property values by the previous crop grown for soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory in Marianna from 1 January 2022 through 31 December 2022.

	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	7	19	40	29	6.6	8	21	23	26	23	35
Cotton	3	10	30	45	12	6.4	3	7	11	22	57	55
Grain sorghum, non-irrigated	14	27	27	27	5	5.8	32	18	18	14	18	24
Grain sorghum, irrigated	8	8	16	32	36	6.8	16	16	20	36	12	32
Rice	5	9	17	32	37	6.7	21	30	23	17	10	25
Soybean	4	7	18	32	39	6.7	14	29	24	20	13	28
Wheat	15	18	28	23	16	6.0	19	23	21	18	20	30
Cool-season grass hay	5	20	40	28	7	6.0	13	14	16	16	41	41
Native warm-season grass hay	12	31	29	20	9	5.8	16	18	10	12	43	40
Warm-season grass hay	14	23	30	27	6	6.0	11	14	13	13	48	48
Pasture, all categories	10	18	33	30	8	6.1	10	11	11	11	57	62
Home garden	6	10	18	29	37	6.6	4	6	5	7	77	130
Turf	8	8	27	44	12	6.3	2	9	9	15	66	75
Home lawn	15	18	27	28	12	6.1	7	10	13	18	51	52
Small fruit	19	17	23	27	14	6.0	5	10	9	12	64	83
Ornamental	13	11	18	30	28	6.5	8	10	9	11	62	67
Average	10	15	25	31	19	6.3	12	15	15	17	41	52

	Mehlich-3 soil potassium[b] (ppm)						Mehlich-3 soil zinc[b] (ppm)					
Previous crop	**<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)
Corn	9	26	33	18	13	106	9	29	15	32	15	3.8
Cotton	1	10	23	29	37	151	6	30	22	30	13	3.6
Grain sorghum, non-irrigated	27	45	14	5	9	75	27	36	9	18	9	2.3
Grain sorghum, irrigated	8	24	24	28	16	121	20	24	16	32	8	3.4
Rice	12	24	27	16	21	110	11	41	19	24	5	3.0
Soybean	8	24	31	14	22	111	11	34	18	30	7	3.3
Wheat	20	20	20	13	25	107	31	36	11	20	2	2.3
Cool-season grass hay	22	32	23	12	12	86	19	32	8	24	17	3.0
Native Warm-season grass hay	40	30	17	7	7	70	21	21	10	21	26	3.8
Warm-season grass hay	39	24	18	9	10	73	15	23	9	21	31	4.4
Pasture, all categories	20	18	20	14	27	111	10	18	9	25	38	5.9
Home garden	10	15	20	17	38	141	4	10	5	17	64	13.0
Turf	24	26	21	12	17	90	4	20	15	34	27	5.1
Home lawn	8	17	27	22	27	128	4	18	14	38	26	5.1
Small fruit	11	17	31	22	19	116	5	19	10	18	47	7.0
Ornamental	17	21	25	17	20	106	6	7	7	22	58	10.1
Average	17	23	23	16	20	106	13	25	12	25	25	4.9

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

Table 8. The annual median Mehlich-3 extractable sulfur (S) concentrations 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 2022.

	Mehlich-3 extractable S by Year[a]																	
Previous Crop	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Slope**
	---Median value (ppm)---																	
Corn	13	16	17	12	11	11	10	11	10	12	9	10	10	10	11	13	13	-0.32[b]
Cotton	13	13	15	12	10	10	10	10	13	9	8	8	8	9	9	8	10	-0.18
Rice	27	25	26	25	23	26	23	25	26	27	25	26	21	18	19	25	23	-0.27
Soybean	14	14	17	14	12	12	11	12	11	12	10	10	10	9	10	12	13	-0.26
Cool-season grass hay	21	19	21	18	15	15	16	16	15	15	13	14	13	14	12	14	16	-0.41
Warm-season grass hay	19	19	21	17	16	15	14	15	14	16	14	14	14	13	13	15	16	-0.32
Pasture, all categories	18	19	22	18	17	16	17	17	16	16	15	15	16	15	14	16	17	-0.26

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

[b] Linear slope unit is ppm/year.

Monitoring Edge-of-Field Sulfate Runoff Losses from Eight Arkansas Discovery Farms

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Abstract

The fate of field-applied nutrients warrants careful consideration regarding agricultural production. Fertilizer-derived nutrients can be subjected to substantial losses through surface runoff events in certain climactic conditions. Although research of nitrogen (N) and phosphorus (P) in surface runoff has been highly documented, the studies of secondary nutrients such as sulfur (as sulfate, SO_4^{2-}) surface runoff have not been as extensive. In May 2022, the Arkansas Discovery Farms Program (ADF) initiated a study measuring sulfate-sulfur (SO_4-S) concentrations and land area losses collected in edge-of-field runoff samples from 8 ADF research sites. The ADF locations are generally categorized as 6 row crop and 2 forage production systems. Mean SO_4-S concentrations in runoff ranged from 2.1 milligrams per liter (mg/L) in Stuttgart (rice and soybeans) to 18.9 mg/L in Dumas (cotton), while sulfate losses ranged from 0.1 pounds per acre (lb/ac) at Wedington and Stuttgart to 1.7 lb/ac in Light. Dumas, Light, and Elkins farms had significantly greater SO_4-S concentrations in edge-of-field runoff samples than Delaplaine, Newport, Stuttgart, and Wedington. Interpreting SO_4-S losses by mass losses per unit area (concentration*runoff volume/land area), Light had significantly greater losses than Newport, Delaplaine, Stuttgart, and Wedington. In addition, variations in significant differences were observed for the other ADF sites in terms of SO_4-S concentrations and land area runoff losses. These observations highlight diverse production and nutrient management strategies among the 8 ADF research locations. Statistical analysis of total runoff per acre showed Newport being significantly higher than Cherry Valley, Dumas, Elkins, and Wedington. Complementary soil sampling events and calculations of SO_4-S losses will supplement awareness of SO_4-S runoff and soil-based dynamics.

Introduction

Sulfur (S) is typically classified as a macronutrient in agricultural and soil science (Bielecka et al., 2015). Sulfur exists in nature as the sulfate ion (SO_4^{2-}) and is involved in plant developmental characteristics such as electron transfer and promoting cell structure (Capaldi et al., 2015) as well as amino acid synthesis (Prajapati et al., 2023). Therefore, SO_4^{2-} is considered a key component of crop yield efficiency and economic profitability.

Sulfate exhibits high mobility in the soil in its inorganic form (Stewart and Sharpley, 1987). As a result of this mobility, SO_4^{2-} (henceforth designated as sulfate-sulfur (SO_4-S)) that has not been influenced by microbial activity and/or incorporated by plant roots (Brady and Weil, 2008) has the potential to be lost from the soil environment via surface runoff and leaching. Consequently, it is imperative that field applications of fertilizers containing sizeable amounts of SO_4-S adhere to the 4-Rs of nutrient management: right place, right time, right amount, and right rate.

Surface runoff potential of primary nutrients such as nitrogen (N), phosphorus (P), and potassium (K) have been studied and documented in Arkansas (Daniels et al., 2019; 2023). However, the fate of secondary nutrients such as SO_4-S regarding surface runoff has not been as widely reported. Furthermore, the effects of diverse agricultural production systems and the impacts of implemented conservation practices on SO_4-S soil behavior and subsequent runoff dynamics merit investigation as well. While sulfate is not necessarily considered a water quality issue, losses in runoff have implications for fertilizer recommendations and agricultural profitability.

The Arkansas Discovery Farms Program (ADF) is currently monitoring SO_4-S in runoff at 8 privately owned farms across Arkansas. These farms are primarily located in eastern and northwest Arkansas, where row crop farming and forage production, respectively, are predominant. The objectives of this research are to compare the concentrations and land area losses of SO_4-S in edge-of-field surface runoff among the 8 experimental locations as well as compare total runoff per acre among these study sites.

Procedures

Data for this report was collected from 8 ADF experimental sites from 2 May 2022 to 24 August 2023. Information for each ADF location is presented in Table 1. Current ADF sites previously supplied with edge-of-field monitoring equipment (Teledyne ISCO, Lincoln, Neb.) were utilized to capture and analyze SO_4-S loss in edge-of-field runoff. Following runoff events instigated by either irrigation or rainfall, flow-weighted runoff samples were collected in 1-liter bottles, mixed and sieved with a 0.45-micron filter with no acid treatment, and kept cold prior to and during transportation (EPA 300.0). These SO_4-S sampling methods adhered to sampling protocols issued by the United States Environmental Protection Agency (USEPA, 2016). The sample collection date and flow data generated from each ADF ISCO unit were noted and

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logged into a project file for continued data maintenance. Runoff samples were then transported to the Arkansas Water Resources Center (AWRC) in Fayetteville, Ark., for SO_4-S analysis. Supplementary SO_4-S samples were collected from 2 tailwater recharge reservoirs at Stuttgart, along with a retention pond and ephemeral creek at Elkins.

Statistical analysis was performed in SAS 9.4 by utilizing a generalized linear mixed model (PROC GLIMMIX) using a gamma distribution and a natural logarithm link comparing mean SO_4-S concentrations and losses in runoff from individual ADF sites and total runoff per acre. Means were separated by a protected least significant difference (LSD) procedure and reported in units of milligrams per liter (mg/L), pounds per acre (lb/ac), and total runoff per acre in inches (in.). An observation from Cherry Valley on 16 August 2023 was excluded from the overall data set as a result of concentrations and ISCO calculated flows being influenced by the draining of a flood off a rice field adjacent to that individual field's sampling location.

Results and Discussion

Analysis of mean SO_4-S edge-of-field runoff concentrations by ADF research site found that concentrations at Dumas were significantly greater ($P \leq 0.05$) than all other ADF locations except Light (Table 2). The Light, Elkins, and Cherry Valley farms had transitional SO_4-S concentrations that were significantly greater than Newport, Wedington, and Stuttgart, although Light was significantly higher in SO_4-S concentrations than Delaplaine (Table 2). Analysis of SO_4-S loss per unit land area revealed that Light had a mean land area loss of 1.7 lb/ac that was significantly greater than Newport, Delaplaine, Stuttgart, and Wedington (Table 2). Additionally, Cherry Valley, Dumas, Elkins, and Newport were not significantly different but had transitional land area losses compared to all other farms except Stuttgart and Wedington. The lowest SO_4-S land area losses were observed at Wedington due to its large watershed drainage area and the production of pasture-raised beef and sheep. Conversely, Elkins is involved in poultry, livestock, and forage production. Broiler houses close to ISCO sampling stations, as well as periodic field applications of poultry litter, most likely have impacted SO_4-S concentrations and loads, which resulted in the significant differences between these two farms. A subsequent analysis of total runoff per acre showed Newport had significantly higher runoff than Cherry Valley, Dumas, Elkins, and Wedington (Table 2). Delaplaine, Light, and Stuttgart had similar total runoff and were transitional from all other ADF sites (Table 2).

Practical Applications

Significant differences in mean SO_4-S concentrations and land area losses in edge-of-field runoff were observed when comparing 8 ADF research locations, illustrating diversity among agricultural production systems. Sulfate-sulfur runoff and land area loss dynamics are influenced by agricultural factors such as nutrient and soil management along with crop selection. As a result of numerous fertilizer products containing SO_4-S in their respective chemical formulations, careful considerations of these agricultural factors should be made in regard to SO_4-S fertilizer efficiency and beneficial economic returns.

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Table 1. Descriptions of Arkansas Discovery Farms (ADF) research locations used in this study by closest city, county, number of fields, crop grown in 2023, total field size, and dominant soil series.

Closest City	County	Number of Fields	Crop Grown[†]	Total Field Size	Dominant Soil Series
				(ac)	
Cherry Valley	Cross	4	Soybean/Rice	195	Crowley/ Hillemann
Delaplaine	Greene	3	Rice	89	Foley-Bonn
Dumas	Desha	4	Cotton/Corn	111	Herbert
Elkins	Washington	3	Crabgrass/Bermudagrass	29	Cherokee
Light	Greene	2	Soybean	62	McCrory
Newport	Jackson	3	Rice	63	Egam
Stuttgart	Arkansas	2	Corn/Rice/Soybean	150	Tichnor/ Dewitt
Wedington	Washington	3	Crabgrass/Bermudagrass/Johnsongrass	269	Pembroke

[†] Soybean (*Glycine max* L.); rice (*Oryza sativa* L.); cotton (*Gossypium hirsutum* L.); corn (*Zea mays* L.) crabgrass (*Digitaria sanguinalis* L.); bermudagrass (*Cynodon dactylon* L.); Johnsongrass (*Sorghum halepense* L.).

Table 2. Arkansas Discovery Farms (ADF) mean edge-of-field runoff sulfate (SO_4-S) concentrations, land area losses, total runoff per acre, and number of observations by ADF location. Means were analyzed and separated at ($P \leq 0.05$).

Farm	SO_4-S[†]	Number of Observations	SO_4-S[†]	Number of Observations	Total Runoff/ac[†]	Number of Observations
	(mg/L)		(lb/ac)		(in.)	
Cherry Valley	8.6 bc	25	1.3 ab	23	0.4 b	23
Delaplaine	5.2 cd	57	0.4 cd	23	0.9 ab	23
Dumas	18.9 a	69	1.1 ab	66	0.4 b	66
Elkins	10.7 b	51	0.9 abc	22	0.4 b	22
Light	15.2 ab	36	1.7 a	31	0.9 ab	31
Newport	3.8 de	59	0.7 bc	59	1.3 a	59
Stuttgart	2.1 f	69	0.2 de	14	0.7 ab	14
Wedington	2.4 ef	18	0.1 e	18	0.3 b	18

[†] Values within a column followed by different lowercase letters are significantly different ($P \leq 0.05$).

Potassium Fertilization Effects on Cotton Yield and Tissue-K Concentration in Arkansas

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Abstract

Potassium (K) deficiency of cotton (*Gossypium hirsutum* L.) has become a common malady across many production regions, including Arkansas. Adequate fertilizer-K management is paramount to ensure optimum plant growth. Field studies were initiated in 2023 evaluating how K availability influences cotton leaf- and petiole-K concentration throughout the growing season. Fertilizer-K rate (0, 40, 80, 120, 160, and 200 lb K_2O/ac) trials were established at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS), Milo J. Shult Agricultural Research and Extension Center (SAREC), and Rohwer Research Station (RRS) in soils with Very Low, Medium, and Optimum soil-test K (STK), respectively. Leaf and petiole samples were collected at first flower and analyzed for K concentrations. Leaf- and petiole-K concentrations increased with increasing K availability (either soil or K fertilization), indicating predictability in diagnosing K deficiency. Leaf- and petiole-K concentrations at first flower were significantly ($P < 0.10$) affected by fertilizer-K rate in all trials except for petiole-K concentration at RRS. Overall, tissue-K concentrations continuously increased with increased fertilizer-K rate, with the greatest leaf- and petiole-K concentration increase (0.71% to 1.21% and 3.27% to 7.0%, respectively) being observed at LMCRS on soil with Very Low K (53 ppm K). Fertilizer-K, regardless of application rate, positively influenced yield at the Very Low STK location, with an average increase of 22% when compared to the no-fertilizer-K control. No significant ($P > 0.10$) yield increase with K fertilization was observed on soils with Medium and Optimum STK. Additional site-year observations will allow more conclusive information regarding cotton tissue-K and yield responses to different K availability.

Introduction

Cotton (*Gossypium hirsutum* L.) is a valuable cash crop that requires large amounts of potassium (K) for its full development, representing a key element due to its importance in plant physiological processes. Potassium deficiency symptoms in cotton are frequently observed in soils with below-optimum K availability (Gulick et al., 1989). Over the last two decades, there has been a significant decrease in soil-test K (STK) across the U.S., with Arkansas showing nearly a 17% increase in samples testing in the Low STK category, where soil nutrient supply would likely be yield-limiting without fertilizer supplementation (The Fertilizer Institute, 2023). Traditionally, K management in Southeastern U.S. cotton production involves a full-season, yield-maximizing fertilizer-K rate applied prior to planting (Bonner,1995; Hand et al., 2021). Fertilization using this approach relies on soil-test results from soil samples normally collected from the 0-to-6 in. depth. However, there have been no recent studies or up-to-date literature investigating the adequacy of this K fertilization management to maximize cotton yield and fertilization efficiency, the K dynamics in the soil-plant system, or tissue-K concentration responses to K fertilization. Furthermore, critical tissue-K concentrations for optimal cotton production in Arkansas have not been defined. The latest studies are from decades ago when Joham (1951) showed that tissue tests can play an important part in determining the nutritional status of cotton plants. Studies by Mullins and Burmester (1990) suggest that a mature cotton crop can contain about 114 lb K_2O/ac, with about 55% of the K in the reproductive tissues (burs and seed). Although the previous information is useful, there is a great need for timely, relevant data regarding cotton nutrition in modern cotton cultivars and production systems.

Tissue analysis allows the end-user to assess the plant's nutritional status during the growing season and correct potential nutrient deficiencies with timely fertilization or adjust the fertilization program for the next year. However, critical tissue-K concentrations or sufficiency ranges for most crops, including cotton, have only been defined for one or two growth stages, highlighting the need for more definitive research. Research by Slaton et al. (2021) has shown that soybean [*Glycine max* (L.) Merr.] tissue-K concentrations decrease at a predictable rate across time during reproductive growth regardless of the K fertilization rate, allowing the definition of growth-stage specific critical tissue-K concentrations. This groundwork led to the development of a decision support tool (Ortel et al., 2022) that can assist producers with the evaluation of soybean K nutritional status and assess the need for a corrective in-season fertilizer-K rate application. A similar research approach should work for developing critical tissue-K concentrations at different growth stages for cotton.

Although tissue sampling of cotton leaves and petioles have both been evaluated by field research, there is no literature defining which of the two plant tissues is more effective for determining the K nutrition status of cotton. Furthermore, there are no recent studies in Arkansas with modern cotton varieties examining the

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adequacy of the current K fertilization recommendations, which highlights the need for additional research to fine-tune fertilizer-K rate recommendations. The objective of this study was to analyze cotton yield and leaf- and petiole-K concentration response to K fertilization in soils with different K availability.

Procedures

Field studies were established at University of Arkansas System Division of Agriculture's properties in the spring of 2023 to study the effects of K fertilization in soils with different STK availability on cotton yield and tissue-K concentration. Trials were located in Marianna, Ark., at the Lon Mann Cotton Research Station (LMCRS) on soil mapped as Zachary silt loam (21.7%; Fine-silty, mixed, active, thermic Typic Albaqualfs), Memphis silt loam (33.1%; Fine-silty, mixed, active, thermic Typic Hapludalfs), and Convent silt loam (45.2%; Coarse-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts), in Fayetteville, Ark., at the Milo J. Shult Agricultural Research and Extension Center (SAREC) on soil mapped as a Captina silt loam (100%; Fine-silty, siliceous, active, mesic Typic Fragiudults), and in Rohwer, Ark., at the Rohwer Research Station (RRS) on soil mapped as a Hebert silt loam (38.5%; Fine-silty, mixed, superactive, mesic Udollic Epiaqualfs) Sharkey and Desha silt loam [61.5%; Very-fine, smectitic, thermic Chromic Epiaquerts (Sharkey) and Vertic Hapludolls (Desha)].

Composite soil samples (six to eight individual cores) were collected from the 0- to 6-in. depth from each replicate before planting and fertilizer-K rate treatments application. The soil was oven-dried, ground to pass through a sieve with 2-mm openings, and submitted to the University of Arkansas System Division of Agriculture's Fayetteville Agricultural Diagnostic Laboratory in Fayetteville, Ark., for analysis of pH (1:2 v/v soil/water mixture; Sikora and Kissel, 2014), Mehlich-3 extractable nutrients (Zhang et al., 2014), and soil organic matter by weight loss on ignition (Zhang and Wang, 2014). Mean soil properties are provided in Table 1.

At each location, fertilizer-K treatment rates were 0, 40, 80, 120, 160, and 200 lb K_2O/ac (muriate of potash; 0-0-60) applied preplant and incorporated. The plots were 4 rows wide (38-in. raised beds at RRS and LMCRS and 36-in. raised beds at SAREC) and 40-ft long for RRS and LMCRS, and 30-ft long for SAREC. Each trial was a randomized complete block with four replications. The Delta Pine 2020B3XF variety was planted on 8, 16, and 17 May 2023 at SAREC, RRS, and LMCRS, respectively. General crop management practices followed the current University of Arkansas System Division of Agriculture Cooperative Extension Service's production recommendations. Cotton was grown using furrow irrigation as needed based on soil moisture and rainfall. All studies received 70 lb P_2O_5/ac (triple superphosphate; 0-46-0), 30 lb N/ac, and 34.3 lb S/ac as ammonium sulfate (21-0-0-24) prior to planting. Additionally, each trial received 80 lb N/ac as urea between first square and first flower. Foliar application of Solubor (0.5 lb B/ac) was done on 25 July at RRS, 10 July at LMCRS, and 11 July at SAREC.

Cotton leaf and petiole samples (15 leaves/petioles per plot) were collected from the uppermost mature leaf from an inside row at first square (42 to 50 days after planting), then weekly from first flower (55 to 66 days after planting) until boll fill (113 to 122 days after planting). At the time of tissue sampling, cotton leaves were separated from the petioles, placed in separate labeled paper bags, oven-dried at 131 °F, ground to pass through a sieve with 1-mm openings, digested with concentrated HNO_3 and 30% H_2O_2 (Jones and Case, 1990), and analyzed by inductively coupled plasma optical emission spectrophotometer to determine the nutrient concentrations at the Fayetteville Agricultural Diagnostic Laboratory.

At maturity, the two center rows of each plot were harvested with a spindle-type picker at LMCRS and RRS and hand-picked at SAREC to determine the yield reported in pounds of seedcotton per acre. Analysis of variance was performed by location on cotton yield and tissue-K data using the GLIMMIX procedure SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.). Differences were interpreted as significant when the *P*-value was ≤ 0.10.

Results and Discussion

The results included in this report represent the first year of this research, and data is still being received, so only seedcotton yield and tissue-K concentration data from the first flower sample timing are presented in this report. Fertilizer-K rate significantly ($P < 0.10$) affected seedcotton yield at LMCRS, where STK was in the Very Low (≤60 ppm) category (Table 2). A positive yield response was observed when fertilizer-K was applied, regardless of rate, with a 13% increase in seedcotton yield, relative to the no-fertilizer-K control, from the application of 40 lb K_2O/ac and a 24% increase, relative to the control, when ≥ 80 lb K_2O/ac was applied. As expected, based on STK levels, no significant cotton yield response to K fertilization was observed at SAREC and RRS. The maximum seedcotton yield among fertilizer-K treatments was 4158 lb/ac at LMCRS, 3435 lb/ac at SAREC, and 2335 lb/ac at RRS, representing 1709, 1412, and 960 lb lint/ac using an average 41.1% lint factor for the DP2020B3XF cultivar (Bourland et al., 2022; 2023). The LMCRS and SAREC yields were 44.7% and 19.6%, respectively, greater than the Arkansas average cotton yield of 1181 lb lint/ac in 2022 (USDA-NASS, 2022).

Leaf-K concentrations at first flower were significantly ($P < 0.10$) affected by fertilizer-K rate at all three locations, and the effect on petiole-K concentration was significant at LMCRS and SAREC, where STK was Very Low and Medium (91–130 ppm), respectively (Table 3). Where the fertilizer-K rate effect was significant, all K application rates resulted in greater tissue-K concentrations than the no-fertilizer-K control, besides the 80 lb K_2O/ac rate at LMCRS, where leaf-tissue K was similar to the control. As expected, average leaf- and petiole-K concentrations in the no-K control increased numerically (not statistically analyzed) as STK increased among the locations (LMCRS < SAREC < RRS). The relative differences in tissue-K between the control and highest application rate also decreased with increasing STK.

The average petiole-K concentrations were 5 to 5.5 times greater than leaf-K concentrations and resulted in greater mean separation among K rate treatments, compared to leaf-K concentration, at LMCRS and SAREC, indicating that petiole-K may be a better indicator of the K nutrition status of cotton at the first flower growth stage. At RRS, however, with Optimum (131–175 ppm) STK, petiole-K did not differ among K rates, whereas differences were observed in leaf-K concentration. It is unclear why leaf-K seems to be more sensitive to changes in K availability, relative to petiole-K, with Optimum STK, whereas petiole-K may be more sensitive at lower STK levels. Tissue data from additional sample timings of these 2023 trials and future studies should help explain changes in K dynamics at different levels of K availability in the soil.

Practical Applications

The 2023 harvest season was the first year of this research, and preliminary results indicate that leaf- and petiole-K concentrations are sensitive to diagnose changes in K availability. In soil with Very Low STK at LMCRS, K fertilization increased cotton yield by up to 24%, showing the importance of adequate K management for profitable cotton production. Data collected in this study is paramount to determining critical tissue-K concentration for cotton, defining the best tissue sampling approach for monitoring K nutritional status, and fine-tuning fertilizer-K rate recommendations. As this research continues, we will have more conclusive information about the K dynamics in soil and plant, cotton response to K fertilization, and the need to update fertilizer-K recommendations for cotton. Results will be disseminated through conferences, crop production meetings, and extension field days in the upcoming years.

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Table 1. Mean (± standard deviation) soil pH, Mehlich-3 extractable nutrients, and soil organic matter (SOM) in the 0–6-in. depth prior to treatment application and planting of cotton K response trials at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS), Milo J. Shult Agricultural Research and Extension Center (SAREC), and Rohwer Research Station (RRS) in spring 2023.

	Location		
Soil property	**LMCRS**	**SAREC**	**RRS**
Soil pH	7.8 (0.1)	5.8 (0.1)	6.1 (0.1)
P (ppm)	31 (1.0)	80 (8.5)	70.8 (15.6)
K (ppm)	53 (4.4)	114 (17.4)	173 (19.8)
Ca (ppm)	1357 (35.4)	501 (34.4)	1346 (204.2)
Mg (ppm)	306 (6.5)	32 (3.6)	215 (33.5)
S (ppm)	7	8	13
Fe (ppm)	315	153	310
Mn (ppm)	217	145	151
Cu (ppm)	2.0	0.9	1.8
Zn (ppm)	2.5	7.3	6.1
B (ppm)	0.5	0.2	0.7
SOM (%)	1.6 (0.05)	1.3 (0.03)	2.0 (0.17)

Table 2. Mean (± standard deviation) seedcotton yield in response to K fertilization rate at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS), Milo J. Shult Agricultural Research and Extension Center (SAREC), and Rohwer Research Station (RRS) in spring 2023.

	Location		
Fertilizer-K rate	**LMCRS**	**SAREC**	**RRS**
(lb K_2O/ac)	------------------------------------	**(lb/ac)**	------------------------------------
0	3275 (142) c[†]	2930 (362)	1728 (342)
40	3697 (311) b	3326 (604)	2284 (187)
80	4053 (162) a	3507 (624)	2335 (282)
120	4045 (241) ab	3435 (495)	2098 (241)
160	4019 (361) ab	3273 (596)	2261 (137)
200	4158 (282) a	3329 (561)	2247 (347)
P-value	0.0031	0.7496	0.2390
C.V. (%)[‡]	7.9	19.2	14.9

[†] Different lowercase letters within a site indicate significant differences ($P \leq 0.10$).
[‡] Coefficient of variation.

Table 3. Effects of K fertilization rate (lb/ac) on cotton leaf and petiole-K concentrations at first flower growth stage at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS), Milo J. Shult Agricultural Research and Extension Center (SAREC), and Rohwer Research Station (RRS) during the 2023 growing season.

	Location					
	LMCRS		SAREC		RRS	
Fertilizer-K rate	Leaf	Petiole	Leaf	Petiole	Leaf	Petiole
(lb K_2O/ac)	(%)					
0	0.71 c[†]	3.27 e	0.89 b	4.32 c	1.11 d	6.48
40	0.96 ab	4.36 d	1.12 a	5.52 b	1.21 c	6.78
80	0.89 bc	5.43 c	1.19 a	5.89 ab	1.23 bc	6.79
120	0.98 ab	5.71 c	1.21 a	6.14 ab	1.30 ab	7.00
160	1.19 ab	6.33 b	1.14 a	6.22 ab	1.36 a	7.19
200	1.21 a	7.00 a	1.26 a	6.42 a	1.35 a	7.19
P-value	0.0504	<0.0001	0.0054	<0.0001	0.0002	0.1721
C.V. (%)[‡]	24.3	14.8	10.5	21.5	5.1	12.8

[†] Means were separated according to Fisher's protected least significant difference. Means followed by the same letter in the column indicate no significant difference at the $\alpha = 0.10$ level. Means without letters indicate that the main effect of fertilizer rate was not significant ($P > 0.10$).

[‡] Coefficient of variation.

Potassium Loss by Runoff in Different Cotton Production Systems in Arkansas

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Abstract

Potassium (K) loss by runoff has become a concern for cotton (*Gossypium hirsutum* L.) production in Arkansas. We investigated the transport of K by runoff in rainfed and irrigated cotton production systems and evaluated the contribution of conservation tillage practices in mitigating K losses by runoff. Research was conducted in 2023 on a cotton trial established in 2018 at the University of Arkansas System Division of Agriculture's Judd Hill Cooperative Research Station, Trumann, Ark. The experiment is a 2 × 2 factorial (two irrigation methods × two soil tillage systems). Irrigation treatments are furrow irrigated and rainfed. Tillage systems are conservation with cereal rye (*Secale cereal* L.) winter cover crop and conventional tillage. Soil-test K, cereal rye biomass production, and K uptake were evaluated in Spring 2023, while runoff water K concentration was analyzed from June 2022 to August 2023. Cereal rye biomass was 562 and 1043 lb/ac and contained 14.6 and 29.1 lb K_2O/ac in irrigated and rainfed treatments, respectively. Soil tillage impacted soil-test K among sampling depths, with Mehlich-3 K being 37 ppm greater in the conservation system at the 0–2-inch depth and 19 and 22% lower in the 0–4 and 4–6-inch depths, respectively, compared to conventional tillage. Runoff water K concentration was not affected by the irrigation system but was significantly ($P < 0.10$) affected by soil tillage. The soil conservation system showed 1.5 times greater average K concentration across runoff events (rain and irrigation) than the conventional tillage system, which might be associated with the higher soil-test K near the soil surface in conservation tillage and the dilution of K concentration in runoff water for the conventional system. More conclusive results will be obtained as this trial continues along with the summary of total water loss and cumulative K loss from each production system.

Introduction

The worldwide demand for potassium (K) fertilizer in agriculture has been increasing, and efficient fertilizer-K use is essential due to the limited and minable supply of K. Cotton (*Gossypium hirsutum* L.) is more sensitive to low soil K availability than most other major field crops and requires large amounts of K for adequate growth and fiber development. From the cotton acreage soil sampled and analyzed by the Marianna Soil Testing Laboratory in 2020, only 30% of the samples had above-optimum soil test-K (DeLong et al., 2022), indicating that 70% of the fields would receive a fertilizer-K application, which highlights the need of efficient fertilizer-K use to avoid yield loss and reduce production costs.

While fertilization is paramount to ensure adequate crop production in soils with limited nutrient availability, applying nutrient rates above the crop needs can increase production costs (i.e., expending money on a nutrient without a positive yield response) and enhance environmental concerns. Nutrient runoff from cropland is a significant concern due to risks of water contamination and agriculture profitability. Alexander et al. (2008) estimated that up to 70% of the phosphorus (P) and nitrogen (N) delivered to the Gulf of Mexico originates from agriculture. Studies from the Arkansas Discovery Farm Program in 10 site-years observation in eastern Arkansas have shown that 22–57 lb K_2O/ac/year is lost via runoff from cotton fields (Daniels et al., 2022). The authors reported that, on average, the amount of K loss was equivalent to $15/ac (based on $0.42/lb fertilizer-$K_2O$) being lost solely due to K runoff. These studies highlight the need to investigate crop management practices that retain K in the field so that fertilizer-K inputs can be decreased without losses in crop yield.

Unlike N and P, K has not been reported as a major environmental concern, and studies evaluating K losses from agricultural production systems are scarce. Losing a significant portion of the applied nutrient poses a risk to farming profitability in the long term. Investigating how conservation agricultural practices, such as reduced tillage and cover crops, can mitigate K losses and understanding the fate of the applied K in the soil system are paramount for sustainable and profitable cotton production. The objectives of this study are to i) investigate the transport of K by runoff in rainfed and irrigated cotton production systems and ii) evaluate the contribution of conservation tillage practices in mitigating K losses by runoff.

Procedures

The experiment was carried out during 2023 in a long-term trial initiated in the Fall of 2018, with the first crop year in 2019 at the University of Arkansas System Division of Agriculture's Judd Hill Cooperative Research Station, Trumann, Ark., in a Dundee silt loam soil. The experiment is a 2 × 2 factorial

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(two soil tillage systems × two irrigation methods), with three replications. Irrigation treatments are i) furrow irrigated and ii) rainfed. Tillage system treatments are i) conservation [cereal rye winter cover crop/no-till in rainfed and low-till in irrigated/~30-ft vegetated turn-row buffer strip at the edge of the field] and ii) conventional [re-bedding in spring/no-till in rainfed and low-till in irrigated/cultivated turn-row & field border]. The irrigated conservation treatment plots are considered low-till because a small conservation plow is used to clear water furrows prior to the first irrigation. Cotton (DP 2020 B3XF) was planted on 6 May 2023 on 12-row wide plots that are 520 ft long. Fertilizer-K (80 lb K_2O/acre, as muriate of potash 0-0-60) was broadcast-applied on the soil surface on 7 June to the entire trial area, followed by the first irrigation. Cotton was harvested on 3 October 2023. All crop management practices (e.g., N and P fertilization, pests, and weed control) followed the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations.

Soil samples were collected from each plot before planting at the 0 to 2, 2 to 4, and 4 to 6-inch depths and submitted for pH, Mehlich-3 nutrients, and soil organic matter (SOM) analysis. Soils were dried at 131 °F, passed through a mechanical grinder (Custom Laboratory Equipment Inc., Dynacrush soil crusher model DC-5), and placed through a sieve with 2-mm openings. Soil water pH was measured in a 1:2 soil:water mixture (Sikora and Kissel, 2014), plant-available nutrients were extracted using the Mehlich-3 method (Zhang et al., 2014), and SOM was analyzed by weight loss on ignition (Zhang and Wang, 2014). The nutrient concentrations of extracts were determined using inductively coupled plasma atomic emission spectrophotometry (ICP-AES; Spectro ARCOS III; Table 1).

Following the cotton harvest in the Fall, cereal rye (*Secale cereal* L.) was broadcast seeded on 14 September 2022 on the conservation tillage plots before cotton stalks were shredded. In Spring 2023, tissue samples of cereal rye were collected on 27 March 2023 before termination to measure the aboveground nutrient content of the biomass. Two 10.9-ft^2 cereal rye sections, with visual growth representative of each plot, were composited for cereal rye treatments. Samples were dried to constant moisture, ground to pass a 1-mm sieve, digested with concentrated nitric acid, and analyzed for nutrient concentrations (Jones and Case, 1990).

Water runoff samples were collected from June 2022 to August 2023, following irrigation or rain events, by using automated water samplers and H-flumes (6712, Teledyne ISCO) installed in each test plot. Following collection, water samples were stored on ice and transported to the Delta Water Quality Research Laboratory, Jonesboro, Ark. Water samples were filtered with a 0.45-µm CA syringe filter and stored frozen prior to chemical analyses. Dissolved K concentration (EPA 200.7) was determined at the Arkansas Water Resources Center Water Quality Laboratory using a Spectro Genesis ICP. The total runoff events varied among treatments due to rainfall only or rainfall plus irrigation runoff events imposed by each treatment (Table 2). In addition, operation issues occurred with ISCO automated water samplers during the growing season in some plots, resulting in fewer runoff samples being collected. Hence, only the overall average water runoff K concentration across all runoff events is presented for each treatment in this report.

The experiment was a randomized block design with a factorial arrangement (2 irrigation systems × 2 soil tillage methods). Each treatment was replicated three times, with replicate being a random effect in the analysis of variance (ANOVA) model. ANOVA was conducted to determine the influence of irrigation, soil tillage, and their interaction (fixed effects) on soil-test K and K concentration in water loss by runoff using the GLIMMIX procedure of SAS v. 9.4 (SAS Institute, Cary, N.C.). For the quantification of Mehlich-3 extractable K, ANOVA was conducted separately for each soil depth (i.e., 0-2, 2-4, and 4-6 inches) with replication as a random effect. When the interaction was nonsignificant, one-way ANOVA was conducted. For the quantification of cereal rye biomass production, K concentration, and K uptake, one-way ANOVA was conducted to measure the main effect of the irrigation system. Means were compared using Fisher's least significant difference (LSD) at the 0.10 probability level.

Results and Discussion

Cereal rye produced up to 1043 lb/ac of aboveground dry matter and contained as much as 29.1 lb K_2O/ac in the rainfed treatment, which was 1.9 and 2 times greater than in the irrigated system, respectively (Table 3). The medium-term adoption (five years) of the soil conservation and conventional tillage systems significantly ($P < 0.10$) impacted the distribution of Mehlich-3 K among soil sampling depths. Overall, the soil-test K at the 0-2-inch depth was 37 ppm greater in the conservation tillage system but was 19% and 22% lower in the 0–4 and 4–6-inch depths, respectively, than in the conventional tillage system (Fig. 1). This trend was expected due to surface application without incorporation of K fertilizer and crop and cover crop biomass deposition, which contributes to soil nutrient stratification.

Preliminary results of runoff water K concentration show that runoff water K concentration did not differ between irrigated or rainfed production systems but was significantly affected ($P < 0.10$) by soil tillage (Table 4). Overall, the soil conservation system showed 1.5 times (i.e., 3.4 mg K/L) greater average K concentration across all runoff events (rain and irrigation) than the conventional tillage system. It is worth noting that the range of runoff K concentration was also numerically higher in the conservation system at both irrigated and rainfed cotton production systems (Table 2). This result might be associated with the higher soil-test K values near the soil surface in the conservation system (Fig. 1) and the fact that soil conventional tillage practices tend to result in increased water loss, which dilutes the nutrient concentration in runoff water.

Practical Applications

The results of this report show that crop management practices, such as no-tillage and cover crops, increase soil K stratification with depth over time. While we observed a greater runoff K concentration in the conservation tillage system, no conclusion can be drawn that this system is losing more K. The amount of nutrient loss, such as K, is associated with the volume of water loss, which usually is lower in the conservation system (greater water infiltration) than in conventional tillage. The volume of water loss and cumulative K loss in lb/ac data is currently being summarized and will be included in future reports. As this research continues, more conclusive information will be provided about the fate of fertilizer-applied-K and crop management practices that contribute to mitigating K loss by runoff.

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Table 1. Mean soil pH, organic matter (SOM), and Mehlich-3 extractable nutrients in the 0–6-inch depth in cotton production systems with different soil tillage and irrigation management at the University of Arkansas System Division of Agriculture's Judd Hill Cooperative Research Station, Trumann, Ark., in spring 2023.

	Irrigated		Rainfed	
Soil test	**Conventional**	**Conservation**	**Conventional**	**Conservation**
pH_{water}	6.5	6.5	6.2	6.3
P (ppm)	19	11	18	14
K (ppm)	70	82	85	78
Ca (ppm)	1157	1162	845	1015
Mg (ppm)	175	168	120	149
S (ppm)	5	5	5	5
Na (ppm)	14	11	8	8
Fe (ppm)	149	138	140	162
Mn (ppm)	87	74	71	72
Cu (ppm)	1.4	1.3	1.4	1.7
Zn (ppm)	1.1	1.1	1.0	1.1
B (ppm)	0.2	0.1	0.1	0.1
SOM (%)	2.1	2.1	1.9	2.2

Table 2. Water runoff K concentration means, standard error, median, range, minimum, and maximum values in cotton production systems with different soil tillage and irrigation management at the University of Arkansas System Division of Agriculture's Judd Hill Cooperative Research Station, Trumann, Ark., from June 2022–August 2023.

	Irrigated		Rainfed	
Water Runoff K Concentration	**Conventional**	**Conservation**	**Conventional**	**Conservation**
	---mg K/L--			
Mean	6.3	8.6	5.9	10.4
Standard Error	0.8	1.5	1.8	1.8
Median	5.1	5.3	5.1	9.3
Range	12.0	29.0	13.0	18.0
Minimum	2.0	2.0	0.3	3.6
Maximum	14.0	31.0	13.3	21.6
Number of Runoff Events	22	25	6	9

Table 3. Winter cereal rye cover crop biomass production, K concentration, and K uptake in irrigated and rainfed cotton production systems at the University of Arkansas System Division of Agriculture's Judd Hill Cooperative Research Station, Trumann, Ark., during spring of 2023.

Irrigation	Cereal rye biomass	Tissue-K concentration	K uptake
	(lb/ac)	(%)	(lb K_2O/ac)
Irrigated	562 b	2.2	14.6 b
Rainfed	1043 a	2.3	29.1 a
Average	*802*	*2.2*	*22.0*
P-value	0.0101	0.1890	0.0133
C.V. (%)[†]	16.0	5.8	19.1

[†] Coefficient of variation.

Table 4. Water runoff K concentration in cotton production systems with different soil tillage and irrigation management at the University of Arkansas System Division of Agriculture's Judd Hill Cooperative Research Station, Trumann, Ark., from June 2022 to August 2023.

	Irrigation		
Tillage	**Irrigated**	**Rainfed**	**Average**
Conservation	8.6 (25)[†]	10.4 (9)	9.5 a[‡]
Conventional	6.3 (22)	5.9 (6)	6.1 b
Average	7.4	8.1	
Tillage	---------- 0.0553[§] ----------		
Irrigation	---------- 0.8144 ----------		
Interaction	---------- 0.4686 ----------		
C.V. (%)[¶]	---------- 35.3 ----------		

[†] Values in parentheses indicate the number of runoff events monitored.
[‡] Different lowercase letters next to means indicate significant differences ($P \leq 0.10$).
[§] ANOVA *P*-values for the main effects of tillage, irrigation, and their interaction.
[¶] Coefficient of variation.

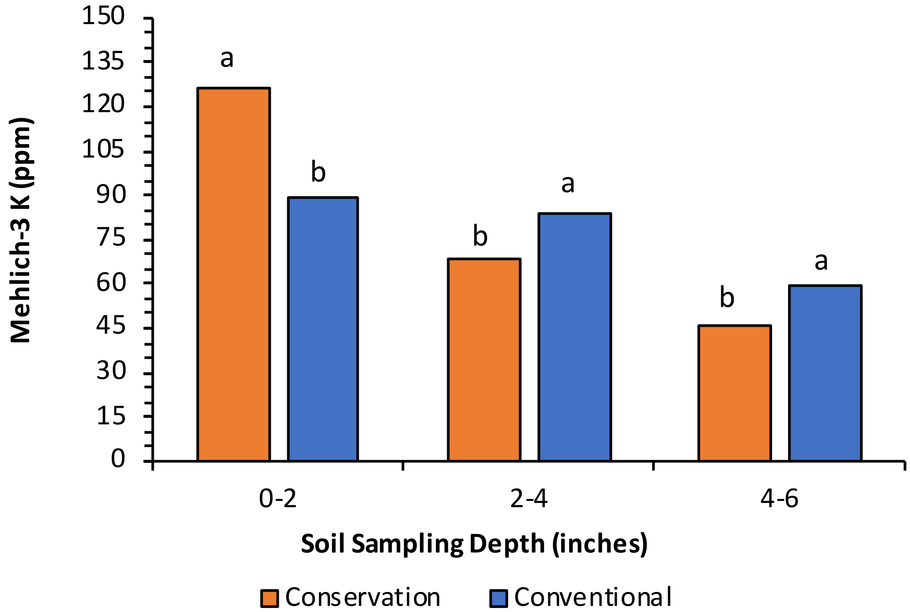

Fig. 1. Soil-test K as affected by different soil sampling depths in conventional and soil conservation cotton production systems. Different lowercase letters indicate significant differences between soil tillage within soil sampling depth ($P \leq 0.10$).

Assessment of In-Field Changes in Soil pH using Gamma-Ray Spectroscopy

O.W. France,[1] A.M. Poncet,[1] and N.A. Slaton[2]

Abstract

Soil testing is widely used to characterize spatial changes in soil pH, but producers are not likely to collect enough soil samples to optimize soil fertility management. Combining soil testing with proximal soil sensing, such as gamma-ray spectroscopy, can help increase soil mapping accuracy with minimum soil sampling labor and cost. However, sensor performance may vary between fields. The objective of this study was to assess the performance of a commercial gamma-ray spectrometer (GRS, or sensor) for proximal sensing of soil pH. Sensor data and soil samples were collected in nine fields from three cropping systems representing a range of soil properties and management practices typical to Arkansas. The GRS pH data were collected and processed using the manufacturer's recommendations and proprietary software. Soil samples were collected at the 4-in. depth using diamond grid sampling in 100 locations within each field, and soil testing was performed for soil pH determination. The data collected in 16 locations per field were set aside and used to assess the sensor performance. The processed GRS pH data that were set aside were post-calibrated using the excluded soil pH values. Statistical analysis was computed to assess the processed and post-calibrated GRS data accuracy. The processed and post-calibrated GRS pH data provided an acceptable estimation of soil test pH in one and three of the nine fields, respectively. Therefore, the manufacturer calibration did not account for all effects driving the site-specific variability in soil pH within the selected fields. In some fields, the post-calibration helped improve the sensor performance, and the collected data could be used together with soil test results to characterize in-field changes in soil pH and execute optimized soil fertility management. Results provided a better understanding of GRS performance and practical applications for Arkansas.

Introduction

Soil pH affects the availability of other nutrients (Nelson, 1968), and strong yield responses to lime application are observed in agricultural fields (Slaton et al., 2006). While correcting soil acidity is one of the most cost-effective ways to improve soil fertility, adequate characterization of spatial variability in soil pH is essential for effective soil fertility management. Such characterization is achieved through soil testing, the backbone of soil fertilization. Soil testing allows for a nearly true determination of soil pH in the sampling locations. Up to a threshold, the greater the sampling resolution, the more accurately in-field changes in soil pH can be gauged, and the more informed the application rate and placement of lime can be.

In Arkansas, whole-field sampling, area-average composite sampling, grid sampling, and zone sampling are all used to assess the nutrient status and pH of fields (DeLong et al., 2022). Grid and zone sampling are specifically used to quantify and map the spatial variability in soil nutrient availability and soil pH that occur in many fields. Yet, few recommendations are available to identify the optimum sampling resolution. Therefore, producers are not likely to collect enough soil samples to generate maps with sufficient accuracy to execute optimized soil fertility management (Mulla and McBratney, 2001). Adequate characterization of spatial variability is required to ensure the accurate placement of inputs. Fortunately, recent technological developments have provided stakeholders with systems that can be used to complement soil sampling and inform soil fertility management.

Gamma-ray spectroscopy is a non-invasive, passive proximal soil sensing method that, when paired with global navigation satellite system technology, can be used to monitor spatial changes in soil texture, pH, and specific nutrient availability with minimum labor (Bierworth et al., 1996; Mahmood et al., 2013). Gamma-ray spectroscopy is used to quantify the gamma signature of three naturally occurring soil radioisotopes: potassium 40, thorium 232, and uranium 238, as well as cesium 137, which is introduced by human activity and commonly used for sensor data calibration (Reinhardt and Herrman, 2019). These soil gamma signatures can be directly correlated with the properties of the soil parent material and indirectly correlated with other soil physical and chemical properties, including soil pH.

Previous research determined that gamma-ray spectrometer (GRS, or sensor) performance may vary between fields and regions and that the collected data may not provide an accurate enough description of site-specific changes in soil fertility to identify the optimum lime and fertilizer application rates (Velasquez et al., 2022). Therefore, additional research is needed to better identify the applications of gamma-ray spectroscopy in Arkansas. The objective of this study was to determine if GRS data provide an acceptable measurement of soil test pH in nine production fields located in the major crop production regions of Arkansas.

Procedures

Experimental Sites

Gamma-ray spectrometer data and soil samples were collected in 2022 or 2023 from nine silt-loam fields located in Conway (fields A to C), Drew (fields D to F), and St. Francis (G to I) counties, Ark. (Table 1). The locations were selected

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to represent typical management practices and field conditions in the River Valley and Mississippi Delta regions of Arkansas. Field size ranged from 25 ac in fields G and H to 50 ac in field B. The dominant soil series were Gallion in fields A and C, Roxana in field B, Rilla in fields D and E, Portland in field F, Calhoun in fields G and H, and Calloway in field I (Soil Survey Staff et al., 2023). The previous crops were corn in fields A to C, cotton in fields D and E, rice in fields F and H, and soybean in fields G and I. The other crops in rotation were soybean in fields A to C, rice and soybean in fields D and E, cotton and soybean in field F, corn and rice in fields G and I, and corn in field H. Cover crop was cultivated after the previous crop in fields A to C, E, and F. Fields A and C were managed using no-till and overhead pivot irrigation. Field B was managed using no-till and no irrigation. Fields D, and G to I were managed using conventional tillage and furrow irrigation. Fields E and F were managed using conservation tillage and furrow-irrigation. Lime was applied in 2020 to field D, and more than 10 years before data collection in fields A to C. Fields E to I do not have a lime application history.

Data Collection and Pre-Processing

In each field, GRS measurements of soil pH were collected using a SoilOptix® commercial sensor (SoilOptix Inc, Tavistock, Ontario, Canada). The raw sensor data were collected along equidistant, parallel passes. The distance between consecutive passes was 40 ft, as specified by SoilOptix Inc. The distance between the GRS and the soil was 3 ft. The raw GRS measurements were recorded at a frequency of five hertz and georeferenced using real-time kinematic positioning (within-field accuracy +/- 1 in.). Soil samples were collected in 100 sampling locations within each field. The soil sampling strategy was diamond grid sampling. The sampling resolution ranged from 4 samples/ac in fields G and H to 2 samples/ac in field D. In each sampling location, the soil samples were collected to a 4-in. depth using the custom-manufactured cone probe described by Drescher et al. (2021). Each 4-in. composite sample was created from 12 cores collected within 15 ft from the sampling locations, respectively. Sampling locations were identified in the field using an EOS Arrow 100 GNSS device (Eos Positioning Systems®, Terrebonne QC, Canada) with submeter accuracy. The real-time GNSS positioning accuracy ranged between 8 and 20 in. Additional soil samples were collected in 1 location per 8 acres for GRS raw data calibration using the same methodology. The additional sampling locations were identified using the SoilOptix Inc. proprietary data collection software. The GRS measurements and soil samples were collected in each field on the same day. All soil samples were submitted to the Marianna Soil Test Laboratory (Marianna, Ark.) for soil pH determination in a 1:2 (v/v) soil-to-water mixture.

The raw GRS data and soil test results from the additional locations were provided to SoilOptix Inc. for processing. The GRS data were processed separately for each field. Empirical calibration and interpolation were performed using proprietary software and algorithms. The processed GRS data were then downloaded from the company's web portal as a point shapefile with a spatial resolution of 335 points/ac. The GRS soil pH value in each diamond grid soil sampling location was calculated as the median processed GRS data found within a 15-ft radius from the sampling location. Such computation was performed in GIS using buffer and spatial intersect functions and resulted in the creation of a data table with 9 fields x 100 sampling locations = 900 rows, and the following columns: fields, coordinates of sampling locations expressed using the World Geodetic System 84 Datum and Universal Transverse Mercator for zone 15 North projection system, soil pH, and associated median GRS pH, referred to as processed GRS pH.

Statistical Analysis

The created dataset was divided into two data subsets using the following methodology. Each field was divided into 16 quadrats so that, on average, approximately 100/16 = 6.25 sampling locations were included within each quadrat (Fig. 1). One sampling location was then selected at random from each quadrat and set aside for statistical analysis. This resulted in the creation of one data subset that included 9 fields x 16 sampling locations = 144 observations, and another data subset that included the 9 fields x (100–16) = 756 remaining observations. Both data subsets also included the following columns: fields, coordinates of sampling locations, soil pH, and associated processed GRS pH. The first data subset containing the 144 observations set aside was used to determine if the processed GRS pH values were an acceptable predictor of soil pH in each field.

Data analysis was computed as follows. The distribution of soil pH and processed GRS pH values were visualized side-by-side using a boxplot and analyzed using an errors-in-variable model, also referred to as a Deming regression model. The Deming regression model was selected because it accounts for errors in observations on both the x- and y-axes when the response and explanatory variables are two empirical metrics, which was the case for our analysis. Soil pH was the response variable. The processed GRS pH values were the explanatory variable. Separate analyses were computed for each field. Residual analysis was performed to verify that the assumption of normality, homogeneity of variance, and lack of spatial correlations (or, in other words, independence) among residuals were verified. Normality was verified using a quantile-quantile plot. Homogeneity of variance was verified by comparing the residual values to the fitted soil test pH values. The lack of spatial correlations among residuals was verified using the Global Moran's I statistic. The processed GRS pH values were an acceptable predictor of soil pH if the Deming regression model residuals were not spatially correlated, the 95% confidence interval around the estimated intercept value included zero (estimation is not biased), and the 95% confidence interval around the estimated slope excluded zero (relationship among variable is statistically significant) and included one (estimation is accurate).

Post-Calibration of the GRS Data

The processed gamma-ray spectrometer data in the first data subset were post-calibrated using the soil pH values from the second data subset containing the remaining 756 observations, the processed GRS data shapefiles, and the following methodology. First, semi-variogram analysis was computed to assess spatial dependencies among the high-resolution processed GRS pH data and the excluded 84 soil pH values in each field. Spatial dependencies were found when the semi-variance between two points varied with distance. When spatial dependencies were found, the corresponding metric—soil pH or high-spatial resolution GRS pH data—was estimated at the 16 selected locations using kriging. Local order 2 polynomial regression fitting (LOESS) was used otherwise. The post-calibrated GRS pH data were then computed using Eq. 1:

$$GRS_{PC,i} = GRS_i + \mu_{ST_{84}} + \left(ST_{INT,i} - \mu_{ST_{INT}}\right) \cdot \frac{\sigma_{ST_{84}}}{\sigma_{ST_{INT}}} - GRS_{INT,i} \qquad \text{Eq. 1}$$

Where $GRS_{PC,i}$ is the post-calibrated GRS value in location i, i is an integer ranging from 1 to 16, GRSi is the processed GRS sensor data in location *i*, μ_{ST84} is the mean soil pH value of the excluded 84 sampling locations, $ST_{INT,i}$ is the interpolated soil pH value in location *i*, μ_{STINT} is the mean interpolated soil pH value in the selected 16 locations, σ_{ST84} is the standard deviation of the soil pH value in the excluded 84 locations, σ_{STINT} is the standard deviation of the interpolated soil pH value in the selected 16 locations, and $GRS_{INT,i}$ is the interpolated GRS sensor data in location i. Equation 1 was created so that the post-calibration process includes two steps: adjustment of the processed GRS value using the interpolated GRS pH and soil pH values, and standardization using the mean and standard deviation of the soil pH values in the 84 excluded locations. Data analysis was then computed to determine if the post-calibrated GRS pH data were an acceptable predictor of the soil test pH values in the 16 selected sampling locations. The distribution of soil test pH, median GRS pH, and post-calibrated GRS pH values were visualized side-by-side using a boxplot. The soil pH and post-calibrated GRS pH data were analyzed using a Deming regression model.

Results and Discussion

Comparison of the Soil Test pH and Processed GRS Data

The median soil pH values were 7.0, 5.8, 6.8, 6.4, 6.8, 6.3, 7.9, 7.7, and 6.6 in fields A to I (Fig. 2). The interquartile range of soil test pH ranged from 6.9 to 7.2, 5.4 to 6.1, 6.5 to 7.0, 6.0 to 6.6, 6.5 to 7.0, 6.1 to 6.6, 7.8 to 8.1, 7.5 to 7.8, and 6.4 to 6.9 in fields A to I, respectively. The median processed GRS pH values were 6.9, 6.4, 6.5, 6.7, 6.5, 6.4, 7.7, 7.5, and 6.7 in fields A to I. The interquartile range of processed GRS pH ranged from 6.8 to 7.0, 6.4 to 6.5, 6.4 to 6.6, 6.6 to 6.7, 6.4 to 6.5, 6.4 to 6.5, 7.6 to 7.8, 7.4 to 7.7, and 6.6 to 6.8 in fields A to I, respectively. Overall, the processed GRS data did not accurately characterize the median soil pH values in fields A to I and consistently underestimated the magnitude of in-field variability in soil pH. The processed GRS data were an acceptable predictor of soil pH in field I (Fig. 3). The processed GRS data were not an acceptable predictor of soil test pH in fields A to H because estimated slope values were not statistically different from zero.

Comparison of the Soil Test pH and Post-Calibrated GRS Data

The post-calibrated GRS pH values were 7.1, 5.7, 6.6, 6.3, 6.8, 6.4, 7.8, 7.5, and 6.6. The interquartile range of processed GRS pH ranged from 6.9 to 7.1, 5.5 to 5.9, 6.2 to 6.8, 6.1 to 6.5, 6.6 to 6.9, 6.2 to 6.6, 7.7 to 8.2, 7.4 to 7.8, and 6.4 to 6.9 (Fig. 4). The post-calibrated GRS data were an acceptable predictor of soil pH in fields B, G, and I (Fig. 5). The post-calibrated GRS data provided a more accurate measurement of the median and variability in soil pH than the processed GRS in all fields. The post-calibrated GRS data were not an acceptable predictor of soil pH in fields A, C, E, F, and H because the estimated slope values were not statistically different from zero. The post-calibrated GRS data were not an acceptable predictor of soil pH in field D because the model residuals were spatially correlated, and the post-calibrated GRS pH data did not explain all site-specific variability occurring in that field.

Practical Applications

The following conclusions were drawn from this study. First, the processed GRS data provided an acceptable estimation of soil pH in only 1 of 9 fields (11.1%). Hence, the manufacturer calibration was not sufficient to account for all site-specific effects affecting the GRS raw data relationships to the soil pH values in most fields. The post-calibrated GRS data provided an acceptable estimation of soil pH in the field previously identified, as well as two additional fields. Therefore, post-calibration of the GRS data using soil pH results can help improve the GRS's ability to characterize the site-specific distribution of soil pH in some, but not all, fields. The post-calibration of already accurately processed GRS data did not affect the GRS data quality. Moreover, the results indicated that gamma-ray spectroscopy does not replace soil sampling. However, in some fields, it may be possible to use this technology together with soil sampling to generate accurate, calibrated, and high-resolution maps of soil pH. Future research will compare the performance of different post-calibration methods and determine the minimum soil sampling resolution needed to adequately post-calibrate the GRS data. Research will also be conducted to evaluate the GRS data accuracy for other soil test metrics, including soil potassium and phosphorus.

Acknowledgments

Project funding was provided by the Arkansas Fertilizer Tonnage Fees administered by the Soil Test Review Board and the University of Arkansas System Division of Agriculture. This work was supported, at least in part, by the USDA National Institute of Food and Agriculture, Hatch project ARK 2734. The authors thank the producers and personnel at the Pine Tree Research Station (Colt, Ark.) for allowing and facilitating data collection for this project.

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Table 1. Experimental sites description and data collection dates. The soil series information was retrieved from the Soil Survey Geographic Database (Soil Survey Staff et. al, 2023).

Field	County	Area	Soil Series	Data Collection Date
		(ac)	(% area)	
A	Conway	40	Gallion (70%), Roxana (30%)	01/26/2022
B	Conway	40	Roxana (51%), Roellen (27%), Moreland (22%)	01/31/2022
C	Conway	40	Gallion (92%), Roxana (8%)	01/13/2023
D	Drew	50	Rilla (57%), Herbert (43%)	02/15/2022
E	Drew	40	Rilla (60%), Herbert (40%)	01/10/2023
F	Drew	27	Portland (71%), Herbert (29%)	04/13/2023
G	St. Francis	25	Calhoun (100%)	04/09/2022
H	St. Francis	25	Calhoun (100%)	11/22/2022
I	St. Francis	30	Calloway (51%), Calhoun (49%)	05/23/2023

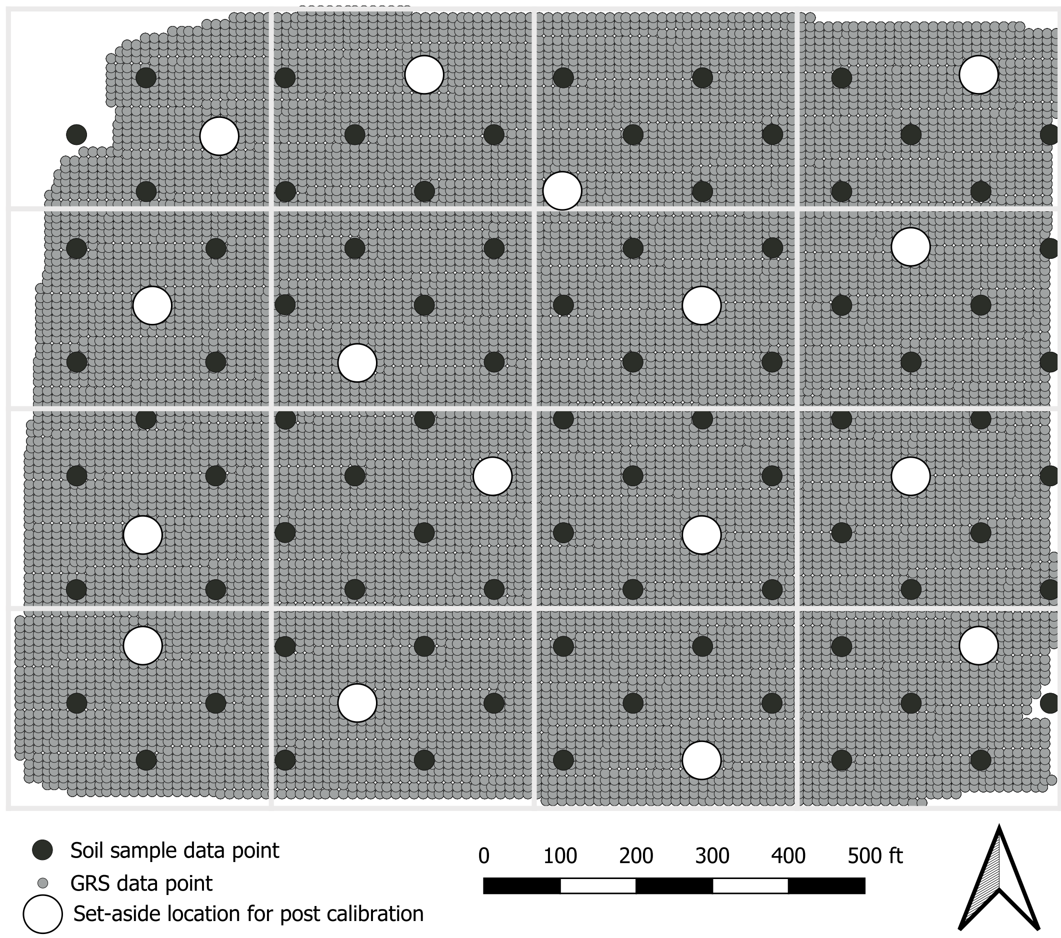


Fig. 1. Fields were divided into 16 quadrats. One sampling location was selected at random from each quadrat and set aside for statistical analysis. The remaining locations were used to post-calibrate the gamma-ray spectrometer (GRS) data in the locations that were set aside. An illustration for field B is provided as an example.

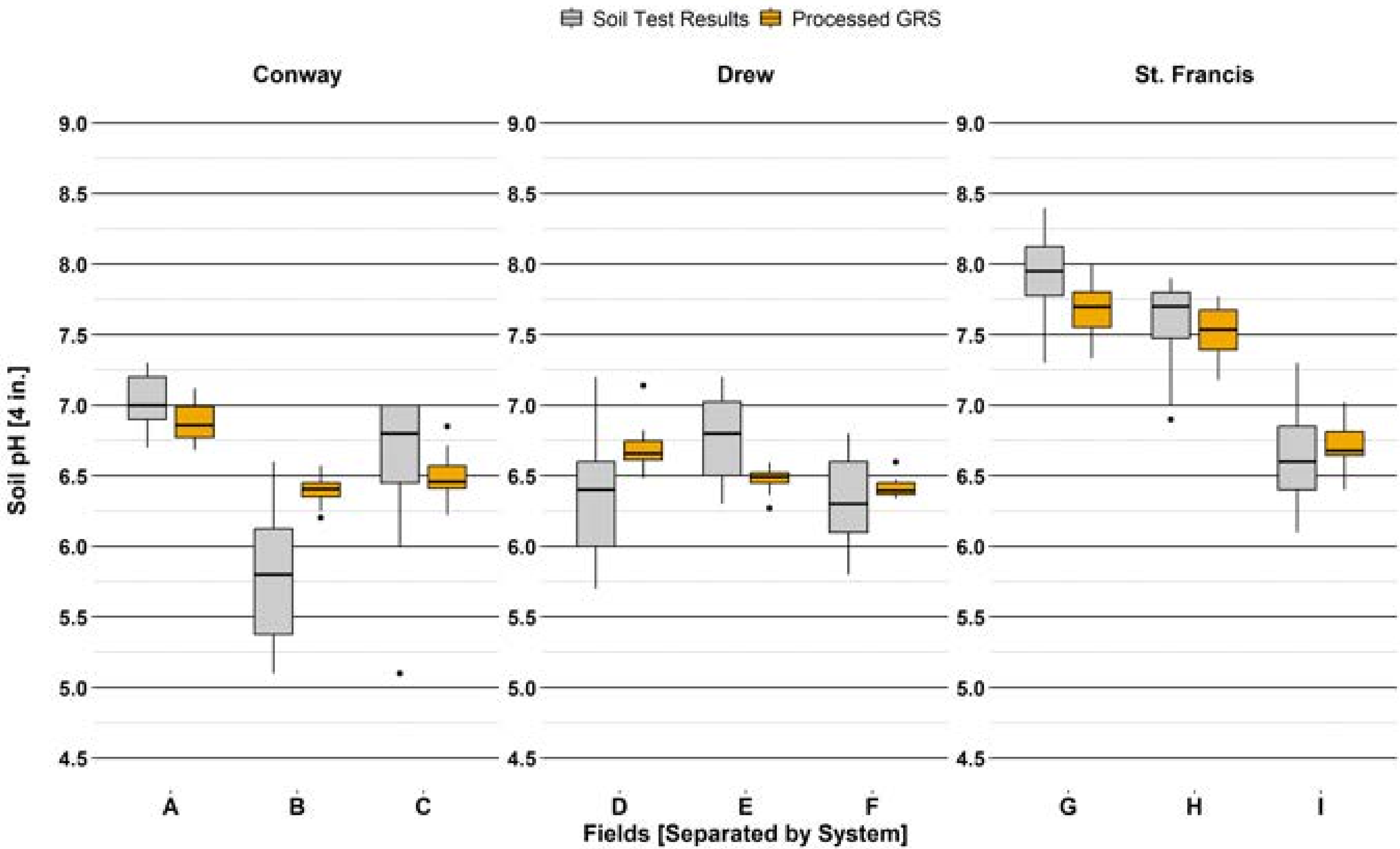
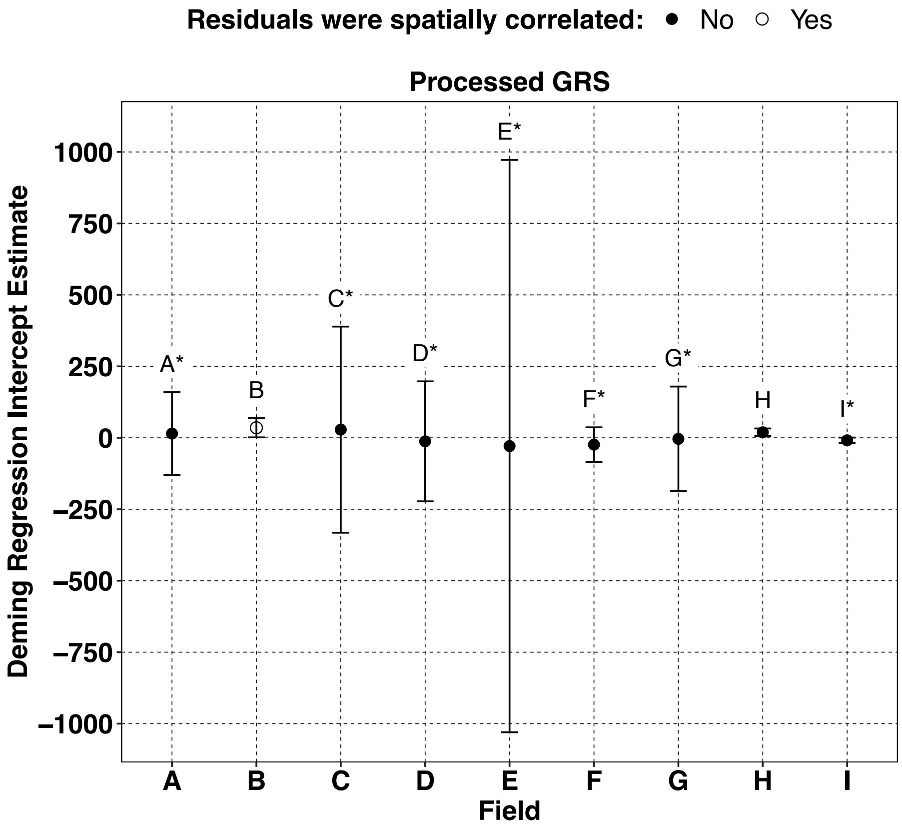


Fig. 2. Distribution of the soil pH and processed gamma-ray spectrometer (GRS) data by field.



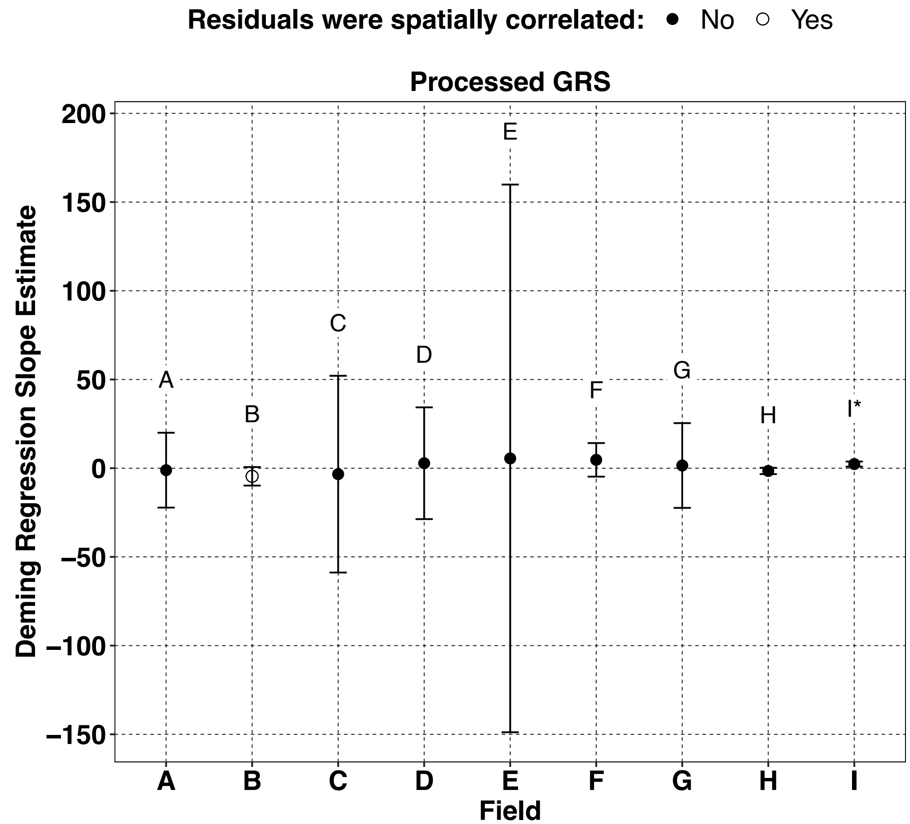


Fig. 3. Estimated intercept and slope values of the Deming regression models computed to determine if the processed gamma-ray spectrometer (GRS) data are acceptable predictors of soil pH in each field. The 95% confidence intervals associated with the model parameter estimates were represented using error bars. The processed GRS data provide an acceptable measurement of soil pH when the 95% confidence interval around the intercept includes zero, the 95% confidence interval around the slope excludes zero and includes 0, and the model residuals are not spatially correlated. When any of the first two criteria were verified, a star was added next to the field name written above the corresponding error bar.

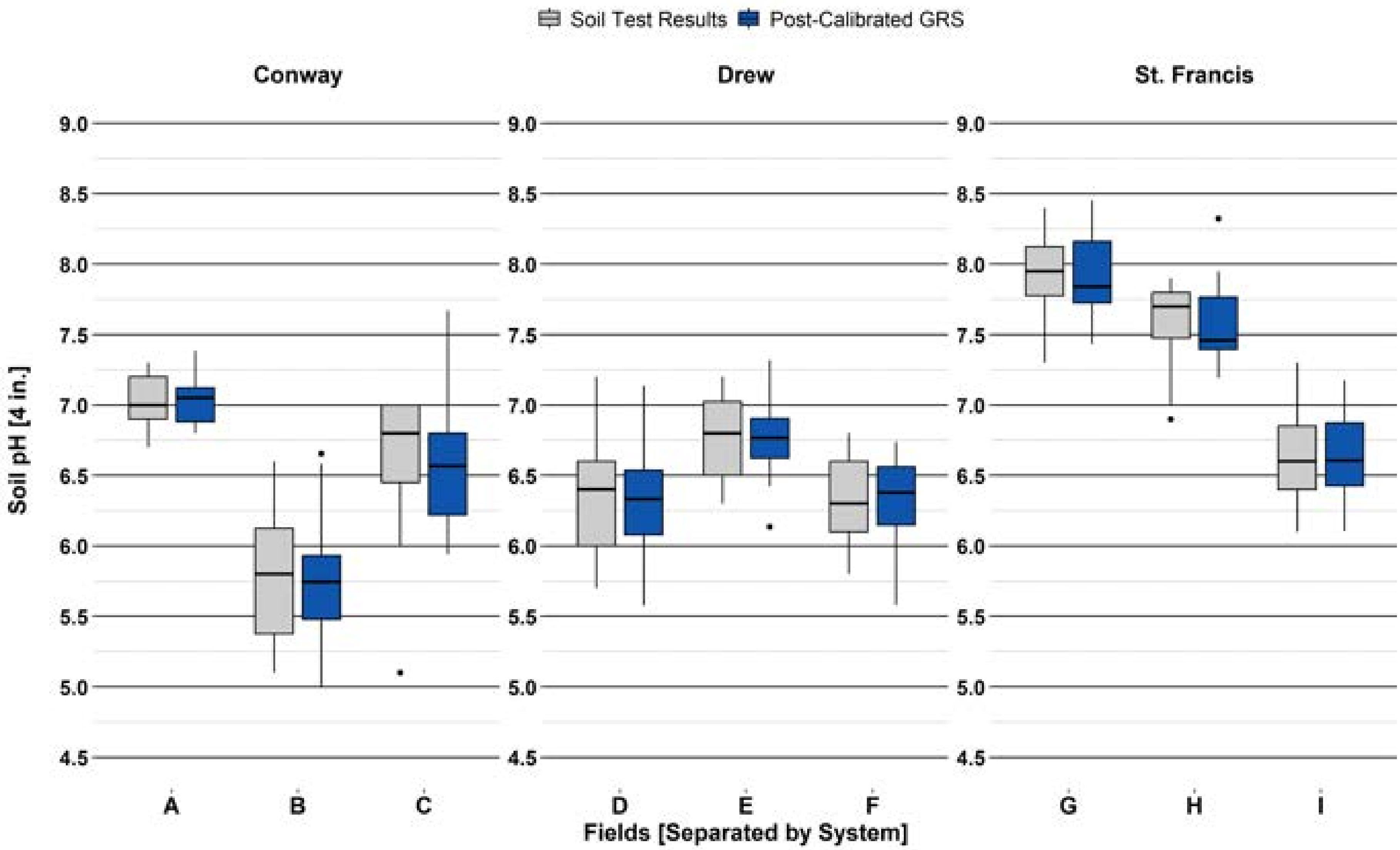


Fig. 4. Distribution of soil pH and post-calibrated gamma-ray spectrometer (GRS) data by field.

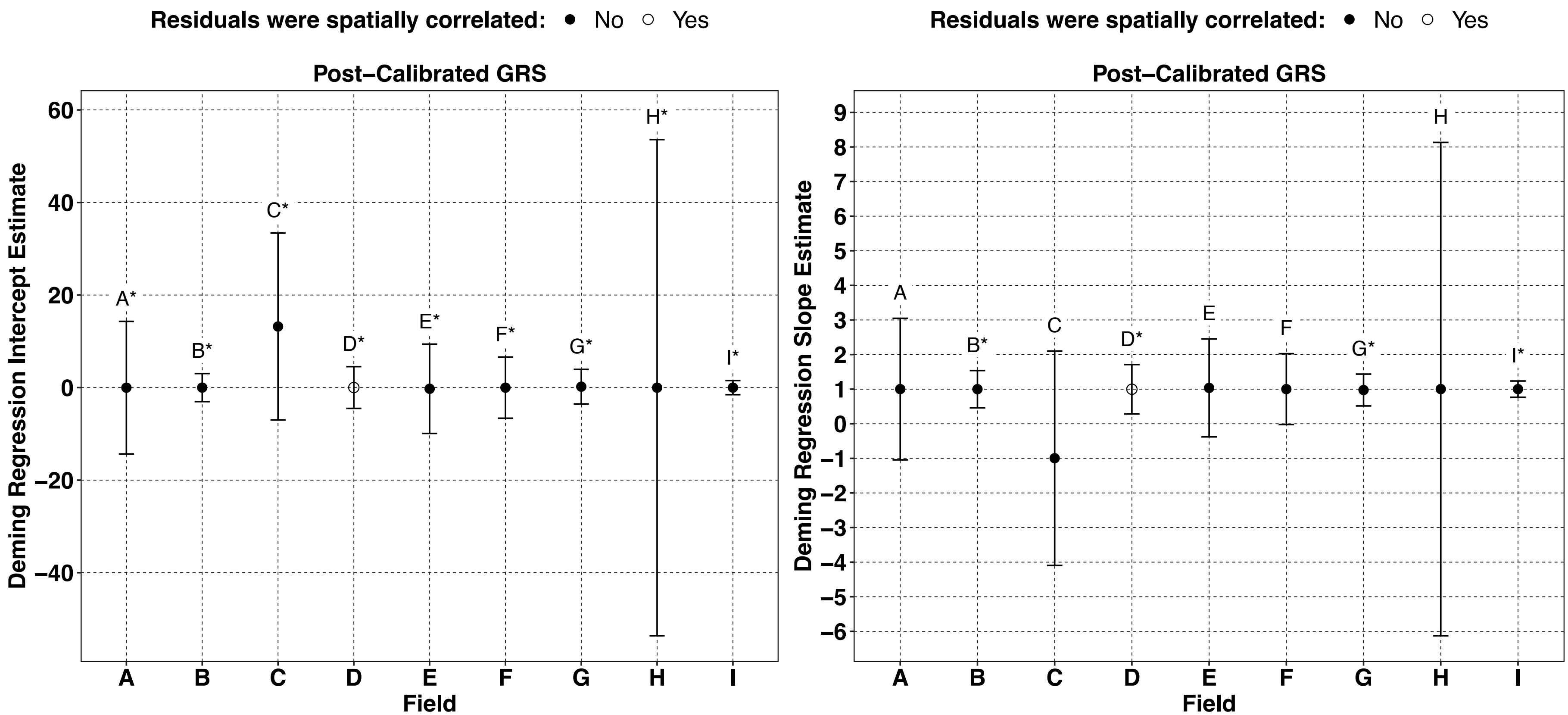


Fig. 5. Estimated intercept and slope values of the Deming regression models computed to determine if the post-calibrated gamma-ray spectrometer (GRS) data are acceptable predictors of soil pH in each field. The 95% confidence intervals associated with the model parameter estimates were represented using error bars. The post-calibrated GRS data provide an acceptable measurement of soil test pH when the 95% confidence interval around the intercept includes zero, the 95% confidence interval around the slope excludes zero and includes 0, and the model residuals are not spatially correlated. When any of the first two criteria were verified, a star was added next to the field name written above the corresponding error bar.

Impact of Nitrogen Fertilization Rate on Two-Year-Old 'Ouachita' Blackberry Yield and Tissue Nutrient Concentration

A.M. Lay-Walters,[1] *T.L. Roberts,*[2] *and A.L. McWhirt*[3]

Abstract

In the southeastern United States (U.S.), the impact of nitrogen (N) fertilizer rates on blackberry (*Rubus* L. subgenus *Rubus* Watson) yield, growth, and fruit quality have not been evaluated. In 2022 and 2023, 6 N rates (0, 30, 60, 90, 120, 150 lb N/ac) were applied via fertigation for 15 weeks to one-year-old Ouachita blackberries in Clarksville, Ark. Plant tissue nutrient samples of primocane and floricane petioles and leaves were collected in alternate weeks throughout the growing season. From late May through early July, fruit harvest was conducted twice a week, and fruit quality parameters were assessed. Floricane yield and fruit quality were not affected by N fertilization rates, except fruit decay after seven days. Nitrogen fertilization rate x sampling date interaction was significant for primocane petiole NO_3-N concentration, where higher N fertilization rates generally had higher petiole NO_3-N concentration than lower rates at several sampling dates. Floricane petiole NO_3-N concentration was not impacted by fertilizer-N rate. However, floricane leaf-N concentration was affected, and the 0 lb N/ac rate had the lowest leaf-N concentration but was not significantly different from other treatments except the 120 and 150 lb N/ac rates. Our first-year observations agree with previous research findings that blackberry primocanes are impacted more immediately by in-season N application compared to floricanes. Our second-year observations concur with existing literature that we would see differences in the N concentration of floricane tissue after a previous year's application of differing rates of N fertilizer. This trial will be continued through 2024 to study the impact of N rate on yield, fruit quality, leaf and petiole nutrient concentration, and cane characteristics in perennial blackberry production to identify a recommended N fertilization rate and the associated leaf- and petiole-N sufficiency ranges for blackberry in Arkansas.

Introduction

In the southeastern United States (U.S.), commercial blackberry (*Rubus* L. subgenus *Rubus* Watson) growers generally base their in-season fertilizer-N application rates on tissue nutrient analysis of primocane leaves collected the previous year in late July to early August when leaf tissue nutrient results are most stable (Strik and Vance, 2017). These results, combined with periodic soil testing and observations of annual growth, have generally been relied on to guide N fertilizer application (Strik and Bryla, 2015). Fertilization management in blackberries can be complicated by the unique biennial growth cycle (Strik, 2017a). In the first year of growth, plants produce primocanes that are generally vegetative, not producing flowers or fruit (Strik, 2017a). Primocanes overwinter and, the following year, become floricanes, bearing fruit in the early to mid-summer. Floricane-fruiting blackberries predominate Southeastern blackberry production; however, there are some varieties of blackberries that can produce fruit on primocanes (Strik, 2017a) and are referred to as primocane-fruiting types.

Multiple production guides recommend blackberry producers apply 50–80 lb N/ac (Strik, 2017b; Bushway et al., 2008; Hart et al., 2006; Fernandez and Ballington, 1999; Krewer et al., 1999; Kuepper et al., 2003). These production guides base their recommendations on best estimates and field observations of grower practices and N rates applied on productive farms. Southeastern blackberry production lacks information based on replicated field experimentation to validate the N rates mentioned previously. Thus, our experimental objectives are to 1) verify if current N rate recommendations for Arkansas and Southeastern blackberry production are sufficient and 2) quantify the effects of N fertilization rates on 'Ouachita' blackberry yield, fruit quality, post-harvest fruit attributes, and leaf- and petiole-N concentrations.

Procedures

Tissue culture propagated 'Ouachita' blackberry plugs (Agristarts, Apopka, Florida) were planted in a Linker fine sandy loam (Fine-loamy, siliceous, semiactive, thermic Typic Hapludults; Web Soil Survey, 2022) in May of 2021 at the University of Arkansas Fruit Research Station in Clarksville, Ark. Blackberries were planted in three rows of woven polypropylene black landscape fabric (Pro 5 Weed Barrier, Dewitt, Sikeston, Mo.), at 2.5 ft spacing in-row, trained on a T-trellis system, and watered via drip irrigation tube with 1 gal/hr emitters placed at each plant. Treatments included six N fertilization rates (0, 30, 60, 90, 120, and 150 lb N/ac) applied using ammonium-nitrate (37-0-0) (EuroChem North America Corp., Tulsa, Okla.). In 2021, the year of plant establishment, all plants were fertilized uniformly by hand with 25 lb N/ac. Fertilizer-N rates were divided equally into 15 weekly applications applied through drip irrigation starting 11 April 2023 and continuing until 26 July 2023, with one week not applied. Additionally, the entire experiment was fertigated with 60 lb K_2O/ac using liquid potassium carbonate (0-0-25) (Growth Products Ltd., Valhalla, N.Y.) split equally over 13 weeks. Based

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on soil test results, no phosphorus (P) was required. Preliminary soil tests in March 2022 revealed an average pH of 6.1, 83 ppm P, 103 ppm K, 850 ppm Ca, 30 ppm Mg, 7.6 ppm S, 2.8 ppm NO_3-N, and 10.0 NH_4-N.

The experiment consists of six N rate treatments with four replicates, resulting in 24 total plots spread evenly across the three rows. Each plot consists of five 'Ouachita' blackberry plants. Treatments were blocked ($n = 4$) perpendicular to the rows.

Alternate week sampling of floricane and primocane leaf and petiole tissues started on 25 April 2023 after N fertilizer application began and continued until 23 August 2023, which was 3 weeks after the last N fertilizer application. Both leaf blades and petioles were collected from the most recently mature leaves on both primocanes and floricanes. Leaf blades and petioles were separated at sampling and analyzed individually. Floricane and primocane leaf blades were analyzed for total-N concentration (%) via combustion following the methods of Campbell (1992), while floricane and primocane petioles were analyzed for nitrate (NO_3-N) concentration (mg/kg) using a modified Cataldo et al. (1975) method. All samples were processed and analyzed by the University of Arkansas Agricultural Diagnostic Laboratory (Fayetteville, Ark.).

Bi-weekly blackberry fruit harvest began on 8 June 2023 and continued through 13 July 2023. Hand-harvested fruit was sorted into marketable and non-marketable (cull) weights. Average berry weight was recorded by subsampling 25 marketable berries at each harvest for each replicate. Ten berries were randomly collected from the cull fruit to assess the percentage of berries affected by white drupe disorder at each harvest for each replicate. Once a week, two clamshells of fruit were collected from each plot. One clamshell per plot was labeled Day 0 and assessed for decay, red drupelet reversion, and fruit leakage. The second clamshell was labeled Day 7, weighed, then placed in a refrigerator (6.1 °C), and assessed seven days later for weight loss, decay, red drupelet reversion, and fruit leakage.

Data were analyzed in SAS (SAS Institute Inc, Cary, N.C.) using Proc Glimmix and mean separation of response variables was performed using Tukey's honestly significant difference for post-hoc analysis. Treatment effects, sampling date, year, and their interaction were assessed for 19 sampling dates for the petiole NO_3-N data. Significant sampling date (year) by N fertilization rate interactions were analyzed using the slice function in SAS to identify N fertilization rate treatment differences at individual sampling dates. The figures presented were created via JMP Pro 16 (SAS Institute Inc, Cary, N.C.).

Results and Discussion

In November 2022, soil nitrate and ammonium concentration had no significant differences ($P > 0.05$) across N rates at either depth (data not shown). In March 2023, soil nitrate and ammonium concentration had no significant differences ($P > 0.05$) across N rates in the 0–4 in. samples. At the 4–8 in. depth, the soil nitrate concentration of 90 lb N/ac had the highest concentration yet was only significantly different ($P < 0.05$) from 30 lb N/ac. At the 4–8 in. depth, soil ammonium concentration was not significantly different across rates (data not shown).

There were no significant differences ($P > 0.05$) across N rates in marketable yield, cull, total yield, average fruit weight, or white drupelet occurrence (Table 1). Fruit decay after seven days in refrigeration was significantly different ($P < 0.05$) across N rate and year as an interaction (Fig. 1). In 2022, decay was not significantly different across N rates. In 2023, percent decay was significantly higher than all N rates in 2022 (Table 1). In 2023, 90 lb N/ac, 120 lb N/ac, and 150 lb N/ac rates had the highest percent decay and were significantly different than all other rates. The 0 lb N/ac had the lowest percent decay in 2023 but was not significantly different from the 30 lb N/ac rate. Fruit weight loss after seven days in refrigeration was significantly different across N rates. The 90 lb N/ac had the highest percent weight loss; however, it was significantly different ($P < 0.05$) from only the 30 lb N/ac. Fruit chemistry, including pH, soluble solids, and titratable acidity, was not significantly different ($P > 0.05$) across N rates.

Primocane leaf total-N concentration was significantly different ($P < 0.05$) across N rates. The 90 lb N/ac, 120 lb N/ac, and 150 lb N/ac rates had the highest total-N concentrations and were significantly different than 0 lb N/ac. The 30 lb N/ac and 60 lb N/ac rates were not significantly different than any other treatment. Primocane petiole NO_3-N concentration was significantly different ($P < 0.05$) across N rate and date (year) as an interaction (Fig. 2). On two dates (20 June 2023 and 24 July 2023) there were significant differences ($P < 0.05$) in petiole NO_3-N among the N fertilization rates. On 20 June, the 150 lb N/ac petiole NO_3-N concentration was significantly different than 0 lb N/ac and 30 lb N/ac. No significant difference ($P > 0.05$) was observed between the rates 30 lb N/ac, 60 lb N/ac, 90 lb N/ac, and 120 lb N/ac. Due to date being nested in year, please refer to our 2022 Sabbe report (Lay-Walters et al., 2023) for significant differences in petiole NO_3-N concentration observed in our first year. Floricane leaf total-N concentration was significantly different ($P < 0.05$) across N rates. The 90 lb N/ac, 120 lb N/ac, and 150 lb N/ac rates had the highest total-N concentrations and were significantly different than 0 lb N/ac. The 30 lb N/ac and 60 lb N/ac treatments were not significantly different ($P > 0.05$) from any other treatment. Floricane petiole NO_3-N concentration was not significantly different ($P > 0.05$) across N rates. In general, leaf- and petiole-N concentrations were higher in primocanes than in floricanes, and primocane petiole NO_3-N was influenced by N fertilization rate. These findings agree with Strik (2017b) who indicated that for blackberry, in-season N applications are directed toward primocane growth, whereas floricane nutrient concentration is primarily determined the previous year.

Practical Applications

These results confirm that in-season N fertilization rate can impact primocane N status, but the effect of N rate varies over the season. As such, growers should use in-season leaf- and petiole-N concentrations from weekly sampling results with caution. Information based on the results discussed above will be disseminated through academic conferences, grower meetings, and extension field days in the coming year (2024). Simultaneously, the third year of our trial will begin in the Spring of 2024 continuing the methodology mentioned in this report.

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Table 1. Effect of nitrogen (N) fertilization rate (lb N/ac) on marketable, cull and total yield and fruit weight, white drupe occurrence, and decay after 7 days on 'Ouachita' blackberry in Clarksville, Ark. 2022 and 2023.

Effects	Marketable Yield†	Cull	Total Yield	Average Fruit Weight	White Drupe	Decay After Seven Days
	kg per plant	(%)	kg per plant	(g)	% of Fruit	% of Fruit
N Rate (lb N/ac)						
0	2.67	30.86	3.75	6.43	15.95	6.30 c
30	2.66	31.42	3.76	6.38	16.44	7.96 bc
60	2.65	31.99	3.80	6.50	13.51	9.53 abc
90	2.75	32.39	3.98	6.55	15.36	13.90 a
120	2.69	32.97	3.86	6.44	17.79	12.63 ab
150	2.92	30.16	4.05	6.60	14.10	14.69 a
P-value	*0.5943*	*0.3158*	*0.5053*	*0.7054*	*0.4307*	*< 0.0001*
Year						
2022	3.11 a	32.01	4.26 a	6.18 b	14.97 a	1.52 b
2023	2.34 b	31.23	3.50 b	6.80 a	15.97 b	20.15 a
P-value	*< 0.0001*	*0.3081*	*< 0.0001*	*< 0.0001*	*< 0.0001*	*< 0.0001*
Fertilization Rate x Year						
P-value	*0.5594*	*0.0916*	*0.2649*	*0.2569*	*0.3636*	*< 0.0001*

† Means followed by the same letter within the same column and same effect are not significantly different at p = 0.05, as determined by Tukey's honestly significant difference post-hoc analysis.

Table 2. Effect of nitrogen (N) fertilization rate (lb N/ac), sampling date, and year on primocane and floricane leaf-N and petiole NO_3-N concentration of 'Ouachita' blackberry in Clarksville, Ark. from April 2022 to September 2022 and April 2023 to August 2023.

	Primocane†		Floricane†	
	Leaf	Petiole	Leaf	Petiole
Effect	**N**	**NO_3-N**	**N**	**NO_3-N**
N Rate (lb N/ac)	**(%)**	**(mg/kg)**	**(%)**	**(mg/kg)**
0	2.65 b	1073 c	2.29 b	855
30	2.71 ab	1081 bc	2.38 ab	709
60	2.76 ab	1137abc	2.40 ab	805
90	2.81 a	1182 a	2.41 ab	859
120	2.86 a	1174 ab	2.43 a	881
150	2.85 a	1212 a	2.45 a	989
P-value	*0.0048*	*0.0012*	*0.0106*	*0.4804*
Sampling Date (Year)				
P-value	*< 0.0001*	*< 0.0001*	*< 0.0001*	*0.001*
Year				
2022	2.66 a	1144.33	2.34 b	853.48
2023	2.89 b	1159.68	2.45 a	872.57
P-value	*< 0.0001*	*0.4052*	*< 0.0001*	*0.7394*
Fertilization Rate x Year				
P-value	*0.7239*	*0.1585*	*0.6581*	*0.354*
Fertilization Rate x Sampling Date (Year)				
P-value	*0.6014*	*0.0017*	*0.2605*	*0.2512*

† Means followed by the same letter within the same column are not significantly different at *P* = 0.05, as determined by Tukey's honestly significant difference post-hoc analysis.

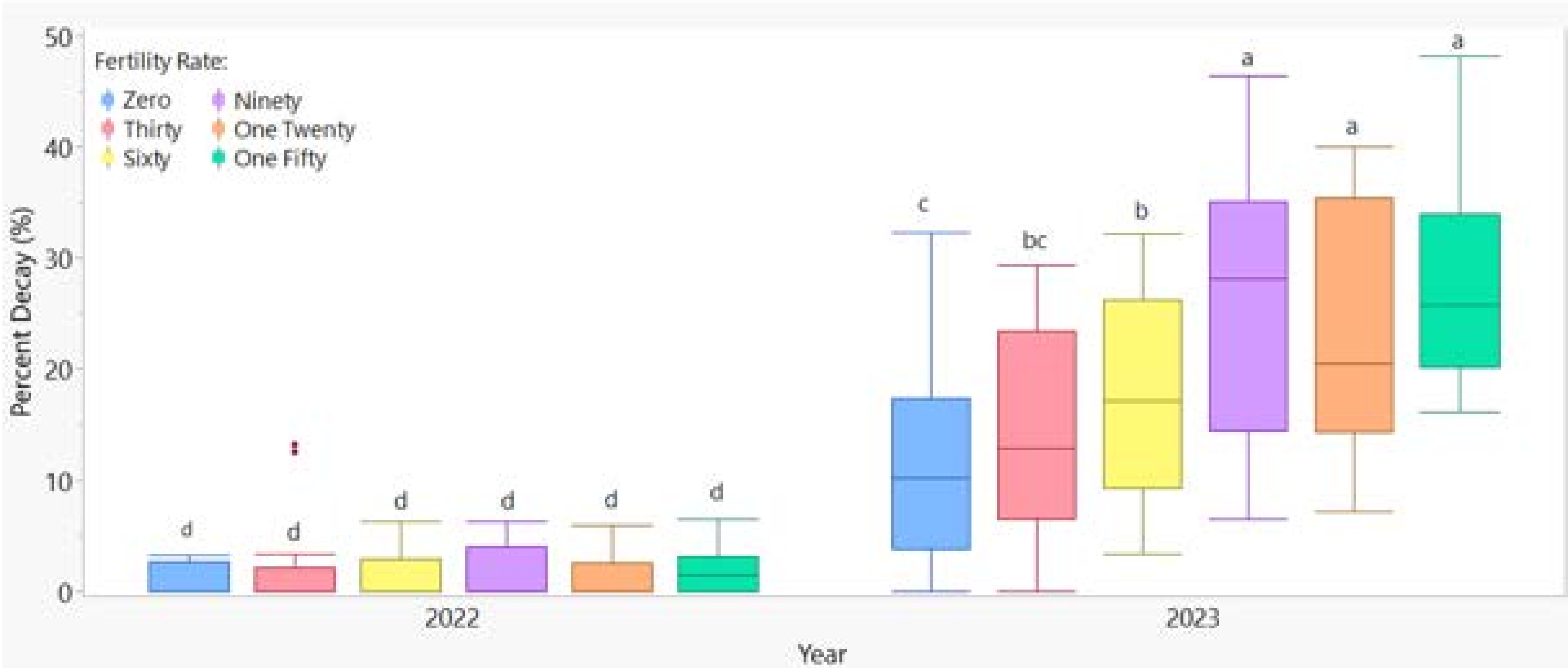

Fig. 1. Interaction effect on percent decay after seven days by N fertilization rate (lb/ac) and year in 'Ouachita' blackberry in Clarksville, Ark. from 2022 to 2023. Boxes with the same letter above them are not significantly different at *P* = 0.05 as determined by Tukey's honestly significant difference post-hoc analysis.

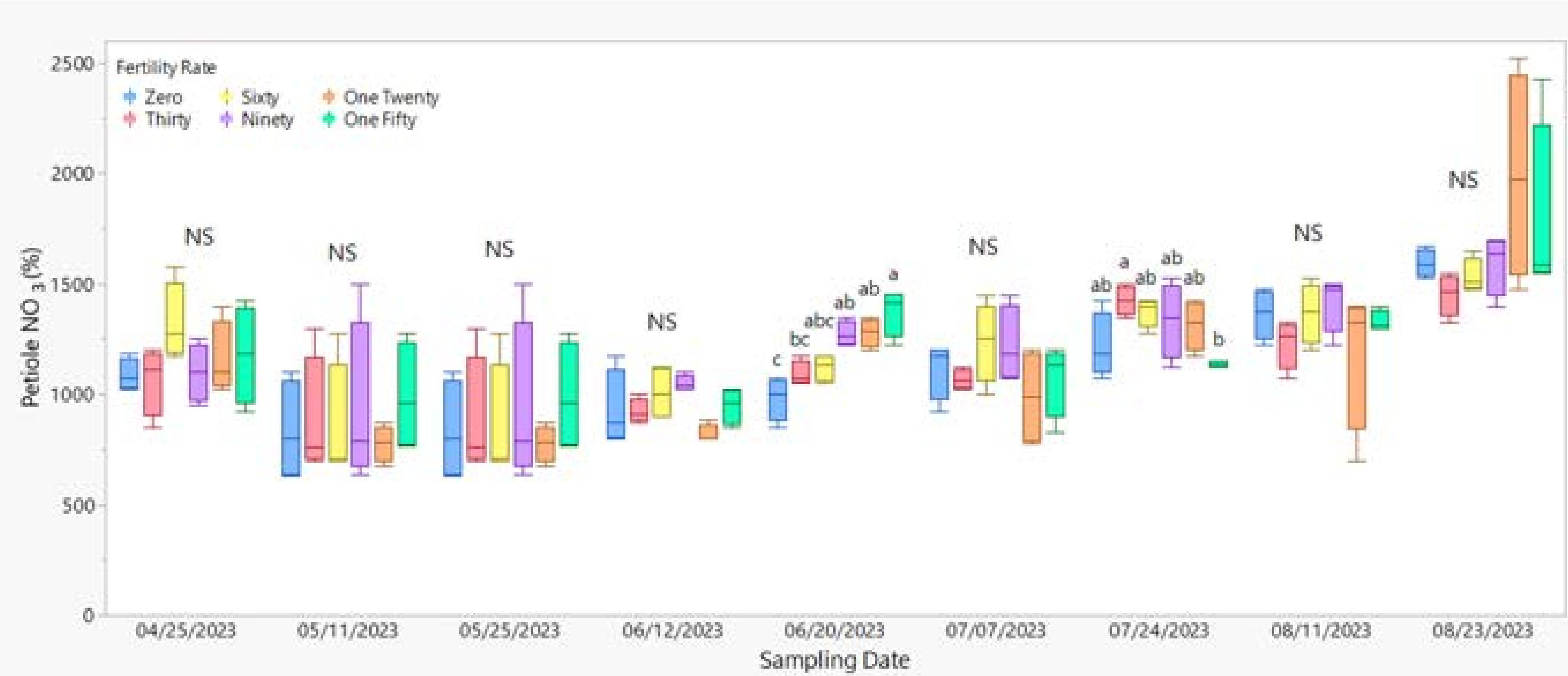

Fig. 2. Interaction effect on primocane petiole NO_3-N concentration by N fertilization rate (lb/ac) and sampling date in 'Ouachita' blackberry in Clarksville, Ark. from April 2023 to August 2023. Boxes with the same letter above them are not significantly different at *P* = 0.05 as determined by Tukey's honestly significant difference post-hoc analysis within the sampling date.

Bermudagrass Forage Yield and Nutrient Removal in Response to Phosphorus and Potassium Fertilization

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Abstract

Soil sampling and fertilization are not commonly performed annually in hay production, but the system removes vegetative material and nutrients from the field each harvest. Sub-optimum P or K availability affects bermudagrass (*Cynodon dactylon* L.) forage yield due to their importance in plant physiological processes. This study aims to monitor bermudagrass yield responses and nutrient removal in response to fertilizer-P and -K rates and to develop optimal fertilizer recommendations for hay production. Field studies were initiated in 2019 and have been repeated every year since then in Batesville and Fayetteville, Ark. 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/ac with split applications occurring at green-up (×1), green-up and following harvest 1 (×2), or green-up and following harvests 1 and 2 (×3). 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/ac, with split applications at the same times as the P trials. Soil nutrient availability and bermudagrass yield and nutrient concentrations were assessed in 2023. Changes in soil-K availability due to long-term fertilizer-K rates significantly ($P < 0.05$) affected forage yield. Overall, 150 lb K_2O/ac treatment increased the forage seasonal yield by 35% and 102%, relative to the no-fertilizer-K control, in Fayetteville and Batesville, respectively. Tissue-K concentrations and K removal increased with increasing fertilizer-K rates. Soil-test P increased with P fertilization in both locations, resulting in greater tissue-P concentrations and P removal. Phosphorus rates ≥30 lb P_2O_5/ac produced an average of 58%, 13%, and 24% greater yield than the no-fertilizer-P control in the first, third, and seasonal total yield, respectively, in Batesville. Sub-optimal P and K fertilization compromises bermudagrass forage yield, while high fertilizer rates build up soil-test levels and increase nutrient removal.

Introduction

Soil management is the basis of agriculture and essential to sustainable forage production systems. Arkansas has 1.3 million acres of hay land, 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. Among the essential plant nutrients, special attention is given to phosphorus (P) and potassium (K) due to their importance in plant physiological processes. Phosphorus is involved in essential plant functions, including energy transfer, photosynthesis, and nutrient movement within the plant, while K has a major role in photosynthesis, water regulation, enzyme activation, and protein synthesis (Marschner, 2012).

Forage fertilization is among the management options with the greatest influence on forage productivity and quality. Surveys indicate that most southern pastures and hay lands are not regularly soil tested and that, of the tested acres, many are deficient in critical soil nutrients (Ball et al., 2015). Hay production systems remove large amounts of aboveground biomass each year, exporting great quantities of nutrients, especially P and K. Furthermore, hay land acres are commonly not fertilized annually and, therefore, may produce suboptimal forage yields that may decline over time. Hence, soil-test P and K values might decrease over time, and deficiencies can subsequently develop if nutrient removal is not replaced with adequate fertilizer rates. However, the extent of warm-season grass yield responses to P or K fertilization may vary according to the forage species, soil, and field management history (Adjei et al., 2001), which requires additional research to evaluate forage yield responses and nutrient removal when subjected to different soils, nutrient availability, and fertilizer-P and -K rates.

This project aims to study how bermudagrass yields respond to different application rates of P and K and to evaluate nutrient uptake in forage through samples collected at each harvest. Inadequate P or K fertilizer might affect the system, as nutrients are extracted from the field in hay faster than they are replenished. On the other hand, excessive application of either P or K fertilizer could lead to unnecessary expenses without enhancing bermudagrass hay yields or forage quality. Thus, the objective of this study is to compare hay yields, nutrient uptake, and soil nutrient concentrations, ultimately helping develop optimal fertilizer recommendations for bermudagrass hay production in Arkansas.

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Procedures

Field studies were established on the University of Arkansas System Division of Agriculture's properties in the spring of 2019 and repeated in 2020, 2021, 2022, and 2023 to evaluate the effects of P and K fertilization on bermudagrass hay yields, nutrient removal, and soil nutrient concentrations. The trials are located in Fayetteville, Ark., at the Milo J. Shult Agricultural Research and Extension Center (SAREC) on a soil mapped as a Pickwick silt loam and in Batesville, Ark., at the Livestock and Forestry Research Station (LFRS) on a soil mapped as a Peridge silt loam. 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 SAREC site in 2012 and that 'Hardie' bermudagrass was sprigged at the LFRS site in 1984. Trials were repeated in each location in 2023, with the plots receiving identical fertilizer-P and -K rate treatments starting in 2019. In 2020, fertilizer-P treatments were misapplied in Batesville, which required establishing a new trial in the spring of 2021 in an adjacent area with the same field management and similar soil physical and chemical characteristics.

Before the fertilizer treatment applications each year, composite soil samples were collected from a 0-to 4-in. depth in each plot, with each composite sample comprised of five to eight 1-in.-diameter cores. Soils were dried at 131 °F, passed through a mechanical grinder (Custom Laboratory Equipment Inc., Dynacrush soil crusher model DC-5), and placed through a sieve with 2-mm openings. Soil water pH was measured in a 1:2 soil:water mixture (Sikora and Kissel, 2014), and plant-available nutrients were extracted using the Mehlich-3 method (Zhang et al., 2014) with nutrient concentrations of extracts determined using inductively coupled plasma atomic emission spectrophotometry (ICP-AES; Spectro Arcos, models 130 or 160; Table 1). Selected fertilizer-P and -K rates for these experiments were based on results from a previously executed study by Slaton et al. (2011). Mehlich-3 plant-available nutrients for each location were presented in previous publications (Bertucci et al., 2020, 2021; Drescher et al., 2022, 2023), but relevant soil Mehlich-3 extractable P and K values from 2019, 2020, 2021, and 2022 are presented again for context. Because soil-test P and K values were expected to vary in response to each of their respective fertilizer-rate treatments, soil-test P and K are shown by treatment for each site-year in Table 2 instead of bulked averages in Table 1.

In the K trials, fertilizer-K was applied over two or three applications to reach cumulative season-total rates. Muriate of potash (60% 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/ac, with split applications occurring at green-up and following the first harvest (×2), or at green-up and following the first and second harvests (×3). 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 30 May and 15 June, 7 July and 25 July, and 14 September and 21 September at Fayetteville and Batesville, respectively.

A blanket application of 150 lb/ac of triple superphosphate (46% P_2O_5) was applied at green-up, for a season total of 69 lb P_2O_5/ac. Nitrogen fertilizer [granulated urea (46% N) treated with N-(n-butyl) thiophosphoric triamide (0.89 g NBPT kg^{-1} urea)] was applied at 130 lb urea/ac in three split applications occurring at green-up, after the first harvest, and after the second harvest, for a season total of 180 lb N/ac.

In the P trials, fertilizer-P was applied over one (×1; at green-up), two, or 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/ac, with split applications occurring at the same dates and timings as the K rate trial for each respective site. Blanket applications of 125 lb/ac of muriate of potash were applied at green-up, after the first harvest, and after the second harvest, for a season total of 225 lb K_2O/ac. Nitrogen fertilization was performed identically as described above for fertilizer-K experiments.

Each trial at Batesville received 725 lb/ac of pelletized lime on 15 March 2023 to maintain soil pH at adequate levels for bermudagrass plant growth, while the trials in Fayetteville each received 968 lb/ac of pelletized lime on 5 May 2023.

Fertilizer-rate treatments were applied by hand to ensure no contamination between plots. Fertilizer-rate treatments were pre-weighed and broadcast by hand in each plot (10 ft × 24 ft) at the previously indicated timings. Blanket fertilizer applications were pre-weighed for the entire experimental area of each trial and each site (7,200 sq. ft.) and broadcast in two directions using a hand-cranked rotary spreader.

Plots were harvested using a self-propelled zero-turn mower (Model T25i, Walker Manufacturing Company, Fort Collins, Colo.) adjusted to a 2.5-in. cutting height. The harvested area of each plot was calculated using the cutting width of the mower (3.0 ft) multiplied by the distance cut (approximately 20 ft after end-trimming plots) within each plot, which was measured and recorded after each harvest. The fresh weight of harvested biomass for each plot was measured immediately after each cutting, and subsamples (~250 g) were collected from each plot, weighed fresh, dried at 131 °F, and weighed again to determine bermudagrass biomass moisture content. Hay yields in this summary are all reported as dry matter yields. The total hay yield was calculated by summing dry matter yields per harvested area from each harvest within a season. After drying, plant tissues were ground to pass a sieve with 1-mm openings, digested with concentrated HNO_3 and H_2O_2 (Jones and Case, 1990), and the concentrations of P, K, and other nutrients in the digests were determined by ICP-AES.

Each fertility study was conducted as a 2×6 factorial with two locations and six fertilizer-rate 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 treatment with location, while the replication 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.). Forage yield data from 2023 were analyzed separately by harvest and summed to analyze the total harvest. Means associated with fertilizer-rate treatments at each location were of greater interest than combined means across locations; thus, a separate analysis of variance (ANOVA)was conducted and reported for each location. Means were separated using Fisher's protected least significant difference ($P < 0.05$). 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

The results included in this report represent the fifth year of fertilizer-K and -P rates applied to the same plots in Fayetteville trials and the fifth and third year of fertilizer-K and -P rates, respectively, applied in Batesville.

Potassium Fertilization

Mehlich-3 extractable K was significantly ($P < 0.05$) affected by fertilizer-K rates in Batesville and Fayetteville (Table 2). The soil-test results at both locations indicate that the soil-test K is increasing as the fertilizer K-rate increases. This pattern has been detectable since the second year of this field study in both locations. The 2023 soil-test results show that the K level among fertilizer-K treatments at both locations was Very Low in the no-fertilizer-K control, Low with 70 lb K_2O/ac, and Optimum or Above Optimum when ≥225 lb K_2O/ac is applied annually.

The changes in soil-K availability due to long-term fertilizer-K rates applied to the same plots resulted in significant ($P < 0.05$) bermudagrass forage yield differences among fertilizer rate treatments (Table 3). Generally, the greatest yields observed either as isolated harvests or accumulated season yields occurred for treatments receiving ≥150 lb K_2O/ac in Fayetteville and ≥70 lb K_2O/ac in Batesville. Considering the total forage yield in the 2023 harvest season, we observed that the treatment of 150 lb K_2O/ac resulted in forage yield increases of 35% and 102%, relative to the no-fertilizer-K control, in Fayetteville and Batesville, respectively. However, it is important to note that plots receiving 70 lb K_2O/ac in Batesville (77% increase relative to the control) did not result in significant differences in accumulated season yields compared to greater fertilizer-K application rates. Therefore, the results suggest that effective management of fertilizer K is a crucial component for achieving profitable forage production.

Bermudagrass forage-K concentration significantly ($P < 0.05$) increased as the fertilizer-K rate increased (Table 4). In addition, the total K removal with bermudagrass forage increased as the fertilizer-K rate increased, with values ranging from 59 to 172 and 43 to 224 lb K_2O/ac among fertilizer-K rate treatments in Fayetteville and Batesville, respectively.

It is worth highlighting that the plots receiving 375 lb K_2O/ac in Fayetteville and Batesville removed about 20% and 75% more K from the field, respectively, without increasing bermudagrass yield compared to the treatment receiving 150 lb K_2O/ac in Fayetteville and 70 lb K_2O/ac in Batesville. Therefore, much of the fertilizer-K applied at the highest K rates resulted in a luxury consumption, removing more K in the harvested forage without yield benefit.

Phosphorus Fertilization

Relative to the mean Mehlich-3 extractable P concentration of 27 ppm prior to initial fertilizer-P treatment application in 2021 at Batesville, soil-test P in 2023 decreased to the Low (16–25 ppm) soil-test category without fertilizer-P application but increased with increasing fertilizer-P application rates (Table 2). After the second year of fertilizer-P application, soil-test P was significantly ($P < 0.05$) greater than the no-fertilizer-P control at application rates ≥60 lb P_2O_5/ac. Soil-test P, among the P-rate treatments, is now in the Low (0 lb P_2O_5/ac), Medium (26–35 ppm; 30 lb P_2O_5/ac), Optimum (36–50 ppm; 60 and 90 lb P_2O_5/ac), and Above Optimum (>50 ppm; 120 and 150 lb P_2O_5/ac) categories, indicating that soil-test P can be adjusted to adequate levels with correct P fertilization. In Fayetteville, soil-test P values are in the Above Optimum soil-test P level and show significant ($P < 0.05$) differences due to the annual fertilizer rates applied in the last four years (Table 2). Fertilizer-P application increased soil-test P, regardless of rate, relative to the control, with the lowest soil-test P values observed in the 30 lb P_2O_5/ac treatment, followed by the 60 and 90 lb P_2O_5/ac rates, and greatest for the 120 and 150 lb P_2O_5/ac treatments, indicating that soil-test P is building rapidly.

No significant ($P > 0.05$) bermudagrass yield responses to P fertilization were observed for individual hay harvests in the Fayetteville P trial in 2023 (Table 5). However, although unexpected for soil with Mehlich-3 extractable P at the Above Optimum level, there was a significant season total forage yield response to fertilizer-P rate (Table 5). Treatments receiving ≥120 lb P_2O_5/ac increased forage yield by 15%, relative to the no-fertilizer-P control, while application rates less than 120 lb P_2O_5/ac resulted in similar yields to the control.

In contrast to the Fayetteville site, the bermudagrass forage yield was significantly ($P < 0.05$) affected by the fertilizer-P rate in Batesville at all three harvests as well as the season total (Table 5). Treatments receiving fertilizer rates ≥30 lb P_2O_5/ac produced maximum yields with an average of 58%, 13%, and 24%, greater than the no-fertilizer-P control, in the first, third, and seasonal total yield, respectively. These results show that sub-optimal P supply impacts bermudagrass growth, resulting in significantly lower forage yields.

Fertilizer-P rate influenced bermudagrass tissue-P concentrations at the first forage harvest in Fayetteville and all the forage harvests in Batesville (Table 6). In Fayetteville, the application of ≥120 lb P_2O_5/ac removed an average of 57 lb P_2O_5/ac in the harvested forage, which is 21% greater than the no-fertilizer-P control treatment, while removal with application rates <120 lb P_2O_5/ac did not differ from the control. In Batesville, the application of ≥90 lb P_2O_5/ac removed an average of 58 lb P_2O_5/ac, which is 71% greater than the no-fertilizer-P control treatment. Application rates of 30 and 60 lb P_2O_5/ac at Batesville also resulted in greater P_2O_5 removal than the control, averaging 49% greater removal than the control.

Practical Applications

The 2023 harvest season is the fifth year of continuous fertilizer-K and -P treatments applied to the same plots (except for the fertilizer-P trial that was established in 2021 in Batesville). The results indicate that soil-test K has changed from 2019 (Low) to 2023 (Very Low to Above Optimum) in response to the fertilizer-K treatments, which is reflected in the forage yield, tissue-K concentrations, and total K removal by the harvested forage. Likewise, the three-year fertilizer-P treatments application to the same plots in the Batesville P trial changed soil-test P from Low to Very Low, Medium, Optimum, or Above Optimum, which reflects the overall forage yield, P concentrations in biomass, and P removal observed during the 2023 growing season. Treatments receiving fertilizer rates ≥30 lb P_2O_5/ac produced seasonal yields up to 24% greater than the no-fertilizer-P control, demonstrating the impact of sub-optimal P supply on bermudagrass growth and forage yields. The fertilizer-P trial in Fayetteville has Above Optimum soil-test level (>50 ppm P), and the seasonal yield increase observed with P fertilization is somewhat unusual and should not encourage P fertilization in fields with similar soil-test P values because yield responses are unlikely, as demonstrated in previous reports (Bertucci et al., 2020, 2021; Drescher et al., 2022, 2023).

These results indicate that soil-test values, forage yield, and hay production profitability can change significantly in a few years if fertilizer-K and -P are not managed properly, suggesting that hay growers should monitor forage yields and nutrient removal to ensure that P and K fertilization programs are adequate. It is essential to continue with these studies to understand better the implications associated with sub-optimal P and K fertilization rates in forage production systems, and fine-tuning the fertilizer-P and -K recommendations for bermudagrass hay production provided by the University of Arkansas System Division of Agriculture.

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Table 1. Mean (*n* = 30) soil chemical properties in the 0- to 4-inch depth for each location and fertilizer trial, collected prior to initial fertilizer treatments in 2019, 2020, 2021, 2022, and 2023.

Location	Trial	Year	pH	Mehlich-3 extractable nutrients										
				P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu	B
				ppm										
Fayetteville	**P**	2019	5.6	96	79	918	47	12	22	236	181	8.0	2.6	0.3
		2020	•	–‡	51	946	35	13	7	232	178	7.8	2.6	0.3
		2021	5.6	–‡	63	919	42	13	5	231	179	8.9	2.6	0.3
		2022	5.4	–‡	129	739	43	15	4	207	171	7.9	2.3	0.4
		2023	5.5	–‡	172	586	68	14	4	250	191	8.0	2.0	0.03
Fayetteville	**K**	2019	5.4	72	68	739	45	12	7	203	191	6.2	2.2	0.3
		2020	•	76	–§	776	36	14	7	212	202	6.3	2.3	0.6
		2021	5.5	83	–§	737	36	14	6	206	207	6.7	2.3	0.2
		2022	5.3	91	–§	555	40	15	5	173	181	6.0	2.0	0.3
		2023	5.3	121	–§	530	79	17	4	235	213	6.3	2.2	0.05
Batesville	**P**	2019	5.7	29	66	979	43	16	9	109	309	0.5	0.6	0.3
		2020	•	–‡	68	977	37	12	8	96	271	0.4	0.5	1.1
		2021†	5.1	27	47	612	26	15	5	91	284	0.3	0.5	0.2
		2022	5.3	–‡	117	658	100	17	6	71	212	0.7	0.4	0.2
		2023	5.9	–‡	138	755	177	14	6	88	252	2.0	0.6	0.2
Batesville	**K**	2019	5.6	32	65	947	33	18	8	120	325	0.5	0.6	0.3
		2020	•	24	–§	838	30	13	9	108	283	0.5	0.6	1.2
		2021	5.7	24	–§	880	29	12	6	101	294	0.4	0.6	0.3
		2022	5.5	31	–§	783	39	15	6	81	254	0.5	0.5	0.4
		2023	5.1	38	–§	635	36	15	6	122	318	0.5	0.5	0.4

† New trial established in an adjacent area in 2021.

‡ Soil-test P values as affected by annual P rate are listed in Table 2.

§ Soil-test K values as affected by annual K rate are listed in Table 2.

• = data not available.

Table 2. Mehlich-3 extractable potassium and phosphorus from Batesville and Fayetteville locations in 2019 (before year 1 fertilization), 2020, 2021, 2022, and 2023.†

Seasonal Total	Fayetteville Potassium Trial					Batesville Potassium Trial				
K_2O rate‡	2019	2020	2021	2022	2023	2019	2020	2021	2022	2023
(lb K_2O/ac)	--------------------Mehlich-3 K (ppm)--------------------					---------------------Mehlich-3 K (ppm)---------------------				
0	67	46 d	49 e	62 e	50 d	65	74 cd	50 d	63 e	57 e
70$^{\times2}$	66	53 d	58 e	78 e	84 d	62	60 d	58 d	72 e	77 e
150$^{\times3}$	63	80 c	100 d	114 d	135 c	64	101 bc	94 c	111 d	114 d
225$^{\times3}$	63	83 c	133 c	165 c	186 b	65	94 bcd	124 b	161 c	159 c
300$^{\times3}$	73	109 b	160 b	211 b	241 a	68	123 ab	201 a	216 b	199 b
375$^{\times3}$	75	140 a	187 a	259 a	286 a	65	160 a	226 a	280 a	313 a
***P*-value**	0.3446	<0.0001	<0.0001	<0.0001	<0.0001	0.6741	0.0007	<0.0001	<0.0001	<0.0001
C.V. (%)	•	•	16.9	12.9	16.6	•	•	17.7	11	14.7
	Fayetteville Phosphorus Trial					**Batesville Phosphorus Trial**				
P_2O_5 rate‡	**2019**	**2020**	**2021**	**2022**	**2023**	**2019**	**2020**	**2021§**	**2022**	**2023**
(lb P_2O_5/ac)	--------------------Mehlich-3 P (ppm)--------------------					---------------------Mehlich-3 P (ppm)---------------------				
0	100	94 bc	97 c	83 d	105 d	27	19	22	22 d	18 c
30$^{\times1}$	92	88 c	96 c	85 d	122 c	29	22	28	32 cd	32 bc
60$^{\times2}$	99	102 abc	113 b	107 c	150 b	27	21	30	38 bc	43 b
90$^{\times3}$	93	107 ab	121 b	127 b	162 b	29	21	25	38 bc	49 ab
120$^{\times3}$	97	109 ab	148 a	151 a	197 a	30	25	31	54 a	68 a
150$^{\times3}$	92	111 a	143 a	156 a	197 a	30	21	23	47 ab	67 a
***P*-value**	0.6608	0.0344	<0.0001	<0.0001	<0.0001	0.7193	0.1015	0.1819	0.0042	<0.0001
C.V. (%)	•	•	10.8	10.6	9.1	•	•	24.5	29.7	32.3

† Means were separated according to Fisher's protected least significant difference. Means followed by the same letter in the column indicate no significant difference at the $\alpha = 0.05$ level. Means lacking letters indicate that the main effect of fertilizer was not significant ($P > 0.05$).

‡ 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 the first and second harvests.

§ New P trial established in an adjacent area in 2021.

• = data not available.

Table 3. Bermudagrass hay yields in response to K fertilization in Fayetteville, Ark., and Batesville, Ark., during the 2023 growing season.†

Seasonal Total	Potassium Trial							
	Fayetteville				Batesville			
K_2O rate‡	Harvest 1	Harvest 2	Harvest 3	Total	Harvest 1	Harvest 2	Harvest 3	Total
lb K_2O/ac	lb forage/ac							
0	659	2,208	2,440 b	5,307 b	1,028	1,695 c	2,057 b	4,779 b
70$^{\times 2}$	789	2,338	2,646 b	5,773 b	2,106	3,114 b	3,234 a	8,455 a
150$^{\times 3}$	1,062	2,461	3,621 a	7,145 a	2,271	3,589 ab	3,790 a	9,650 a
225$^{\times 3}$	1,249	2,141	3,474 a	6,864 a	2,251	3,887 a	3,528 a	9,665 a
300$^{\times 3}$	695	2,585	3,606 a	6,887 a	1,922	3,216 ab	3,866 a	9,003 a
375$^{\times 3}$	761	2,461	3,802 a	7,023 a	2,336	3,051 b	3,790 a	9,177 a
P-value	0.0983	0.2877	<0.0001	0.0005	0.0693	<0.0001	0.0011	<0.0001
C.V. (%)	46.0	14.4	14.5	9.7	38.4	19.1	17.0	16.8

† Means were separated according to Fisher's protected least significant difference. Means followed by the same letter in the column indicate no significant difference at the α = 0.05 level.

‡ 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 the first and second harvests.

Table 4. Bermudagrass forage K concentration and total K_2O removal in response to K fertilization in Batesville and Fayetteville, Ark., during the 2023 growing season.†

Seasonal total K_2O rate‡	Fayetteville				Batesville			
	Forage K Concentration			Total K_2O removal§	Forage K Concentration			Total K_2O removal§
	Harvest 1	Harvest 2	Harvest 3		Harvest 1	Harvest 2	Harvest 3	
(lb K_2O/ac)	(%K)			(lb K_2O/ac)	(%K)			(lb K_2O/ac)
0	1.00 d	1.04 e	0.74 d	59 d	0.71 d	0.85 d	0.69 e	43 c
70$^{\times 2}$	1.31 c	1.54 d	1.25 c	95 c	1.10 c	1.49 c	1.18 d	128 b
150$^{\times 3}$	1.83 b	1.85 c	1.50 b	143 b	1.54 b	1.93 b	1.41 c	193 a
225$^{\times 3}$	1.97 b	2.09 b	1.69 ab	155 ab	1.74 a	2.22 ab	1.61 b	208 a
300$^{\times 3}$	2.04 b	2.14 ab	1.79 a	161 ab	1.79 a	2.45 a	1.83 a	221 a
375$^{\times 3}$	2.34 a	2.33 a	1.80 a	172 a	1.85 a	2.38 a	1.84 a	224 a
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
C.V. (%)	11.1	10.5	12.8	13.7	8.2	17.8	12.4	17.73

† Means were separated according to Fisher's protected least significant difference. Means followed by the same letter indicate no significant difference at the α = 0.05 level. Means lacking letters indicate that the main effect of fertilizer was not significant ($P > 0.05$).

‡ 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 the first and second harvests.

§ Total K_2O removal was calculated by multiplying forage K concentration by dry matter yield at each harvest, multiplying by a K to K_2O conversion factor (1.205), then summing the values from each harvest.

Table 5. Bermudagrass hay yields in response to P fertilization in Fayetteville, Ark., and Batesville, Ark., during the 2023 growing season.†

Seasonal Total	Phosphorus Trial							
	Fayetteville				Batesville			
P_2O_5 rate‡	Harvest 1	Harvest 2	Harvest 3	Total	Harvest 1	Harvest 2	Harvest 3	Total
lb P_2O_5/ac	---lb forage/ac---							
0	1,186	1,932	3,800	6,917 c	1,764 b	3,309 b	4,230 b	9,304 b
30×1	1,280	1,867	3,540	6,687 c	2,738 a	3,764 ab	4,640 ab	11,143 a
60×2	953	2,274	3,922	7,149 bc	2,828 a	3,968 a	4,775 a	11,571 a
90×3	1,129	2,222	4,022	7,373 bc	3,036 a	4,045 a	4,824 a	11,905 a
120×3	1,675	2,224	4,232	8,131 a	2,675 a	3,967 a	4,723 a	11,365 a
150×3	1,464	2,331	4,004	7,799 ab	2,655 a	4,084 a	4,907 a	11,647 a
P-value	0.2517	0.1386	0.2555	0.0029	0.0470	0.0502	0.0400	0.0257
C.V. (%)	40.4	17.2	11.1	7.7	23.2	11.4	7.2	10.8

† Means were separated according to Fisher's protected least significant difference. Means followed by the same letter indicate no significant difference at the α = 0.05 level. Means lacking letters indicate that the main effect of fertilizer was not significant ($P > 0.05$).

‡ 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 the first and second harvests.

Table 6. Bermudagrass forage P concentration and total P_2O_5 removal in response to P fertilization in Batesville and Fayetteville, Ark., during the 2023 growing season.†

Seasonal total P_2O_5 rate‡	Fayetteville				Batesville			
	Forage P Concentration				Forage P Concentration			
	Harvest 1	Harvest 2	Harvest 3	Total P_2O_5 removal§	Harvest 1	Harvest 2	Harvest 3	Total P_2O_5 removal§
(lb P_2O_5/ac)	----------------(%P)----------------			(lb P_2O_5/ac)	----------------(%P)----------------			(lb P_2O_5/ac)
0	0.34 c	0.35	0.25	47 b	0.16 c	0.17 c	0.15 b	34 c
30×1	0.34 c	0.36	0.26	45 b	0.20 ab	0.20 bc	0.18 ab	49 b
60×2	0.36 bc	0.31	0.23	45 b	0.19 abc	0.22 ab	0.18 ab	52 b
90×3	0.36 bc	0.33	0.24	48 b	0.19 bc	0.24 ab	0.20 a	56 ab
120×3	0.39 ab	0.36	0.25	58 a	0.20 ab	0.24 ab	0.20 a	56 ab
150×3	0.41 a	0.34	0.25	55 a	0.23 a	0.25 a	0.22 a	61 a
P-value	0.0036	0.1230	0.1440	0.0008	0.0354	0.0040	0.0495	<0.0001
C.V. (%)	7.9	7.8	8.5	10.2	14.9	14.1	18.7	11.1

† Means were separated according to Fisher's protected least significant difference. Means followed by the same letter indicate no significant difference at the α = 0.05 level. Means lacking letters indicate that the main effect of fertilizer was not significant ($P > 0.05$).

‡ 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 the first and second harvests.

§ Total P_2O_5 removal was calculated by multiplying forage P concentration by dry matter yield at each harvest, multiplying by a P to P_2O_5 conversion factor (2.29), then summing the values from each harvest.

Soil Sampling Cost Versus Benefit with Uniform Rate Technology Versus Variable Rate Technology for Potassium Fertilizer for Soybean

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Abstract

Increasing the number of soil samples collected in a field increases the spatial accuracy of soil test potassium (STK) information. This added information comes at the cost of higher soil sampling charges that are expected to be offset by yield gains or fertilizer cost savings associated with more closely matching field-specific spatial soybean (*Glycine max* L.) potassium (K) needs provided by soil reserves and fertilizer K. Using a 60-ac field near Lonoke, Ark., 65 soil samples were collected in the spring of 2021. Using that information, an STK map with 602 subsections or grids, sized 65 ft x 65 ft, was created using ArcGIS software to produce a fertilizer prescription map. Profit-maximizing fertilizer-K rates were calculated for each of the 602 grids using the Potash Rate Calculator (PRC) with a 75 bu./ac yield target and average crop and fertilizer prices. Simulated soybean yields from PRC for each grid were the basis for calculating field partial returns or yield times the soybean price less costs of fertilizer applied, soil sampling charges of $5.50 per sample, and a fertilizer application upcharge for variable rate technology (VRT) vs. uniform rate technology (URT) of $2/ac to obtain a relative profitability difference between URT and VRT. This process was repeated by successively cutting the number of soil samples in half to make different STK and fertilizer prescription maps that would lead to different relative field profitability estimates. The results of these simulations provided information on the benefits of added soil sampling information in terms of yield, fertilizer use, and profitability of VRT vs. URT fertilizer application. The field had an average (std. dev.) STK of 84 (10.2) ppm, requiring an average (std. dev.) profit-maximizing K fertilizer rate of 178 (17) lb/ac of 0-0-60 fertilizer with VRT at the highest sampling density. Optimum partial returns were obtained using URT application, collecting 5 soil samples leading to the highest relative profitability across sampling and application method strategies.

Introduction

Producers struggle with making profit-maximizing fertilizer rate decisions and whether or not to apply fertilizer i) using spatial prescription maps based on soil test potassium (STK) that vary the fertilizer rate by grid (variable rate technology, VRT) or ii) at a uniform rate (URT) based on the average STK in the field (Lowenberg-DeBoer and Erickson, 2019). Part and parcel to this decision is how many soil samples to collect to build soil maps that vary in accuracy and cost (Lawrence et al., 2020; Finger et al., 2019; Franzen and Peck, 1995). Also, gaining extra accuracy could lead to more or less fertilizer use and yield differences with more costly VRT than URT fertilizer equipment. The answer to this question is complex as yield response to K-fertilizer by soybean is dependent on STK (Marschner, 2012; Slaton et al., 2010; 2013) and because the profit-maximizing fertilizer-K rate also depends on crop price and fertilizer cost. To that end, the Potash Rate Calculator (PRC), available online (Popp et al., 2020; 2021; Oliver et al., 2022; 2023), has assisted producers with making profit-maximizing fertilizer rate decisions at the field level by specifying the average field-level STK, crop price, the cost of 0-0-60 fertilizer, and fertilizer application charges (labor, fuel, equipment, or custom charges per acre).

Spatial variation in STK exists and can be captured using soil mapping software like ArcGIS Pro v. 9.5 (ESRI, Redlands, Calif.) that can subdivide a field into smaller subsections or grids by interpolating soil sample information from sampling sites to grids (Fig. 1). Grid size, interpolation method, and number of soil samples thus impact the accuracy of spatially available STK in a field (Kravchenko, 2003; Mallarino and Wittry, 2004). Grid size depends on how fast equipment can vary application rate along its path and perhaps even across the width of the implement when employing section control such that input is not applied at equal rates across the width of the implement. The intent is to match input use to field conditions that vary spatially so as not to over- or under-apply the input in question.

The objective of this research was to use a sample field and collect soil information at varying levels of accuracy (i.e., number of soil samples) to develop profit-maximizing fertilizer-K prescription maps (that change with STK map accuracy) that could be used for fertilizer application using VRT equipment capable of changing application rate at the grid level vs. URT equipment that would apply at the same profit-maximizing rate for the entire field. Comparing partial returns (revenue less fertilizer and soil sampling costs), relative field profitability across different levels of soil STK mapping accuracy and application method would then reveal the economically optimal choice regarding the number of soil samples to collect and the application technology to choose.

Procedures

Using a 60-ac field near Lonoke, Ark., as an example field, 65 soil samples were collected to assess soil resources of avail-

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able K at a high sampling density (<1 ac/sample) compared to more common sampling densities ranging between 1 to 5 ac/sample (Delong et al., 2013; 2023). This was done to capture spatial variation in STK in detail as shown in the leftmost panel of Fig. 1. The field was broken down into 65 ft x 65 ft grids or subsections with STK values from sample sites interpolated to grids using inverse distance weighting in ArcGIS as is common practice for creating soil maps (Matcham et al., 2021). That grid size was chosen because of the average operating width of fertilizer application equipment (assuming no section control) and the time it takes for application rates to change when equipment travels at 10 mph or 15 ft/sec and a 2 sec lead time for changing application rate (C. Jayroe, pers. comm.).

Using that grid-specific STK, we then employed the PRC tool to provide grid-specific profit-maximizing fertilizer-K rate recommendations in pounds of 0-0-60/ac (K*), assuming a 75 bu./ac irrigated soybean yield potential along with a 2013–2022, ten-year average price for soybean (P) of $10.82/bu. (USDA-NASS, 2023) and a similar ten-year average price for muriate of potash (0-0-60) fertilizer price (FP) of $494/ton (MSBG, 2023). Those grid-specific K* would then lead to yield estimates (Ŷ) using the PRC tool and the soil map with 65 soil samples, representing the best available information, and thereby a per acre revenue projection (Ŷ·P). Subtracting: i) per acre fertilizer cost (K*·FP/2000); ii) an upcharge for VRT application of $2/ac (if VRT was used); and iii) soil sampling charges ($5.50/sample) pending number of soil samples used for the field, would then lead to per acre partial return estimates that varied by application method (VRT vs. URT) and the number of soil samples collected.

The latter variation by the number of soil samples collected was achieved by successively cutting the number of soil sampling sites in half and recreating soil STK maps as shown in Fig. 1. As such, we used 65, 33, 17, 8, and 5 sampling sites for the field (Fig. 1) to assess how many acres were covered with a single soil sample (0.9, 1.8, 3.5, and 12 acres, respectively).

Results and Discussion

The soil maps created using different numbers of soil samples led to the K fertilizer prescription maps shown in Fig. 2. As expected, K* varied more across the field with greater STK map accuracy. Table 1 summarizes the average and standard deviation of STK across the 602 grids, along with yield and K* rate information. Notably, URT fertilizer rates based on STK averages for the field led to profit-maximizing under URT (UK*) that were higher than the average K* for VRT. This is likely a field-specific result, as K* was not normally distributed across space. At the same time, K* and UK* increased with fewer soil samples used for making STK maps. This is again field-specific as sites chosen impacted average STK values. Per acre yields were more variable with K* than UK* application rates. Since yield estimates varied using the 65-sample soil map (to reflect the most accurate STK information), varying input use to maximize profit per grid led to greater yield variability in comparison to using a single profit-maximizing rate. On average, however, yields were very similar between VRT and URT. They decreased with greater soil sampling efforts because of less fertilizer use (as a result of higher average STK) with more accurate soil sampling information.

Net revenue per acre (Ŷ·P–K*·FP/2000) for VRT or (Ŷ·P-*UK**·FP/2000) for URT varied by $0.07/ac for URT and $0.46/ac for VRT across soil sampling accuracy scenarios, with the highest values reported for the most accurate soil sampling information (Table 2). Hence, the VRT application added a maximum of $0.41/ac with the most accurate soil sampling information compared to URT. However, that added benefit for VRT came at the cost of a $2/ac upcharge for VRT vs. URT and thus makes URT more profitable. In terms of soil sampling costs, charges increased from $0.46/ac with the least soil sampling to $6.01/ac with most soil sampling or a difference of $5.55/ac across soil sampling strategies. Since profitability under URT increased by only $0.07/ac and $0.46/ac when employing VRT when moving from least to most accurate soil information, that increase in cost for soil sampling ($5.55/ac) exceeded the benefit attained with added information. Hence, the soil sampling strategy with the least number of soil samples collected was profit-maximizing.

Practical Applications

The profit-maximizing fertilizer application strategy for this field, this crop, and this crop price and fertilizer cost scenario was to apply using URT and minimize the cost of soil sampling. This conforms to assertions made by Lowenberg-DeBoer and Erickson (2019). Splitting the cost of soil sampling across several end uses and perhaps not soil sampling every year can justify spending money on greater STK map accuracy since partial return differences across sampling strategies were small (moving from 5 to 8 samples, for example, cost $0.27 in partial returns at the initial soil sampling charge of $5.50/sample). The $2/ac VRT upcharge for custom application, as reported by Mississippi State University, however, would need to drop substantially before producers can profitably employ VRT K application, again, at least in this field as VRT's maximum benefit compared to URT was only $0.41/ac. Further research is needed to replicate these findings across several fields, other crops, and other fertilizer cost and crop price scenarios to assess how profitable VRT vs. URT and soil sampling accuracy are. As a caveat, the lowest cost sampling strategy may also be somewhat error-prone in the sense that the choice of fewer locations can influence the average STK value for the field more so than with a greater level of soil sampling, as each sampling site affects the average more with fewer samples. This leaves Lawrence et al.'s (2020) quest for an optimal spatial soil sampling density an open question.

Acknowledgments

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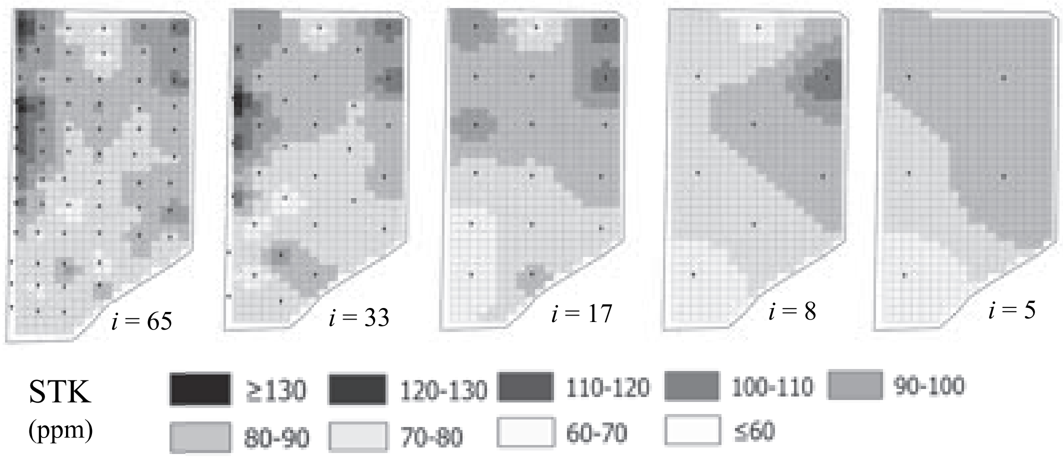

Fig. 1. ArcGIS Pro (ESRI, Redlands, Calif.) soil test potassium maps using inverse distance weighting with 602 – 65 ft x 65 ft grids using (*i*) soil samples and sampling sites (·) of Mehlich-3 extractable soil K values in the top 6 in. soil layer in the spring of 2021, Lonoke, Ark.

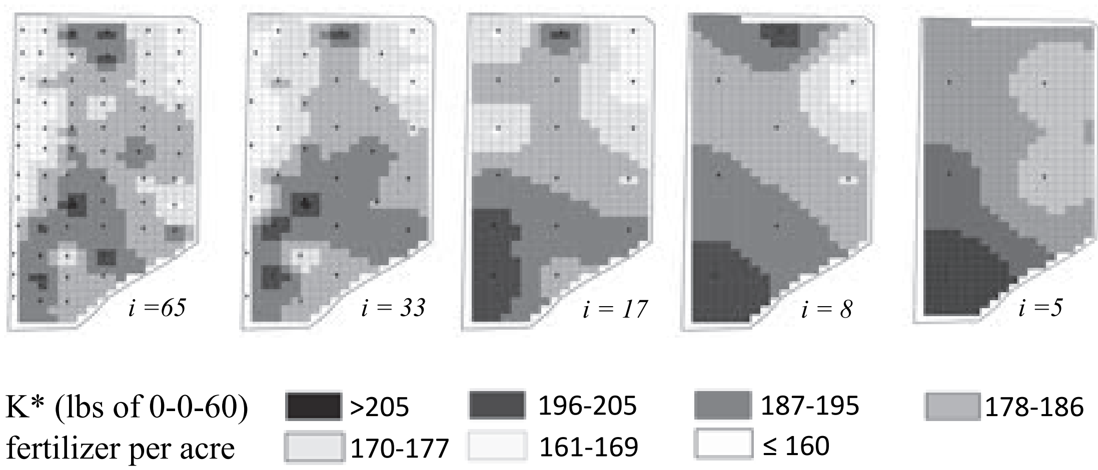

Fig. 2. Profit-maximizing fertilizer-K rates (K*) based on soil test potassium maps with different numbers of soil samples (*i*) and sampling sites (·) for variable rate technology (VRT) application for a 60-ac irrigated soybean field near Lonoke, Ark.

Table 1. Estimated marginal means for Mehlich-3 extractable soil-test K (STK) values in the top 6-inch soil layer and their resultant profit-maximizing K fertilizer rates for variable rate technology (VRT; K*) and uniform rate technology (URT; UK*) using 10-yr average soybean price (P = $10.82/bu.), fertilizer-K cost (FP = $494/ton of 0-0-60), and a 75 bu./ac irrigated soybean yield target and the profit-maximizing rate (PRC) tool to estimate yield at decreasing soil sampling density from left to right in a 60-ac field near Lonoke, Ark., 2021.

	Soil Sampling Strategy				
# of samples (*i*)[a]	**65**	**33**	**17**	**8**	**5**
Statistic	--------------------------------STK in ppm--------------------------------				
Average STK	83.5	82.8	81.2	78.5	79.2
Standard Deviation	10.2	9.7	8.8	8.2	7.2
	-------------------------K* in lb of 0-0-60/ac-------------------------				
Average K*	178	180	182	186	185
Standard Deviation	17	16	12	11	8
UK*	180	181	183	187	186

[a] See Figs. 1 and 2 for soil sampling sites, resultant STK maps, and profit-maximizing VRT prescription maps.

Table 2. The average soybean yield, fertilizer cost, net revenue, and relative profitability or partial return differences by soil sampling strategy [variable *VRT) or uniform (URT) rate technology] and fertilizer application method.

	Soil Sampling Strategy				
# of samples (*i*)[a]	**65**	**33**	**17**	**8**	**5**
Avg. Yield (Std. Dev.)	---------------------------------in bu./ac---------------------------------				
VRT[b]	72.61 (0.30)	72.62 (0.29)	72.67 (0.24)	72.73 (0.23)	72.72 (0.18)
URT	72.61 (0.03)	72.63 (0.02)	72.68 (0.01)	72.75 (0.00)	72.73 (0.00)
Fertilizer Cost	----------------------------------in $/ac----------------------------------				
VRT	44.24	44.52	45.16	46.05	45.91
URT	44.68	44.92	45.43	46.27	46.06
Net Revenue (Y·P-Fertilizer Cost)					
VRT	746.43	746.33	746.15	745.97	745.96
URT	746.02	746.02	746.00	745.95	745.97
Soil Sampling Charges (in $/acre)	6.01	3.05	1.57	0.74	0.46
Partial Return[c]					
VRT	738.42	741.28	742.58	743.23	743.50
URT	740.01	742.97	744.43	745.21	**745.50**

[a] See Figs. 1 and 2 and Table 1 for soil sampling sites, resultant STK maps, profit-maximizing VRT prescription maps, average STK, and fertilizer use.
[b] VRT = variable rate technology with different K* per 65 ft x 65 ft grid. URT = uniform rate technology with UK* applied uniformly across the field.
[c] Partial return = Net revenue – Soil sampling charge – VRT upcharge of $2/ac if using VRT. The highest partial return, highlighted in bold numbers, is the profit-maximizing strategy.

Cotton Response to Nitrogen on Silt Loam Soils

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Abstract

Nitrogen (N) fertilizer is essential to maximize cotton (*Gossypium hirsutum*) yield in most fields across Arkansas, and research regarding optimal rates and timings is limited. Small-plot N response trials were implemented on silt loam soils at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) and Rohwer Research Station (RRS) in 2023. The cotton cultivar DP 2020 B3XF was planted at both locations, and the cultivar DP 2038 B3XF was also planted at the RRS adjacent to the first cultivar. The six N fertilizer treatments included a nontreated control and a split application of 30 lb N/ac applied preplant and incorporated, followed by 90 lb N/ac sidedress to represent a low and high check, respectively. The four additional N applications were made at the first square growth stage and were applied as sidedress applications of 40, 80, 120, and 160 lb N/ac. The Arkansas Extension recommendation for the production region is 110 lb N/ac. Cotton was managed using Cooperative Extension Service recommendations, and yield was determined using a small plot cotton picker and an assumed turnout of 41%. Cotton lint yields at the LMCRS were excellent, reaching >1115 lb/ac for all treatments, and the cotton was responsive to N fertilizer application. At the RRS, cotton yields were suboptimal (<670 lb/ac) but similar to reports from previous years, with only a significant yield response observed in the DP 2020 B3XF cultivar. Yield results for the LMCRS indicate that 80 lb N/ac (yield of 1613 lb /ac) or 30 lb N/ac applied preplant and incorporated, followed by 90 lb N/ac sidedress (yield of 1603 lb/ac.) can be used effectively. These results suggest that N management in cotton can be refined to provide producers with additional options and that in-season N applications can be sufficient to maximize cotton yield potential with no preplant N.

Introduction

Nitrogen (N) fertilizer can be a significant input cost for producers, and its proper management can provide one of the highest returns on investment when done properly. Most soils where non-leguminous row crops are planted will require some level of N fertilization to maximize crop yield. The management of N in cotton (*Gossypium hirsutum*) provides a unique set of challenges that is much different than what is commonly encountered for cereal crops such as corn (*Zea mays* L.) and rice (*Oryza sativa* L.) due to cotton's indeterminate growth habit. Excessive N applications to cotton can result in added vegetative growth that limits yield potential but can also exacerbate the yield loss due to delays in maturity and increased pest pressure (Gerik et al., 1998; Moore, 2008). During the last five years, there has been little research to address the N rates and application timings for modern cotton cultivars in Arkansas. The most recent research conducted by Teague et al. (2022) focused on identifying the need to provide N credits for cotton following peanut (*Arachis hypogea*) in rotation. The results from this trial suggested that sidedress N rates of as little as 80 lb N/ac could be applied without preplant N to achieve maximal cotton yields when following peanut in rotation. The objective of this study was to compare the yield response of cotton to sidedress N applications on silt loam soils in Arkansas.

Procedures

During the 2023 growing season, small plot trials were established at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) near Marianna, Ark., and at the Rohwer Research Station (RRS) near Rohwer, Ark., to assess cotton response to N fertilization. A single trial was conducted at the LMCRS on a Convent silt loam (Coarse-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts; Soil Survey Staff, 2023) and was established on 16 May 2023 using the cotton cultivar DP 2020 B3XF (Bayer CropScience, Monheim, Germany). Two N response trials were conducted at the RRS on Sharkey (Very-fine, smectitic, thermic Vertic Hapludolls; Soil Survey Staff, 2022) and Desha silt loams (Very-fine, smectitic, thermic Chromic Epiaquerts; Soil Survey Staff, 2022) and were established on 17 May 2023 using the cotton cultivars DP 2020 B3XF and DP 2038 B3XF (Bayer CropScience, Monheim, Germany). The previous crop at the LMCRS was soybean (*Glycine max* L.), and the previous crop at the RRS for both trials was grain sorghum (*Sorghum bicolor*). Soil samples (6 cores/composite) were collected from within each replication of the trial from a 0–6 in. depth and composited by replication prior to planting. Soils were submitted to the University of Arkansas System Division of Agriculture's Fayetteville Agricultural Diagnostic Laboratory in Fayetteville, Ark., for analysis. A broadcast application of 50 lb P_2O_5/ac was made at both the LMCRS and RRS locations and applied as triple superphosphate (46% P_2O_5). Additionally, a broadcast application of 140 and 40 lb K_2O/ac was applied as muriate of potash (60% K_2O) at the LMCRS and RRS, respectively. The N treatments for all three locations followed the same N rate and application strategy applied as granulated urea (46% N) treated with N-(n-butyl) thiophosphoric triamide (0.89 g NBPT kg^{-1}

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urea). Nitrogen treatments included a nontreated control, four sidedress N rates of 40, 80, 120, and 160 lb N/ac, and a split application treatment that received 30 lb N/ac preplant and 90 lb N/ac at sidedress. All preplant fertilizers were incorporated into the beds prior to planting. The six N fertilizer treatments were arranged in a randomized complete block design with four replications.

Cotton was established on raised beds and planted at a depth of 0.5–0.75 in. with a target seeding rate of 42,000 seeds/ac. Emergence dates were 24 May 2023 for the LMCRS and 23 May 2023 for the RRS. Each plot consisted of four rows (38-in. row spacing) and a plot length of 60 ft. Cotton was furrow-irrigated and managed by individual research stations using standard production practices as outlined by the University of Arkansas System Division of Agriculture's Cooperative Extension Service. Sidedress N applications were made at the first square growth stage, which occurred on 29 June 2023 and 28 June 2023 at the LMCRS and RRS, respectively. Nitrogen fertilizer was incorporated with irrigation within 2 days of application. The two center rows of each cotton plot were harvested with a spindle-type cotton picker equipped with an electronic weight measurement system. Lint yield was determined based on a standard cotton turnout of 41%.

Results and Discussion

Weather conditions were favorable for cotton establishment at each trial location during the spring of 2023. Cotton stands were adequate and uniform, with emergence occurring roughly one week after planting. During the summer, weather patterns required irrigation at both locations, and the temperatures were conducive to optimal cotton yields. Soil test data for the two research locations are presented in Table 1. Soil pH was near optimal at the LMCRS (6.4) and was alkaline at the RRS (7.7). Soil organic matter was similar at both locations, with the LMCRS being 1.6% and the RRS being 1.7%. Mehlich-3 extractable P was 27 and 25 ppm for the LMCRS and RRS, respectively. Mehlich-3 extractable K was 45 and 151 ppm for the LMCRS and RRS, respectively, and the value for LMCRS indicated that a K fertilizer application was warranted to maximize cotton yield potential.

Cotton lint yield for the three locations is presented in Table 2, and there were significant differences in cotton lint yield amongst the six N fertilizer treatments. The sidedress N rates were selected to assess in-season N management strategies compared to a nontreated control as well as an optimal N fertilizer program of 30 lb N/ac applied preplant and incorporated, followed by 90 lb N/ac applied at the first square growth stage. The cotton lint yields at the LMCRS were almost three times higher than what was observed at the RRS, although the planting dates and at least one of the cultivars used were similar across both locations. As an observation, the overall cotton growth for both cultivars at the RRS was much greater than that at the LMCRS, and the excess growth may have contributed to the reduced yields that were reported.

At the LMCRS, cotton lint yields ranged from 1115 to 1613 lb/ac, with the lowest reported yield occurring in the nontreated control plot that received no N fertilizer. The two highest yielding treatments resulted in cotton lint yields of 1613 and 1603 lb/ac and resulted when 80 lb N/ac was applied in-season at the first square growth stage and for the "optimal" N management treatment that received 30 lb N/ac applied preplant and incorporated followed by 90 lb N/ac at first square. The two highest yielding treatments were not statistically different than the two highest in-season N application rates of 120 and 160 lb N/ac, but did result in a numerical increase in cotton lint yield of roughly 150 lb/ac. The overall cotton lint yields from this trial at the LMCRS were similar to other N trials conducted previously at this location with the only difference being a lower yield reported in the nontreated control by Mozaffari et al. (2015). Cotton yield results at the LMCRS using a well-adapted, high-yielding cotton cultivar indicate that yields can be maximized using a single sidedress application of 80 lb N/ac at the first square growth stage. These findings are similar to what was reported by Teague et al. (2022), who concluded that there was no advantage to N application rates above 80 lb N/ac on loamy sand when cotton follows peanut in rotation.

At the RRS, two well-adapted, high-yielding cotton cultivars were planted adjacent to one another in the same field and received the same N treatment structure. Although the two cultivars were not statistically compared, the yields were similar. For the DP 2020 B3XF cultivar, the cotton lint yields ranged from 467 to 663 lb/ac, with the lowest reported yield occurring in the nontreated control plot that received no N fertilizer. For the DP 2020 B3XF cultivar, the optimal N treatment was excluded from the treatment structure, and only the sidedress N applications were compared. The highest yielding treatment occurred when 120 lb N/ac was applied at the first square growth stage and was not different from the 160 lb N/ac treatment. The maximal yield increase from N fertilizer application for the DP 2020 B3XF cultivar was only 196 lb/ac, suggesting that the responsiveness to N fertilizer at this location was limited by some other factor. For the DP 2038 B3XF cultivar, the yields ranged from 489 to 548 lb lint/ac, and there were no statistical differences amongst N treatments. The maximal yield increase from N fertilizer application for the DP 2038 B3XF cultivar was only 59 lb/ac, suggesting that the responsiveness to N fertilizer at this location was limited by some other factor like what was observed for DP 2020 B3XF. Cotton yield results from the 2022 cotton variety trials at the RRS the previous year reported similarly low yields with a range of 349 to 1018 lb lint/ac (Bourland et al., 2023). The reported yields for DP 2020 B3XF and DP 2038 B3XF from the 2022 cotton variety trial at the RRS were 664 and 477 lb lint/ac, respectively.

Practical Applications

Our research findings, although limited in scope due to the lack of response to N at the RRS, suggest that N management strategies in cotton may be revised. At the LMCRS, where yields were responsive to N applications, it was apparent that several N strategies could be implemented to maximize cotton lint yield. Two N application strategies resulted in similar cotton lint yields at the LMCRS, with one being more of a traditional approach of both preplant and in-season N applications and the other being a sidedress only application. Overall, it appears that producers can apply N at several points during the cotton growing season and maximize yield potential. Future research should focus on refining the use of in-season N application strategies and the development of decision support tools to aid producers in N management. Additional research is needed to verify these results and provide producers with clear N application rates and timings to maximize cotton yield on silt loam soils.

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Table 1. Mean (*n* = 4) soil chemical properties in the 0-to-6-inch depth collected prior to initial fertilizer treatment application and cotton planting in 2023 for trials conducted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) and Rohwer Research Station (RRS).

			Mehlich-3 extractable nutrients								
Location	pH	LOI	P	K	Ca	Mg	S	Fe	Mn	Cu	B
	-	%	(ppm)								
LMCRS	6.4	1.6	27	45	1123	258	5.6	276	176	1.6	1.6
RRS	7.7	1.7	25	151	900	176	7.5	205	79	1.0	1.2

Table 2. Mean (*n* = 4) cotton lint yields as influenced by nitrogen treatment at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) and Rohwer Research Station (RRS) during 2023.

Nitrogen Treatment[a]	LMCRS DP 2020 B3XF	RRS DP 2020 B3XF	RRS DP 2038 B3XF
	Lint Yield (lb/ac)		
0 lb N/ac	1115 c	467 b	489 a
40 lb N/ac SD	1402 b	462 b	548 a
80 lb N/ac SD	1613 a	526 b	545 a
120 lb N/ac SD	1454 ab	663 a	518 a
160 lb N/ac SD	1456 ab	558 ab	500 a
30 PP + 90 lb N/ac SD	1603 a	-	506 a

[a] PP = preplant incorporated nitrogen applications and SD = sidedress nitrogen applications.

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

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Abstract

Cover crops have the potential to affect soil-test P and K concentrations and the following crop's response to fertilization by influencing soil nutrient cycling. This report summarizes year 7 results of a field trial examining the influence of cover crop and fertilizer-P and -K application on corn (*Zea mays*) yield response and soil-test P and K. Research was conducted at 2 locations with soil samples collected from the 0–6-in. depth at cover crop planting in fall 2022 and termination in spring 2023. The sixth annual fertilizer-P and -K treatment applications were made to fertilizer treatment subplots, and corn was planted following cover crop termination. Cereal rye (*Secale cereal*) biomass (2795–4361 lb/ac) contained the equivalent of 20–32 lb P_2O_5 and 72–94 lb K_2O/ac, while biomass from winter fallow treatments at one location averaged 934 lb/ac and contained the equivalent of 8 lb P_2O_5 and 29 lb K_2O/ac. Winter fallow biomass was not sampled at the other location. Dry matter and nutrient accumulation were generally greater with cereal rye than in winter fallow treatments, but fertilizer rate did not influence dry matter or nutrient accumulation. Cover crop did not significantly influence spring soil-test values, but fertilizer rates were consistently reflected in soil-test values following 5 annual applications, with values increasing as rates increased. At one location, corn yields following cereal rye were reduced by 26 and 23 bu./ac in the P- and K-rate trials, respectively, relative to corn following winter fallow. At the other location, grain yields following cereal rye averaged 10 bu./ac greater than corn following winter fallow in the P-rate trial, while yields were unaffected by cover crop treatment in the K-rate trial. Fertilizer-K, regardless of rate, increased yields by an average of 17 bu./ac at one location, but fertilizer rate did not greatly influence yields in the other trials.

Introduction

Winter cover crops have the potential to enhance nutrient availability and cycling, increase soil organic matter (SOM), reduce soil erosion and weed pressure, increase infiltration, and improve soil moisture retention when properly managed in a row crop rotation (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, the cover crop did not influence grain yield or soil-test P and K in samples collected following summer crop harvest (Carver et al., 2017). Cereal rye (*Secale cereal*) did not affect soil-test P or K in the first year of a corn/soybean rotation trial in Missouri, but soil-test P was greater with cereal rye, relative to winter fallow, following the second year of cover cropping (Haruna and Nkongolo, 2020). Similarly, a long-term trial in Brazil 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 the 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. 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 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 the management of long-term plots rotated between corn, cotton (*Gossypium hirsutum*), and soybean cash crops that receive different annual fertilizer-P and -K rates and are grown with or without a cereal rye cover crop to monitor short- and long-term changes in soil chemical properties and soil health. Slaton et al. (2018, 2019) and Smartt et al. (2020, 2021, 2022, 2023) describe the initial soil properties and the soil-test and cash crop responses to cover crop and fertilizer rates across the first 6 years of this project.

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This report summarizes year 7 results focused on examining the effect of cover crop and fertilizer-P and -K rates on corn yield and soil-test values and the influence of cover crop on changes in soil-test values between soil samples collected at cover crop establishment in fall and cover crop termination in spring.

Procedures

Trials were established in 2017 at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS) and Lon Mann Cotton Research Station (LMCRS). The 5.7-ac 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%). The 10-ac field used at LMCRS has soils mapped as Calloway (54%), Loring (28%), and Memphis (1%) silt loam, and Marvell fine sandy loam (16%) (Slaton et al., 2018). Mean soil properties for the no-P or no-K fertilizer control treatments of each trial in 2023 are provided in Table 1. Plots were 4 rows (38-in. 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 without fertilizer treatment application, followed by a cereal rye cover planted at each location in the fall of 2017, an initial fertilizer treatment application in the spring of 2018, and a cotton crop in the 2018 growing season. Soybean was the cash crop in 2019, and the three-year corn-cotton-soybean rotation continued with corn in 2023. Following soybean harvest in fall 2022, cover crop treatments were established by drill-seeding cereal rye (80 lb/ac; 6-in. row spacing) on 1 November at RRS and 3 November at LMCRS. Two composite soil samples, each including 6, 1.0-in. diameter soil cores (0-6 in. depth) from the shoulder of the raised beds, representing the east and west sides of each plot, were collected on 21 December 2022 at RRS and 20 December 2022 at LMCRS. Additional soil samples were collected on 12 April 2023 at RRS and 13 April 2023 at LMCRS to examine the influence of cover crop growth and sample time on selected soil chemical properties. Soil samples were analyzed for soil pH, Mehlich-3 extractable nutrients, and SOM (loss on ignition, LOI) by the University of Arkansas System Division of Agriculture's Fayetteville Agricultural Diagnostic Laboratory at the Milo J. Shult Arkansas Agricultural Research and Extension Center, Fayetteville, Ark.

Tissue samples of cereal rye and winter fallow weeds were collected immediately before cover crop termination on the same dates of spring soil sampling to measure the aboveground nutrient content of the biomass. Two 3-ft sections of a drilled row of cereal rye, having visual growth representative of each plot, were composited for cereal rye treatments, and winter fallow treatments were sampled by collecting all aboveground biomass from a 3.0 ft^2 section of each plot. Winter fallow biomass was not sampled at LMCRS in 2023 due to sparse vegetation with little biomass production. Samples were dried to a constant moisture, ground to pass a 2-mm sieve, digested with concentrated nitric acid, and analyzed for nutrient concentrations. Various winter grass and broadleaf weed species were present in winter fallow treatment plots at RRS, while very few plants were present at LMCRS.

At each location, fertilizer-P treatment rates were 0, 40, 80, and 120 lb P_2O_5/ac (triple superphosphate), and fertilizer-K treatment rates were 0, 60, 120, and 180 lb K_2O/ac (muriate of potash). The sixth annual fertilizer-P and -K 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 1 or 2, respectively, additional passes down the length of the plots. A blanket application of 46 lb P_2O_5/ac was applied to the K trial, and 120 lb K_2O/ac was applied to the P trial at each location with the drop spreader. Fertilizer treatment and blanket P and K applications were made on 3 May 2023, and corn (DKC65-99) was planted at 33,000 seed/ac on 4 May at LMCRS. Ammonium sulfate (21% N and 24% S; 100 lb/ac), zinc sulfate (35.5% water soluble Zn and 17% S; 33 lb/ac), and urea (46% N; 100 lb/ac) were also surface-applied on 3 May, providing 57, 30, and 12 lb/ac of N, S, and Zn, respectively. Additional applications of 110 lb N/acre as urea (46% N) occurred on 19 May and 1 June at LMCRS, for a total of 277 lb N/ac. At the RRS, fertilizer treatments were applied on 3 May, blanket P, K, and ammonium sulfate (21% N and 24% S; 100 lb product/ac) was applied on 4 May, and corn (CP5678) was planted at 33,000 seed/ac on 8 May 2023. Additional applications of 110 lb N/ac as urea ammonium nitrate (32% N) occurred on 22 May and 2 June at RRS, for a total of 241 lb N/ac.

The corn at each location received recommended pest control based on the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations. Corn was harvested on 14 September at LMCRS and on 16 September 2023 at RRS. Corn grain yield was measured by harvesting the 2 middle rows of 139-ft and 125-ft long sections in the middle of each plot at LMCRS and RRS, respectively. Following corn harvest, a 5:1 (w/w) blend of cereal rye and hairy vetch (*Vicia villosa*) was planted on 3 November 2023 at LMCRS and on 9 October 2023 at RRS.

The effect of winter plant growth and nutrient uptake on soil-test P and K was evaluated by calculating the difference between spring and fall sample means from each plot (fall 2022 minus spring 2023). The experimental design of each trial was a 3-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 was performed by location and nutrient on winter plant dry matter and nutrient uptake, selected soil-test properties, and corn yield data using the MIXED procedure of SAS v. 9.4 (SAS Institute, Cary, N.C.). Differences were interpreted as significant when the P-value was ≤ 0.10.

Results and Discussion

Fertilizer rate did not influence ($P > 0.10$) aboveground dry matter accumulation, tissue concentration, or nutrient uptake in the trials at LMCRS, where across the two trials, cereal rye dry matter averaged 2795 lb/ac, with tissue-P and -K averaging 0.323% and 2.17%, respectively, accumulating 8.9 lb P/ac and 60 lb K/ac (data not shown). Similarly, dry matter accumulation and nutrient content of vegetation sampled prior to cover crop termination were not affected by fertilizer rate in the P-rate trial (Table 2) or K-rate trial (Table 3) at RRS. Tissue-P and

-K concentrations, however, were influenced by fertilizer rate at RRS, where 2 of the 3 fertilizer rates in each trial resulted in greater tissue concentration than the no-fertilizer-control treatment. In the P-rate trial at RRS, the effect of cover crop was significant for dry matter accumulation and P content of the biomass, which were 4.9 and 4.2 times greater with cereal rye, relative to weedy vegetation in winter fallow. Although dry matter accumulation and K content were more than 3 times greater from cereal rye in the K trial at RRS, the difference was not statistically significant, and tissue-P and -K concentrations were not affected by cover crop treatment at RRS. Cereal rye at RRS contained an average of 14 and 78 lb/ac of P and K, respectively, which would be equivalent to 32 lb P_2O_5 and 94 lb K_2O/ac, indicating substantial nutrient uptake can occur from fall and winter cover crop growth.

Soil-test P in the spring was significantly affected by fertilizer-P rate in both P trials, where soil-test P increased with increasing fertilizer-P rate but was not affected by cover crop treatment or its interaction with P rate (Table 4). Compared to spring 2022 soil samples, soil-test P in the LMCRS P trial decreased at application rates ≤40 lb P_2O_5/ac and increased at higher application rates (Smartt et al., 2023). Changes in soil-test P between cover crop planting and termination were not affected by cover crop, P rate, or their interaction, but an average decrease of 2.5 ppm was observed. Interestingly, soil-test P in the RRS P trial, relative to spring 2022, decreased by 6- to 9-ppm at all fertilizer-P rates. This result was unexpected as application rates ≥80 lb P_2O_5/ac have consistently increased spring soil-test P over the years in this trial, but the average decrease of 15.5 ppm between cover crop planting in 2022 and termination in 2023 was considerably greater than previous years, where soil-test P had not decreased by more than 4 ppm over that timeframe. While P accumulation by winter vegetation may have contributed to the decrease in soil-test P, it does not explain observed differences, as P content of cereal rye was greater than winter fallow vegetation but unaffected by fertilizer-P rate; whereas, the difference in soil-test P was unaffected by cover crop and a significant increase was observed with increasing P rate. The temporal change in soil-test P suggests a substantial loss of soil-P between fall 2022 and spring 2023 at RRS, which could be the result of spatial variability in soil cores within the treatments and/or surface soil erosion as loss of the surface-applied fertilizer would likely be greater as P application rates increase.

Spring 2023 soil-test K was significantly affected by fertilizer-K rate in both K trials, where soil-test K increased with increasing fertilizer-K rate but was not affected by cover crop treatment or its interaction with K rate (Table 5). Relative to spring 2022 soil samples, soil-test K increased with the application of 180 lb K_2O/ac at LMCRS and ≥120 lb K_2O/ac at RRS, while a decrease in soil-test K occurred at lower application rates (Smartt et al., 2023). Soil-test K from cover crop planting in the fall to spring termination decreased by an average of 3.4 ppm at LMCRS but was not affected by cover crop, fertilizer-K rate, or their interaction. At RRS, however, the cover crop effect was significant, with a greater average decrease in soil-test K with cereal rye (30 ppm decrease) relative to winter fallow (21 ppm decrease). A greater decrease in soil-test K with cereal rye was expected since the biomass contained over 3 times the amount of K contained in winter fallow biomass.

The interaction of cover crop treatment and fertilizer-P rate was significant for corn grain yield at LMCRS (Table 6). Within the winter fallow treatment, corn yields did not differ among P-rate treatments and averaged 195 bu./ac. With a cereal rye cover crop, fertilizer-P application, regardless of rate, reduced corn yields (average of 166 bu./ac) relative to all other treatment combinations. The no-fertilizer-P control following cereal rye resulted in an intermediate grain yield of 180 bu./ac that did not differ significantly from the winter fallow no-fertilizer-P control or 120 lb P_2O_5/ac rate treatment. The 15- to 29-bu./ac decrease in grain yield following cereal rye, relative to winter fallow, may be an indication of N limitation resulting from immobilization as the cereal rye residue decomposes, but that does not explain the greater yields from the control, relative to where P was applied, based on similar cereal rye dry matter accumulation among P-rate treatments. Perhaps a closer examination of N dynamics within the system or nutrient removal with harvested grain could help determine if this result is truly an effect of differences in fertilizer-P rate, but soil-test data, cereal rye tissue data, and previous crop grain yields do not provide an obvious explanation. Corn grain yield was also significantly influenced by cover crop at RRS, averaging 164 bu./ac with winter fallow and 174 bu./ac with cereal rye, but did not differ based on P-rate or the interaction of the factors. The increase in grain yield with cereal rye, relative to winter fallow, was likely the result of increased soil moisture under cereal rye residue early in the season at RRS. Although moisture was not measured, corn plants in winter fallow plots of this trial exhibited visible signs of water deficit stress prior to the initiation of irrigation. It is worth noting that cover crop did not influence grain yields at RRS in 2020, the last time corn was cropped in these trials, but cereal rye resulted in a similar 25 bu./ac decrease in corn yield, relative to winter fallow, at LMCRS (Smartt et al., 2021). The lack of grain yield response to fertilizer-P was expected in these trials due to both locations having Medium soil-test P (17–35 ppm) in the no-fertilizer-P control plots.

Fertilizer-K rate, cover crop treatment, or their interaction did not significantly affect corn grain yields in the K-rate trial at RRS, which averaged 171 bu./ac in 2023 (Table 7). The interaction was not significant at LMCRS either, but grain yields were influenced by cover crop and fertilizer rate. Similar to the P-rate trial at LMCRS, grain yields averaged 23 bu./ac less following cereal rye, relative to corn following winter fallow (corn grain yields averaged 24 bu./ac less following cereal rye in 2020). In contrast to the P-rate trial at LMCRS, however, corn grain yields increased by an average of 17 bu./ac when fertilizer-K was applied, relative to the no-fertilizer-K control. This response was expected, based on the no-fertilizer-K treatment having Low soil-test K (61–90 ppm). Application rate treatments of 60, 120, and 180 lb K_2O/ac had Medium (91–130 ppm), Optimum (131–175 ppm), and Above Optimum (>175) soil-test K levels, respectively, in spring 2023, so it is not surprising that yields did not differ among those treatments. A yield response was expected, with the fertilizer-K rate treatments at RRS having the same range of soil-test K categories as at LMCRS, but yield increases do not always occur at Low soil-test K, so the lack of response was not completely surprising. Differences in soil moisture were not apparent in the K-rate trial at RRS, perhaps due to less difference in dry matter accumulation between winter fallow and cereal rye plots, relative to the P-rate trial, or differences in soil properties between the trials.

Practical Applications

Aboveground dry matter sampled in spring 2023 and nutrient uptake of that biomass was consistently greater with cereal rye, relative to winter fallow, but cover crop treatment generally had little effect on soil-test values. Corn grain yields, however, were decreased by 26 and 23 bu./ac following cereal rye, relative to winter fallow, in LMCRS P- and K-rate trials, respectively, while cereal rye resulted in a 10 bu./ac yield increase in the P-rate trial at RRS and did not influence yields in the K-rate trial. The effect of cover crop treatment in 2023 was similar to the last time corn was planted (2020), where a comparable yield decrease from cereal rye (24–25 bu./ac) was observed at LMCRS. In 2020, grain yields did not differ, based on cover crop treatment, at RRS, but improved water retention with cereal rye seemingly increased corn grain yields in one trial in 2023. Soil-test P of the non-P-fertilized control treatment is in the Medium category at both locations and slowly decreasing over time, increasing the likelihood of yield responses in the future, but grain yields did not positively respond to fertilizer-P in 2023. In fact, corn yields following cereal rye decreased by an average of 14 bu./ac when fertilizer-P was applied, relative to the no-fertilizer-P control. This result was unexpected and requires further evaluation. Soil-test K is in the Low category in both trials, where a yield response to fertilizer-K is likely. Although yields were not affected by K-rate at RRS, the trial at LMCRS was responsive to fertilizer-K in 2023, where an average 17 bu./ac increase was observed with K application. The influence of planted cover crops and weeds on nutrient cycling outside of the summer cropping season is apparent and needs to be further studied in relation to nutrient requirements of summer cash crops. Following soybean and with less nitrogen limitation, the cereal rye planted in fall 2022 accumulated greater biomass than the previous season and, as expected, had a greater influence on the 2023 summer crop. A cover crop mixture including a legume (hairy vetch) was planted following the harvest of the 2023 corn crop with the goal of enhancing cover crop growth for a potentially stronger influence on the cropping system in 2024.

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Table 1. Mean soil pH, organic matter (SOM), and Mehlich-3 extractable nutrients in the 0–6-inch depth for the no-fertilizer-P or no-fertilizer-K control treatments of the P and K trials at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) and Rohwer Research Station (RRS) in spring 2023.

	LMCRS		RRS	
Soil property	**P trial**	**K trial**	**P trial**	**K trial**
Soil pH	7.5	7.3	6.5	6.4
P (ppm)	22	38	25	38
K (ppm)	109	67	144	62
Ca (ppm)	1,080	1,184	660	672
Mg (ppm)	332	319	108	101
S (ppm)	5	5	4.7	4.7
Fe (ppm)	176	184	233	243
Mn (ppm)	135	125	98	97
Cu (ppm)	1.1	1.2	0.7	0.7
Zn (ppm)	3.1	3.9	3.1	3.0
B (ppm)	0.6	0.8	0.2	0.7
SOM (%)	1.49	1.75	1.37	1.27

Table 2. Influence of the cover crop (CC) main-plot effect, the fertilizer-P rate subplot effect, and their interaction on aboveground dry matter and tissue-P concentration and content prior to cover crop termination in spring 2023 in the seventh year of the fertilizer-P rate trial at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS).

	Dry matter			Tissue P			P content		
Annual P rate†	**Winter fallow**	**Cereal rye**	**Rate mean**	**Winter fallow**	**Cereal rye**	**Rate mean**	**Winter fallow**	**Cereal rye**	**Rate mean**
(lb P_2O_5/ac)	------------(lb/ac)------------			--------------(% P)--------------			------------(lb P/ac)------------		
0	840	4,358	2,599	0.347	0.297	0.322 c‡	2.89	13.0	7.93
40	968	4,763	2,866	0.380	0.327	0.353 b	3.61	15.3	9.47
80	787	4,209	2,498	0.383	0.313	0.348 bc	2.95	13.0	7.97
120	958	4,113	2,535	0.413	0.360	0.387 a	4.00	14.8	9.40
CC mean	888 b	4,361 a	--	0.381	0.324	--	3.36 b	14.0 a	--
P rate	----------0.5171----------			---------- 0.0119 ----------			---------- 0.1038 ----------		
Cover crop	----------0.0089----------			---------- 0.2722 ----------			---------- 0.0052 ----------		
Interaction	----------0.6859----------			---------- 0.9200 ----------			---------- 0.6622 ----------		
C.V. (%)	------------17.3------------			------------- 7.8 -------------			------------ 15.1 ------------		

† Fertilizer-P rate treatments were applied for the first time in 2018, these data reflect the cumulative effect of five annual applications.

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

Table 3. Influence of the cover crop (CC) main-plot effect, the fertilizer-K rate subplot effect, and their interaction on aboveground dry matter and tissue-K concentration and content prior to cover crop termination in spring 2023 in the seventh year of the fertilizer-K rate trial at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS).

	Dry matter			Tissue K			K content		
Annual K rate[†]	Winter fallow	Cereal rye	Rate mean	Winter fallow	Cereal rye	Rate mean	Winter fallow	Cereal rye	Rate mean
(lb K_2O/ac)	-----------(lb/ac)-----------			------------(% K)------------			-----------(lb K/ac)-----------		
0	1,000	3,548	2,274	2.18	2.38	2.28 c[‡]	21.8	84.5	53.2
60	947	2,780	1,864	2.72	2.60	2.66 a	26.2	73.0	49.6
120	936	2,780	1,858	2.56	2.50	2.53 ab	23.9	68.8	46.4
180	1,032	3,207	2,120	2.30	2.56	2.43 bc	23.7	83.8	53.7
CC mean	979	3,079	--	2.44	2.51	--	23.9	77.6	--
K rate	----------0.4799----------			----------0.0054----------			----------0.8234----------		
Cover crop	----------0.1025----------			----------0.5334----------			----------0.1094----------		
Interaction	----------0.6257----------			----------0.1199----------			----------0.6722----------		
C.V. (%)	------------26.3------------			-------------6.0-------------			------------30.2------------		

† Fertilizer-K rate treatments were applied for the first time in 2018, these data reflect the cumulative effect of five annual applications.

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

Table 4. Influence of the cover crop (CC) main-plot effect, the fertilizer-P rate subplot effect, and their interaction on soil-test P in spring 2023, before annual fertilizer-P treatment application, and the difference in soil-test P between cover crop establishment in fall 2022 and termination in spring 2023 in the seventh year of fertilizer-P rate trials at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) and Rohwer Research Station (RRS).

	Soil-test P						Soil-test P difference					
	LMCRS			RRS			LMCRS			RRS		
Annual P rate[†]	Winter fallow	Cereal rye	Rate mean	Winter fallow	Cereal rye	Rate mean	Winter fallow	Cereal rye	Rate mean	Winter fallow	Cereal rye	Rate mean
(lb P_2O_5/ac)	------------------------------(ppm)------------------------------											
0	21.7	22.0	21.9 c[‡]	27.5	22.1	24.8 d	1.1	2.3	1.7	8.3	11.2	9.8 c
40	34.1	30.8	32.5 b	41.3	37.2	39.3 c	2.3	3.3	2.8	12.4	15.0	13.7 bc
80	49.6	43.2	46.4 a	60.6	55.2	57.9 b	0.6	4.7	2.6	16.6	19.0	17.8 ab
120	54.8	45.9	50.4 a	88.4	84.7	86.5 a	3.4	2.6	3.0	16.6	24.8	20.7 a
CC mean	40.1	35.5	--	54.5	49.8	--	1.8	3.2	--	13.5	17.5	--
P rate	---------<0.0001---------			---------<0.0001---------			----------0.9368----------			----------0.0055----------		
Cover crop	----------0.1098----------			----------0.1634----------			----------0.2946----------			----------0.4634----------		
Interaction	----------0.2776----------			----------0.9925----------			----------0.7174----------			----------0.6155----------		
C.V. (%)	-----------10.6------------			-----------11.6------------			------------146------------			-----------28.5------------		

† Fertilizer-P rate treatments were applied for the first time in 2018, these data reflect the cumulative effect of five annual applications.

‡ Different lowercase letters within a site indicate significant differences ($P \leq 0.10$).

Table 5. Influence of the cover crop (CC) main-plot effect, the fertilizer-K rate subplot effect, and their interaction on soil-test K in spring 2023, before annual fertilizer-K treatment application, and the difference in soil-test K between cover crop establishment in fall 2022 and termination in spring 2023 in the seventh year of fertilizer-K rate trials at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) and Rohwer Research Station (RRS).

	Soil-test K						Soil-test K difference					
	LMCRS			RRS			LMCRS			RRS		
Annual K rate[†]	Winter fallow	Cereal rye	Rate mean	Winter fallow	Cereal rye	Rate mean	Winter fallow	Cereal rye	Rate mean	Winter fallow	Cereal rye	Rate mean
(lb K_2O/ac)	(ppm)											
0	62	72	67 d[‡]	68	55	62 d	3.4	12.5	7.9	11.7	20.6	16.2
60	117	104	111 c	103	95	99 c	16.8	5.2	11.0	26.6	26.4	26.5
120	173	161	167 b	149	146	147 b	-14.9	4.8	-5.0	16.3	29.4	22.9
180	199	188	194 a	208	215	211 a	-9.8	9.2	-0.3	28.8	44.8	36.8
CC Mean	138	131	--	132	128	--	-1.1	7.9	--	20.9 b	30.3 a	--
K rate	<0.0001			<0.0001			0.1762			0.4699		
Cover crop	0.1487			0.2861			0.3153			0.0634		
Interaction	0.7178			0.8282			0.1814			0.9261		
C.V. (%)	14.7			15.1			381			87.0		

† Fertilizer-K rate treatments were applied for the first time in 2018, these data reflect the cumulative effect of five annual applications.

‡ Different lowercase letters within a site indicate significant differences ($P \le 0.10$).

Table 6. Corn grain yield as affected by annual fertilizer-P rate, cover crop (CC), and their interaction during the seventh year of long-term fertilizer-P rate trials at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) and Rohwer Research Station (RRS) in 2023.

	LMCRS			RRS		
Annual P rate[†]	Winter fallow	Cereal rye	Rate mean	Winter fallow	Cereal rye	Rate mean
(lb P_2O_5/ac)	(bu./ac)					
0	193 AB[‡]	180 B	186	165	164	164
40	198 A	169 C	183	171	178	174
80	198 A	166 C	182	162	177	170
120	192 AB	162 C	177	159	178	169
CC Mean	195	169	--	164 b[§]	174 a	--
P rate	0.1292			0.1743		
Cover crop	0.0460			0.0951		
Interaction	0.0620			0.1590		
C.V. (%)	3.4			4.3		

† Fertilizer-P rate treatments were applied for the first time in 2018, these data reflect the cumulative effect of six annual applications.

‡ Different uppercase letters next to means indicate significant differences in cover crop/P rate treatments ($P \le 0.10$).

§ Different lowercase letters within a site indicate significant differences ($P \le 0.10$).

Table 7. Corn grain yield as affected by annual fertilizer-K rate, cover crop (CC), and their interaction during the seventh year of long-term fertilizer-K rate trials at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) and Rohwer Research Station (RRS) in 2023.

	LMCRS			RRS		
Annual K rate†	Winter fallow	Cereal rye	Rate mean	Winter fallow	Cereal rye	Rate mean
(lb K_2O/ac)	(bu./ac)					
0	187	164	176 b‡	167	168	168
60	212	182	197 a	176	167	171
120	202	182	192 a	172	174	173
180	198	180	189 a	173	171	172
CC Mean	200 a	177 b	--	172	170	--
K rate	0.0124			0.7168		
Cover crop	0.0212			0.8398		
Interaction	0.6858			0.5738		
C.V. (%)	4.9			4.4		

† Fertilizer rate treatments were applied for the first time in 2018, these data reflect the cumulative effect of six annual applications.

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

Cotton Response to Topdress Nitrogen Fertilizer in Years 1 and 2 Following Peanut in Northeastern Arkansas

T.G. Teague,[1,2] N.R. Benson,[1] and J. Nowlin[1]

Abstract

Should producers adjust their N fertilizer management for cotton (*Gossypium hirsutum*) grown in rotation with the N-fixing legume, peanut (*Arachis hypogaea*)? To address this question, an on-farm study was conducted in 2022 and 2023 in Mississippi County, Ark. in the first and second years of cotton grown in rotation following peanut. The heterogeneous, alluvial sandy soil in the commercial field was classified as a Routon-Dundee-Crevasse complex (Typic Endoqualfs). Fertilizer applications and yield assessments were made with the cooperating producer's equipment. A base rate of 80 lb N/ac was broadcast applied prior to squaring. Supplemental fertilizer-N treatments of 0, 20, or 40 lb N/ac were applied as a topdress at the time of first flowers (~60 days after planting) and represented total-N rates of 80, 100, and 120 lb N/ac. In-season plant monitoring was used to quantify maturity delay and to identify plant structural changes in response to N in different soil textural zones of the spatially variable field. Soil electrical conductivity measures (EC_a) were used as a proxy for soil texture to classify zones. Our results showed that in both years following peanut, there were significant treatment effects on lint yield with differences among soil texture classes. In year 1 following peanut, yield from cotton in the coarse-sand textured soil zone (ca. 35% of the field) trended upward with increased N. In the loamy sand areas of the field, there was no yield penalty for reduced fertilizer-N. In year 2, the topdress application significantly increased the yield of cotton in both soil textural zones compared to the base rate alone. These findings correspond with earlier on-farm work conducted in 2020–2022. Expanded research is needed to increase the understanding of the benefits of cotton-peanut rotation and how directed soil sampling for N fertilization could improve N fertilizer management efficiency.

Introduction

Peanut (*Arachis hypogaea*) production has expanded in eastern Arkansas in the past decade. Even though the crop is credited with increasing soil nitrogen (N) availability because of biological N fixation, it is unclear whether Arkansas cotton (*Gossypium hirsutum*) producers should modify their N management to exploit peanut N-credits in their cotton-peanut rotation. Cooperative Extension recommendations from other peanut-producing states suggest that N-credits can range from 20 to 60 lb N/ac for crops planted after peanut (Crozier et al., 2010; Caddel et al., 2012); however, recent results from Florida research, conducted in a subtropical growing environment on sandy soils, show peanut N-credits are negligible (Jani et al., 2019; 2020). Updated fertilizer management guidelines for cotton-peanut systems with the current varieties and conservation tillage systems are lacking in the mid-South.

This report summarizes a 2022–2023 study conducted in response to requests from Northeast Arkansas cotton producers for applied, on-farm research to determine if N credits are warranted following a peanut crop or if the standard fertilizer practices (~90-120 lb N/ac) should be maintained. Reductions in fertilizer expenditures would lower production costs and also reduce the negative consequences of overuse of N fertilizer associated with late-season rank growth, maturity delays (Teague, 2016), and negative environmental impact. The field trial was conducted in the major cotton production areas of Northeast Arkansas, where heterogenous soils are common. We included consideration of soil texture in our experiment to examine plant response to N management across different soil textures. These findings will help inform crop managers on decisions regarding soil sampling methodology and suggest possible options for variable rate fertility practices for site-specific management to reduce costs and improve profitability as well as reduce environmental impacts.

Procedures

The experiment was conducted in 2022 and 2023 in a commercial field located adjacent to the Manila Airport Complex (35.889297, -90.140778) in Mississippi County, Ark. There were 3 N fertilizer treatment rates with 6 replications. Plot strips were 24 rows wide (raised beds spaced at 38 in.) and 250-ft long (0.22 acres; Fig. 1). A base level of 80 lb N/ac fertilizer (urea) was broadcast across the experiment 32 days after planting (DAP). For the experimental treatments, N fertilizer (urea) treatments were applied as a "topdress" application. The N treatments were: 1) base 80 lb/ac (80N), 2) base + topdress 20 lb/ac (100N), and 3) base + topdress 40 lb/ac (120N). The topdress fertilizer was broadcast-applied in 24-row swaths during the week of first flowers (6 July 2022, 57 DAP and 29 June 2023, 57 DAP) using the cooperating producers' commercial spreader. Treatments were repeated in 2023, and plots were not re-randomized. All production activities in both years were performed by the cooperating producers following their standard management practices and using their equipment. Irrigation was provided with a center pivot sprinkler system, and all plant and soil assessments, including yield evaluations,

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were made only in irrigated field areas. Details on production timing and inputs are summarized in Table 1.

Soils were classified as Routon-Dundee-Crevasse complex (Typic Endoqualfs). We included soil texture in our experimental design, sampling protocols, and analysis because of heterogeneous soils in the study area. Located in the Mississippi Alluvial Plain, the field site also lies in the New Madrid seismic zone, where fields are characterized by large sandy deposits associated with sand blows resulting from paleoliquefaction during earthquake-induced events (Tuttle et al., 2002). To account for spatial variability, soil sampling, as well as plant and pest monitoring activities, were stratified to include two soil texture categories (zones). These zones were established using indirect measurements of soil electrical conductivity (Soil EC_a) made in spring 2020 using a Veris 3150 EC Surveyor®. Georeferenced soil ECa data were mapped in ArcGIS Pro (ESRI; Redlands, Calif.) and delineated into 7 zones using the natural-breaks classification (Fig. 1). For practical purposes for field scouting and for yield data interpretation, soil EC_a classifications were further grouped to produce two soil textural zones: 1) loamy-sand category which represented the three highest EC classifications [soil EC_a values from shallow layer (0–24 in.) with values <13 mS/m], and 2) coarse sand, which represented the lowest soil EC_a classifications [soil EC_a values from shallow layer (0–24 in.) with values <13 mS/m]. The coarse-sand areas, likely related to sand deposits associated with sand blows, category encompassed ca. 35% of the field.

Soil sample collections (0–6-in.) were made in each soil textural zone in May 2022. In 2023, soil sampling was expanded to include 0-to 6-in. (shallow) and 6- to12-in. (deep) depths at designated sample sites within each soil texture category. In both years, 8 composite samples [4 cores, 0.75-in.-wide using 0.75-in. inner diameter, AMS probe (AMS Inc., American Falls, Idaho)] were collected per plot at sampling sites in each of the 6 replications. Samples were submitted to the University of Arkansas System Division of Agriculture Soil Testing Laboratory for routine soil testing procedures.

Sample points for plant and soil monitoring activities, including hand-harvests for fiber quality assessments, were set within each plot strip with site selection based on soil EC_a, field imagery, and field observations (Fig. 1). The georeferenced sample points were set ~14 DAP and marked in the field using 6-ft flags. The flags served as a guide for field scouts who followed a strict sampling protocol for plant and pest monitoring activities each week by rotating the position of their sample points in areas adjacent to the flag in order to avoid the thigmonastic effects of re-sampling the same plants each week.

Plant monitoring activities were initiated during the first week of squaring and included evaluations of plant main-stem nodal development, height, and first-position square and boll retention. Data collection used standard COTMAN Squaremap and nodes above white flower (NAWF) sampling protocols (Ooterhuis and Bourland, 2008). Plant maturity measurements included calculations of days from planting to physiological cutout (NAWF = 5) and were based on standard output from the COTMAN software. Arthropod pest numbers were monitored at weekly intervals using sweep net and drop cloth sampling procedures.

Yield assessments were based on calibrated geo-referenced yield monitor data collected from the cooperating producers' John Deere cotton picker. Yield data were post-calibrated using final module weights retrieved from the gin. Georeferenced soil EC_a and yield monitor data layers were spatially joined in ArcGIS Pro. A two-way factorial structure was used for analysis of yield data, with fertilizer treatment, block effect, and soil EC_a classifications included as covariates. Analysis of variance was conducted using mixed model procedures (Proc GLIMMIX). Mean comparisons were made using the LSMEANS procedure with the Tukey adjustment ($P \leq 0.05$; SAS Institute; Cary, N.C.).

Fiber quality was evaluated using a 40-boll sample collected during hand harvest. Hand-harvested 40-boll samples were collected at flagged sample sites in 2022. Samples were ginned (lab gin without the use of lint cleaners), and lint samples were sent to the Texas Tech Fiber and Biopolymer Research Institute for HVI (high volume instrument) evaluations. No hand-picked samples were collected in 2023.

Results and Discussion

Growing conditions and rainfall (Table 2) in the 2022 and 2023 growing seasons generally were favorable for cotton production. There were exceptional cotton yields in northeastern Arkansas in both years.

Results from the routine soil sampling analysis indicated differences between the soil texture categories in mean Mehlich-3 extractible nutrients in both 2022 and 2023 (Tables 3-5). In 2022, concentrations of P were higher in the coarse sand compared to the loamy sand, and concentrations of Mn were lower in the coarse sand compared to the loamy sand ($P = 0.05$; Table 3). In 2023, experienced soil samplers exercised greater precision in their site selection for sampling specific soil textural zones compared to 2022 collections; sampling also included 2 depths. Results for 2023 showed significant ($P < 0.01$) soil texture effects with higher concentrations of P and K in coarse compared to loamy sand soil textural zones (Table 4). There were also higher concentrations of Ca, Mg, Na, S, Mn, Cu, B and NO_3-N associated with loamy sand compared to coarse sand. Depth of the soil sample also significantly affected nutrients with higher concentrations of P, K, S, Mn, Zn, B, and NO_3-N associated with the shallow compared to deep samples and higher levels of Na and Cu in the deep compared to shallow samples (Table 4). The pH values of soil samples collected at the shallow depth were higher compared to deep samples. Results from the routine soil sampling analysis indicated no differences in soil test results for NO_3-N associated with the 2022 N fertilizer treatments (Table 5). The highest NO_3-N concentrations were observed in the loamy sand texture in shallow-depth samples.

COTMAN growth curves provide a gauge of crop fruiting dynamics through the season in response to growing conditions. The mean number of squaring nodes [main-stem fruiting branches (sympodia) that have not developed to the flowering stage] are plotted by DAP for each growth curve. Prior to first flowers, the number of squaring nodes is equal to the number of main-stem sympodia; after flower initiation, squaring nodes can be determined by counting the NAWF. Growth curves are derived from in-field measurements and, in the COTMAN system, are compared to the Target Development Curve (TDC), a standard curve that represents the optimal pace (measured in DAP) of nodal development and flower initiation in cotton. The TDC assumes that first square appears 35 DAP, first flower at 60 DAP with NAWF = 9.25, and physiological cutout (defined as NAWF = 5) at 80 DAP.

COTMAN growth curves for the 2022 and 2023 field studies (Fig. 2) show variation in squaring node development among plants growing in field areas with different soil textures and among fertilizer-N treatments in 2022 but not in 2023. Growth curves for both years showed that scouts observed squares around 35 DAP, and squaring node development generally followed the pace of the TDC. Typically, we expect a reduced rate of squaring node development for plants growing in the coarse sand areas compared to loamy sand field areas; however, such differences were not apparent in this field study in either crop season, indicating good growing conditions. First flowers were observed ~60 DAP. During the effective flowering period, growth curves deviated from the TDC for all treatments. For both years, we observed maturity delays for all treatment combinations, and physiological cutout was extended past the expected 80 DAP. Delays were likely associated with the timing of cloudy, overcast conditions during the effective flowering period in both years. Physiological cutout (NAWF = 5) ranged from 83 to 94 DAP (Table 6). There were no significant effects of N fertilization on days to cutout in either year ($P > 0.15$).

There were significant yield effects noted with year, N rate, and soil texture ($P = 0.001$); however, there were significant year*fertilizer*soil texture interactions ($P = 0.001$). Overall yields were significantly higher in 2022 compared to 2023. Mean lint yield ranged from a high of 1806 lb/ac with 120 lb N/ac in the loamy sand in 2022 to a low of 1501 lb/ac with 80 lb N/ac in the coarse sand textural zone in 2023 (Table 7). In both years, lint yield from cotton in the coarse sand was significantly lower compared to loamy sand zones. Yields in coarse sand areas increased with the mid-season topdress application in both 2022 and 2023. In loamy sand soil textural zones, there was no yield penalty for eliminating the mid-season topdress in year 1 following peanut; however, a yield penalty was observed in 2023 if there was no N topdress. These findings correspond with earlier on-farm work conducted in 2020, 2021, and 2022 (Teague et al., 2021; 2022; 2023).

Results from fiber quality analysis of 40-boll hand-picked samples (Table 8) showed no significant differences in fiber quality parameters or boll size among N rate treatments. Mean boll size was similar for samples collected from plants growing in coarse sand compared to loamy sand. The fiber results showed similar length and strength values for samples collected in different soil textural zones. No fiber properties were significantly different.

Practical Applications

For cotton grown in the first year following peanut, there was no significant yield advantage for increasing N rates above a base 80 lb N/ac in field areas comprised of soil with a loamy sand texture. In the coarse sand soil textural zones, however, there was a positive yield response to the topdress fertilizer-N applied at first flowers. In the second year of cotton following peanut, lint yield was improved with a midseason topdress N application, regardless of soil texture. More work is needed to increase our understanding of how directed soil sampling in fields with heterogenous soils could inform crop managers and lead to improved efficiency in fertilizer management. In cotton-peanut rotation systems, additional research is needed to explore the potential benefits of variable rate applications of N in spatially variable fields.

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Table 1. Dates of planting, irrigation, fertilization, harvest-aid applications, and harvest for 2022 and 2023 seasons in the peanut cotton rotation nitrogen research study in Manila, Ark.

Year	Operation	Date	Days after planting
2022	Date of cotton planting	10 May	0
	Soil sample collection	20 May	-16
	Base fertilizer application	11 June	32
	Topdress urea application[a]	6 July	57
	Irrigation (sprinkler)	13, 20, 27 June; 1, 6 July	34, 41, 48, 52, 57
	First application harvest-aid products	19 September	139
	Machine harvest	9 October	152
2023	Date of cotton planting	3 May	0
	Soil sample collection	24 May	21
	Base fertilizer application	29 May	26
	Topdress urea application[a]	29 June	57
	Irrigation (sprinkler)	30 June; 3, 22 Aug	38, 92, 111
	First application harvest-aid products	9 September	129
	Machine harvest	3 October	153

[a] Only treatment-specific plots received the topdress (prescription) urea applications.

Table 2. Monthly precipitation (inches) measured at the study site for the 2022 and 2023 season compared with the 30-year average for Mississippi County, Manila, Ark.

Mean Month	30-Year Average	2022 Rainfall	2023 Rainfall
	-------------------------------------(in.)-------------------------------------		
May	5.37	4.51	6.36
June	3.99	2.22	2.15
July	4.04	4.29	5.38
August	2.36	6.25	5.54
September	2.88	2.61	1.99
Total Season	15.76	19.88	21.41

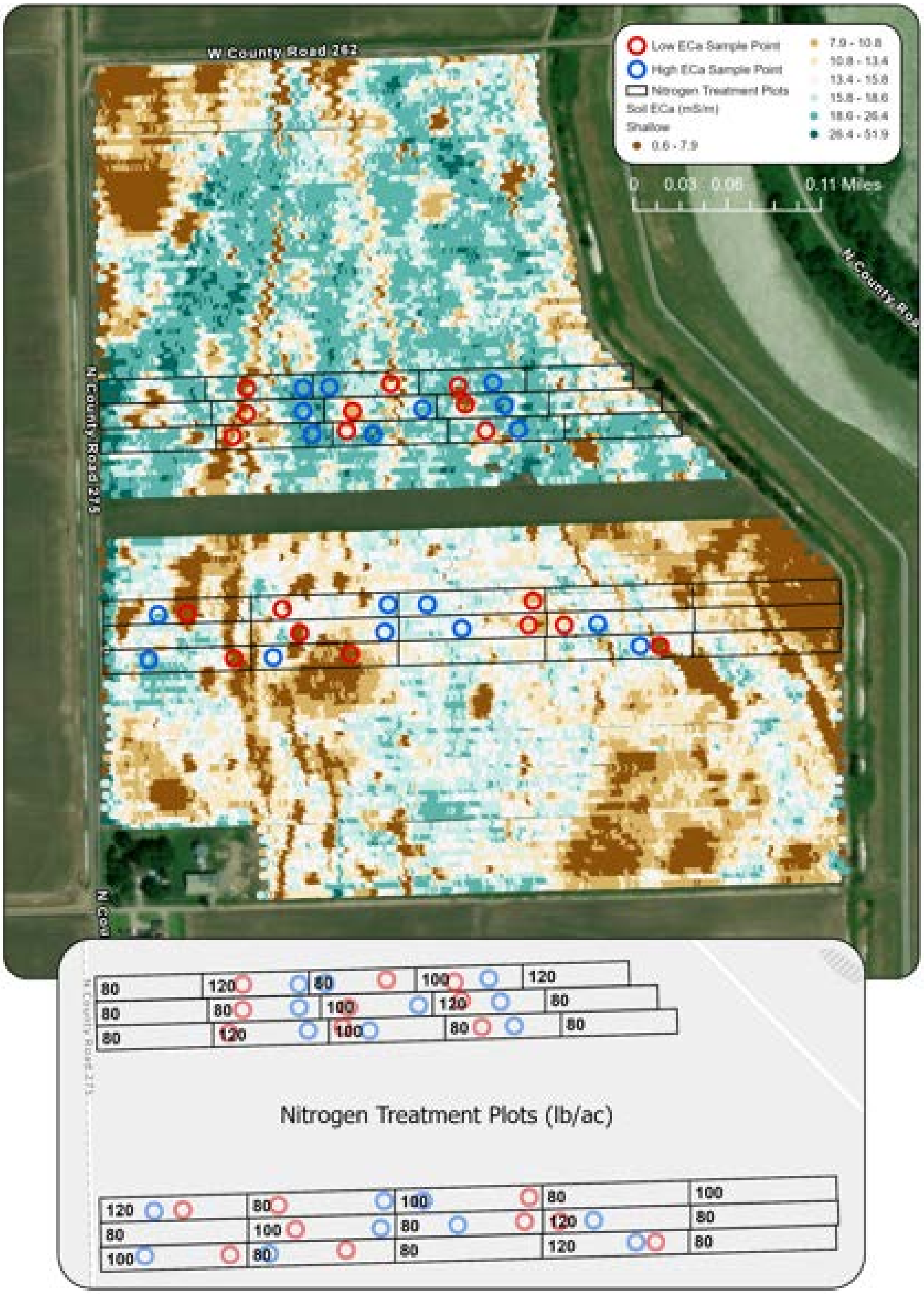

Fig. 1. Field plan overlaid on soil apparent electrical conductivity (EC_a, shallow) map showing spatial variation in soil texture for the N fertilization trial for 2022 and 2023 cotton grown in a 3-year rotation with peanut. The entire field is shown above and includes outlines of the plots with total N application rates. Plots were 250 ft long and 24 rows wide. Sample points shown (right) were designated for hand-harvest for fiber quality assessments and served as the field reference points for scouts in soil, plant, and pest monitoring activities. Yield assessments were made from 2 cotton picker swaths, each 6 rows wide from the center 12 rows of each 24-row plot in irrigated areas of the field study in Manila, Arkansas.

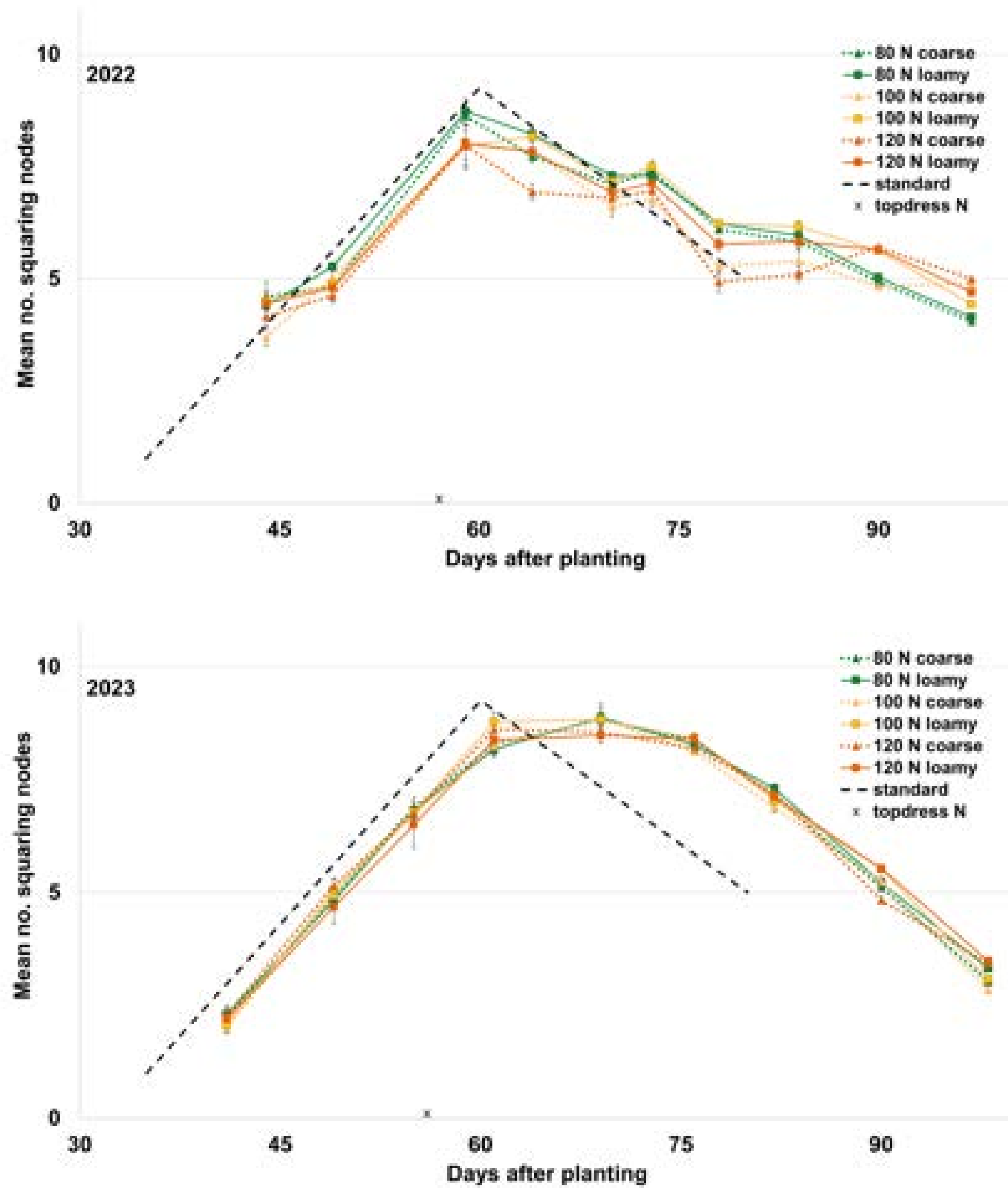

Fig. 2. COTMAN growth curves for cotton in the 2022 and 2023 peanut-cotton rotation N fertilization trial showing mainstem squaring node development of plants in coarse sand and loamy sand areas of treatment plots which received the base rate of 80 lb N/ac at ~30 days after planting (DAP) plus a topdress application of either 0, 20, or 40 lb N/ac at first flower at 57 DAP.

Table 3. Mean soil pH and Mehlich-3 extractable nutrients from 0 to 6-in. depth in samples[a] collected in two soil texture zones established using soil EC_a measures (<13 mS/m or ≥13 mS/m) and collected prior to fertilizer applications in 2022 peanut-cotton rotation nitrogen research study in Manila, Ark.

	Coarse sand		Loamy sand	
Soil property	***mean***	***SEM***	***mean***	***SEM***
Soil pH	7	0.03	7	1.5
P (ppm)	63.0	2.1	54.0	3.9
K (ppm)	252.0	4.3	242.0	17.8
Ca (ppm)	972.0	20.4	1000.0	4.7
Mg (ppm)	137.0	4.4	148.0	0.2
Na (ppm)	7.0	0.2	7.0	0.1
S (ppm)	7.0	0.1	8.0	3.4
Fe (ppm)	204.0	4.3	198.0	2.6
Mn (ppm)	104.0	2.5	119.0	0.0
Cu (ppm)	0.7	0.03	0.7	0.1
Zn (ppm)	5.2	0.3	4.4	0.02
B (ppm)	0.7	0.01	0.7	1.0
NO_3-N	30.9	1.2	33.4	0.02
OM	1.7	0.03	1.7	1.5

[a] Means and standard error of the mean (SEM) from 8 composite samples per site (4 cores per composite) from routine soil analysis made at the University of Arkansas System Division of Agriculture's Soil Test Laboratory, Fayetteville, Ark.

Table 4. Mean soil pH and Mehlich-3 extractable nutrients from soil samples[a] collected in two soil texture zones established using soil ECa measures (<13 mS/m or ≥13 mS/m) at two depths (0- to 6-in. (shallow) or 6- to 12-in. (deep)) in second cotton crop year of 3-year cotton-peanut rotation, 2022, Manila, Ark.

	Soil textural category				Sampling depth			
	Coarse sand		Loamy sand		Shallow (0- to 6-in.)		Deep (6- to 12-in.)	
Soil property	***mean***	***SEM***	***mean***	***SEM***	***mean***	***SEM***	***mean***	***SEM***
Soil pH	6.4	0.05	6.3	0.04	6.5	0.03	6.2	0.03
P (ppm)	34.4	2.8	23.4	1.9	37.2	1.9	20.7	2.4
K (ppm)	168.9	9.1	149.0	10.5	210.6	5.0	107.2	4.5
Ca (ppm)	780.4	29.9	930.3	31.1	868.9	28.8	841.8	36.7
Mg (ppm)	95.3	3.6	114.8	3.8	109.3	3.9	100.7	4.0
Na (ppm)	9.1	0.3	11.5	0.4	9.4	0.4	11.2	0.4
S (ppm)	5.6	0.2	6.6	0.2	6.4	0.2	5.9	0.2
Fe (ppm)	179.9	7.2	169.1	5.2	177.8	4.4	171.3	7.7
Mn (ppm)	60.4	2.9	85.3	3.2	82.6	3.4	63.1	3.3
Cu (ppm)	0.9	0.0	1.2	0.0	1.0	0.0	1.1	0.0
Zn (ppm)	3.7	0.3	3.8	0.3	4.2	0.2	3.4	0.3
B (ppm)	0.4	0.01	0.4	0.01	0.5	0.01	0.3	0.01
NO_3-N	6.7	1.0	9.4	1.2	12.4	1.1	3.6	0.5

[a] Means and standard error of the mean (SEM) from 8 composite samples per site (4 cores per composite) from routine soil analysis made at the University of Arkansas System Division of |Agriculture's Soil Test Laboratory, Fayetteville, Ark.

Table 5. Mean results from soil analysis for NO_3-N from soil samples[a] collected in two soil texture zones established using soil electrical conductivity (EC_a) measures (<13 mS/m or ≥13 mS/m) at two depths [0- to 6-in. (shallow) or 6- to 12-in. (deep)] from 2023 N-treatment plots in the second cotton crop year of 3-year cotton-peanut rotation, 2023, Manila, Ark.

			N Fertilizer applied in 2022 (lb N/acre)					
			80		100		120	
Variable	Sample depth	Soil textural class	*Mean*	*SE*	*Mean*	*SE*	*Mean*	*SE*
			ppm					
NO_3-N	Shallow	Coarse sand	9.3	3.0	8.5	2.7	14.0	0.9
		Loamy sand	14.3	3.1	14.3	2.7	14.2	3.0
	Deep	Coarse sand	2.5	0.3	2.2	0.5	3.7	1.5
		Loamy sand	5.0	1.6	3.7	1.3	4.8	2.0

[a] Means (SE) and standard error of the mean (SEM) from 8 composite samples per site (4 cores per composite) from routine soil analysis made at the University of Arkansas System Division of Agriculture's Soil Test Laboratory, Fayetteville, Ark.

Table 6. Mean number (±SEM) of days from planting to physiological cutout (nodes above white flower (NAWF)=5) for three different nitrogen fertilizer rates for plants in coarse sand and loamy sand soil texture categories in the first (2022) and second (2023) years of cotton following peanuts, Manila, Ark.

		Mean no. days to cutout		
		N fertilizer rate (lb/ac)		
Year	Soil texture	120	100	80
		days		
2022	Loamy sand	91 ± 4.5	94 ± 0.9	90 ± 1.8
	Coarse sand	83 ± 6.7	84 ± 6.5	90 ± 2.7
2023	Loamy sand	92 ± 0.7	92 ± 0.9	91 ± 0.7
	Coarse sand	90 ± 1.2	92 ± 1.2	91 ± 0.92

Table 7. Fertilizer-N rate and soil texture effects on cotton lint yields from calibrated yield monitor measured harvest results in year 1 (2022) and year 2 (2023) following peanut, Manila, Ark.

		Mean Lint yield†		
		N fertilizer rate (lb/ac)		
Year	Soil texture	120	100	80
		lb lint/ac		
2022	Loamy sand	1806 A	1779 A	1778 A
	Coarse sand	1722 B	1731 B	1677 C
2023	Loamy sand	1654 a	1603 b	1572 c
	Coarse sand	1543 cd	1511 de	1501 e

† Means in the same year followed by the same letter are not significantly different [Tukey-Kramer Grouping for Least Squares Means (α = 0.05)].

Table 8. Mean boll weight and results from fiber quality assessments (HVI[a]) for 40-boll samples showing soil texture effects in 2022[b] peanut-cotton rotation nitrogen research study in Manila, Ark.

Soil texture	Boll weight	Micronaire	Length	Uniformity	Strength	Elongation
	(g)	(Mic)	(in.)	(UI)	(g/tx)	(%)
Coarse sand	5.05	4.01	1.13	80.8	29.9	6.3
Loamy sand	4.83	3.97	1.15	81.9	30.8	6.1
P-value	*0.34*	*0.82*	*0.80*	*0.21*	*0.23*	*0.28*

[a] HVI assessments made at the Fiber & Biopolymer Research Institute, Texas Tech University, Lubbock.
[b] Hand harvests were not performed in 2023.

Appendix: Soil Testing Research Proposals

2023–2024 Soil Testing Research Proposals

Principal Investigator (PI)	**Co-PI**	**Proposal Name**	**Year of Research**	**Funding Amount (US$)**
Mike Daniels	James Burke, Lee Riley, Pearl Webb, and Trenton Roberts	Sulfate Loss in Runoff from Arkansas Discovery Farms Research Sites	2 of 3	23,156
Gerson Drescher	Matt Bertucci, Trenton Roberts, Bronc Finch, and Dirk Philipp	Continued Assessment of Bermudagrass Forage Yield and Nutrient Uptake in Response to Phosphorus and Potassium Fertilization	2 of 3	29,071
Gerson Drescher	Trenton Roberts, Nathan Slaton, and Alden Smartt	Long-Term Phosphorus and Potassium Cover Crop Fertilization Trial	1 of 3	55,071
Gerson Drescher	Arlene Adviento-Borbe, Tina Teague, Mike Daniels, and Michele L. Reba	Potassium Loss by Runoff in Different Cotton Production Systems	1 of 3	19,994
Amanda McWhirt	Trenton Roberts, Amanda Lay-Walters (Ph.D. Student)	Verifying Nitrogen Rate Recommendations for Blackberry Grown in Arkansas	2 of 3	18,892
Aurelie Poncet	Nathan Slaton	Can We Use Proximal Sensing to Improve Soil Sampling in Arkansas	3 of 3	45,000
Aurelie Poncet	Donald Johnson	A Survey to Evaluate Stakeholder Perceptions and Priorities Regarding Soil Sampling, Soil Testing, and Fertilizer Recommendations	2 of 3	10,000
Michael Popp	Nathan Slaton and Aurelie Poncet	Decision Tools for Profit-Maximizing Potassium Fertilizer Rate Recommendations	2 of 3	30,160
Trenton Roberts	Gerson Drescher	Cotton Response to Nitrogen and Potassium Fertilization	1 of 3	52,000
Nathan Slaton	Trenton Roberts and Gerson Drescher	Post-Doctoral Position and Graduate Assistantships	2 of 3	151,666
Tina Teague	N.R. Benson and John Nowlin	Optimizing Fertilizer Management in Arkansas Cotton in Rotation with Peanut	3 of 3	20,000
			Total:	**455,010**

DIVISION OF AGRICULTURE

RESEARCH & EXTENSION

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