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Wayne E. Sabbe Arkansas Soil Fertility Studies 2022

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Nathan A. Slaton and Mike Daniels, Editors

DIVISION OF AGRICULTURE
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Cover: Lauren McCullough of Good Roots, an Arkansas PBS program on agriculture, interveiws Steve Stevens of Dumas, one of the farmers taking part in the Arkansas Discovery Farm program. (U of A System Division of Agriculture photo by Lee Riley).

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WAYNE E. SABBE
ARKANSAS
SOIL FERTILITY STUDIES
– 2022 –

Nathan A. Slaton and Mike Daniels, Editors
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 2022 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 2021 plus nine research reports from projects evaluating soil fertility, nutrient fate, or response to fertilization of forages, row crops, and blackberries conducted in 2022 and a supplemental section showcasing ten reports from the Arkansas Discovery Farms Program.

The Arkansas Discovery Farms Program was established in 2010 with programmatic leadership from Drs. Mike Daniels and Andrew Sharpley for the purpose of conducting water quality research on privately-owned, working row crop and livestock farms. The Arkansas Discovery Farms Program collects data from farms with diverse production systems to evaluate the effectiveness of soil and water conservation practices at the field- and farm-scale levels. The ten reports highlight the efforts of cooperating farmers, students, staff, and faculty who work as a team to make this program highly successful. More information on the Arkansas Discovery Farms Program can be found at https://aaes.uada.edu/centers-and-programs/discovery-farm-program/.

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.

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

This publication is available as a research series online at:
https://aaes.uada.edu/communications/publications/

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Discovery Farms Program Research

Arkansas Soil-Test Summary for Samples Collected in 2021

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 2021 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 2021, 167,656 client soil samples submitted by the public were analyzed. Of the total samples, 44,830 were submitted as field-average samples, representing 990,969 acres for an average of 20 ac/sample. Grid soil samples accounted for 122,823, or 73% of all submitted samples. Soil samples from the Southern Mississippi River Alluvium, River Terraces, and Valley Loess, geographic areas with row-crop agriculture, represented 43% of the total field-average samples and 66% of the total acreage. Soil association numbers show that most samples were from soils common to row-crop and forage production. Crop codes with near complete metadata indicate that land used for i) row-crop production accounted for 65% and 37%, ii) hay and pasture for 18% and 19%, and iii) home lawns and gardens accounted for 8% of sampled acreage and 28% of submitted samples, respectively. This report includes a summary of the gradual upward trends in median soil pH and the gradual downward trends of Mehlich-3 extractable P, K, and Zn for soil cropped to corn (*Zea mays*), cotton (*Gossypium hirsutum*), rice (*Oryza sativa*), soybean (*Glycine max*), and warm-season grass for hay production for 2006–2021.

Introduction

The University of Arkansas System Division of Agriculture has a rich history in agricultural services, including soil testing. The Fertilizer Tonnage Fee was established in the 1950s with the funds used to provide Arkansas citizens with low-cost soil-testing services for nutrient management and research. The Arkansas Soil Testing Program has grown over the years and is the second-largest public soil-testing program in the United States regarding 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, most of the soil samples are believed to be submitted to and analyzed by the University of Arkansas System Division of Agriculture's Marianna Soil Test Laboratory (MSTL), located in Marianna, Ark. The large number of soil samples analyzed annually by the MSTL creates a 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 2021 and includes a special summary detailing the trends in median soil pH and Mehlich-3 extractable P, K, and Zn for soil cropped to corn (*Zea mays*), cotton (*Gossypium hirsutum*), rice (*Oryza sativa*), soybean (*Glycine max*), and warm-season grass for hay production.

Procedures

Soil-test data from samples submitted to the MSTL between 1 January 2021 and 31 December 2021 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 not completed at the time of sample submission 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. 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 spectro-

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photometer (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. A 16-year summary from 2006-2021 shows the trends in median soil pH and Mehlich-3 extractable P, K, and Zn for soil cropped to corn, cotton, rice, soybean, and warm-season grass for hay production.

Results and Discussion

Between 1 January 2021 and 31 December 2021, there were 183,949 soil samples analyzed by the MSTL. After removing 15,288 standard-solution and check-soil samples measured for quality assurance, the total number of client (e.g., researchers, growers, and homeowners) samples was 168,661 comprising 1005 research and out-of-state samples and 167,656 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 1,780,735 acres for an average of 15 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 167,656 client samples, 122,823 (73%) were submitted as grid samples. The balance of the samples (44,830) 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 for 77% of the submitted samples, followed by grid sizes of 5.0 acres (9.9% samples), 2.0 acres (7.5%), 1.0 acre (1.7%), 4 acres (1.4%), and 10 acres (1.4%). The five counties with the most grid samples submitted include Crittenden (19,460 samples); Poinsett (18,828); Clay (16,280); Little River (10,678); and Mississippi (8,408), with most of these samples being grid samples. 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 43% of the total field-average samples and 66% 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 38 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 2,872 (Clarksville-Nixa-Captina-Jay), 2,770 (Dundee-Dobbs-Bosket-Sharkey), 2,444 (Dewitt-Stuttgart), 1,735 (Ethel-Immanuel-Lagrue-Henry), and 1,713 (Carnasaw-Clebit-Sherless-Pirum). However, the soil associations representing the largest acreage were 85,745 (Ethel-Immanuel-Lagrue-Henry), 83,847 (Dundee-Dobbs-Bosket-Sharkey), 75,266 (Dewitt-Stuttgart), 73,436 (Henry-Grenada-Calloway-Calhoun), and 28,969 (Perry-Portland-Rilla), which represented 14%, 14%, 12%, 12%, and 5% 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 64% of the sampled acreage and 36% of submitted samples, ii) hay and pasture production accounted for 18% of the sampled acreage and 19% of submitted samples, and iii) home lawns and gardens accounted for 8% of sampled acreage and 30% of submitted samples (Table 4). Among row crops listed in Table 4, 35% 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 3.00 million harvested acres in 2021, respectively (USDA-NASS, 2021). 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 6.6 (Table 5). However, the predominant soil pH range varies among Arkansas counties (Table 6) and cropping systems (Table 7).

Table 7 summarizes the percentage of acreage from field-average soil samples that falls within selected soil-test levels (as defined by concentration ranges) and the median concentrations for each of the cropping system categories. Soil-test nutrient availability index values 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 rice and soybean in the rotation, and the lowest median K concentrations occur in soils following hay and turf codes. Soil collected following cotton and wheat (*Triticum aestivum*) 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.

Sixteen-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. For crops grown on well-buffered soils, the annual change in soil pH and soil-test P and K values can be relatively small and be overwhelmed by fluctuations from spatial and temporal variability. One advantage of public soil-testing programs is that annual soil nutrient summaries allow for trends across time to be tracked, and the data represents a relatively large number of samples each year. We last reported 10-year trends (DeLong et al., 2017) and extended these trends using data from 2016-2021 (DeLong et al., 2018, 2019, 2020, 2021, 2022). The trends in median soil pH and Mehlich-3 extractable P, K, and Zn for soil cropped to corn, cotton, rice, soybean, and warm-season grass for hay production are shown in Figs. 1 through 4.

The slow increase in soil pH in row-crop fields is partially due to the use of groundwater high in calcium and magnesium bicarbonates for irrigation (Fig. 1). Periodic low soil pH values that deviate from the overall trend in soil pH may reflect dry post-harvest soil conditions at the time of sample collection, which may cause soil pH to be lower than normal.

Mehlich-3 extractable P is declining for all cropping systems, with the trend for the greater rates of decline for soils with the greatest median soil-test P values (warm-season grasses and cotton, Fig. 2). Linear regression through the annual data points shows the median soil-test P has declined by 2.4 ppm/year for warm-season grass hay, 1.8 ppm/year for cotton, 1.1 ppm/year for corn, and are relatively stable (<0.5 ppm/year) for rice and soybean.

Similar 16-year trends were found for Mehlich-3 extractable K (Fig. 3). Soils used for warm-season grass hay production initially had intermediate soil-test K values but, after 16 years, now have the lowest median K values due to the greatest rate of soil-test K decline (2.8 ppm/year), especially between 2006 and 2010. Decreasing soil-test P and K values on soils used for warm-season grass production is likely due to restrictions on the use of poultry litter on those soils and limited use of commercial fertilizers containing P and K to fertilize pastures and hay fields. The rate of soil-test K decline was 2.6 ppm/year following corn, 2.4 ppm/year following cotton, 1.2 ppm/year following rice, and stable following soybean (<0.5 ppm/year). The slow decline of soil-test P and K in soils used for row-crop production may be related to variable rate fertilization, greater nutrient export from high crop yields, increased nutrient loss, or combinations of these and other factors. The fertilizer tonnage of P and K fertilizers sold in Arkansas has fluctuated some but, on average, has not declined appreciably during this 16-year period (data not shown). The trend could also be due to a bias in the data as the number of field-average soil samples submitted during this time has declined since 2006 as more farmers are using grid soil samples which are not represented in these data.

Mehlich-3 extractable Zn is also declining across time for all five of the crops represented in this summary (Fig. 4), with rates of decline from <0.1 to 0.2 ppm/year. Soil samples collected following corn had the least decline across time and suggest a recent trend to increase slightly. Possible reasons for soil-test Zn to decline include reduced application of poultry litter to soils used for warm-season grass hay production and the marketing of row-crop fertilization strategies that use relatively low Zn rates, including in-furrow bands, seed treatments, and Zn coating on macronutrient fertilizers rather than broadcast application of granular Zn fertilizers.

Practical Applications

Grid soil samples continue to represent 70–75% of all soil samples submitted to the MSTL. Of the non-grid soil samples submitted with near complete metadata in 2021, 55% of the samples and 83% 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 showed the upward trends in median soil pH and the gradual downward trends of Mehlich-3 extractable P, K, and Zn for soil cropped to corn, cotton, rice, soybean, and warm-season grass for hay production for 2006–2021.

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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 2021 through 31 December 2021.

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	131,516	7	5,492	3	24	Lee	123,031	7	6,680	4	18
Ashley	3,474	0	254	0	14	Lincoln	3,201	0	187	0	17
Baxter	1,423	0	294	0	5	Little River	30,219	2	10,807	6	3
Benton	11,351	1	1,771	1	6	Logan	3,494	0	282	0	12
Boone	11,983	1	590	0	20	Lonoke	147,286	8	4,995	3	29
Bradley	417	0	62	0	7	Madison	6,280	0	445	0	14
Calhoun	349	0	37	0	9	Marion	3,442	0	188	0	18
Carroll	7,157	0	378	0	19	Miller	9,428	1	316	0	30
Chicot	11,259	1	603	0	19	Mississippi	24,165	1	8,549	5	3
Clark	8,581	0	1,205	1	7	Monroe	17,711	1	760	0	23
Clay	51,115	3	16,596	10	3	Montgomery	2,401	0	190	0	13
Cleburne	6,591	0	415	0	16	Nevada	3,923	0	189	0	21
Cleveland	673	0	62	0	11	Newton	2,302	0	171	0	13
Columbia	1,277	0	159	0	8	Ouachita	232	0	111	0	2
Conway	9,728	1	472	0	21	Perry	2,453	0	101	0	24
Craighead	36,832	2	8,135	5	5	Phillips	18,297	1	1,847	1	10
Crawford	4,595	0	423	0	11	Pike	713	0	60	0	12
Crittenden	78,036	4	21,106	13	4	Poinsett	106,556	6	20,710	12	5
Cross	45,737	3	4,072	2	11	Polk	6,923	0	399	0	17
Dallas	591	0	62	0	10	Pope	1,898	0	341	0	6
Desha	24,353	1	7,774	5	3	Prairie	38,666	2	1,879	1	21
Drew	2,146	0	409	0	5	Pulaski	9,913	1	1,347	1	7
Faulkner	27,858	2	922	1	30	Randolph	12,632	1	1,092	1	12
Franklin	5,520	0	249	0	22	Saline	8,442	0	3,314	2	3
Fulton	4,522	0	329	0	14	Scott	1,513	0	103	0	15
Garland	2,757	0	1,886	1	1	Searcy	2,092	0	153	0	14
Grant	406	0	119	0	3	Sebastian	1,424	0	621	0	2
Greene	114,420	6	9,252	6	12	Sevier	9,517	1	337	0	28
Hempstead	3,382	0	218	0	16	Sharp	6,881	0	328	0	21
Hot Spring	2,110	0	177	0	12	St. Francis	8,723	0	385	0	23
Howard	3,377	0	228	0	15	Stone	3,974	0	310	0	13
Independence	5,092	0	506	0	10	Union	2,174	0	236	0	9
Izard	5,708	0	268	0	21	Van Buren	2,529	0	287	0	9
Jackson	286,372	16	5,758	3	50	Washington	27,334	2	2,804	2	10
Jefferson	39,709	2	1,662	1	24	White	8,299	0	1,103	1	8
Johnson	4,516	0	331	0	14	Woodruff	50,580	3	953	1	53
Lafayette	2,003	0	144	0	14	Yell	4,457	0	281	0	16
Lawrence	110,705	6	2,375	1	47	Sum or Avg.	1,780,735		167,656		15

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 2021 through 31 December 2021.

Geographic area	Acres Sampled	% of total acres	No. of samples	% of total samples	Acres/ sample
Ozark Highland	78,482	13	5,568	19	14
Boston Mountains	24,880	4	2,122	7	12
Arkansas Valley and Ridges, Eastern Part	26,397	4	1,925	7	14
Ouachita Mountains	18,498	3	3,242	11	6
Southern Mississippi River Alluvium	156,555	25	5,139	18	30
Arkansas River Alluvium	35,028	6	1,250	4	28
Red River Alluvium	4,688	1	487	2	10
Southern Mississippi River Terraces	161,228	26	4,189	15	38
Western Coastal Plain	9,391	2	1,130	4	8
Southern Mississippi Valley Loess	91,344	15	3,020	11	30
Cretaceous Western Coastal Plain	12,602	2	529	2	24
Sum or Average	619,091		28,601		19

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 2021 through 31 December 2021.

						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	15,792	3	759	3	21	6.4	77	145	6.4
2. Clarksville-Nixa-Captina-Jay	28,882	5	2,872	10	10	6.5	64	127	5.9
3. Newnata-Eden-Moko-Summit	1,162	0	86	0	14	6.5	63	120	6.9
4. Alred-Tonti-Gatewood	17,412	3	1,035	4	17	6.2	34	105	3.1
5. Alred-Gatewood-Mano-Ocie	7,766	1	445	2	17	6.5	89	152	9.3
6. Gatewood-Moko-Ocie	78	0	4	0	20	5.5	198	75	15.3
7. Portia-Estate-Moko	458	0	25	0	18	6.3	70	112	7.6
8. Brockwell-Boden-Portia	6,933	1	342	1	20	6.2	43	106	3.8
9. Linker-Enders-Steprock-Mountainburg-Sidon	10,926	2	658	2	17	6.1	60	100	4.6
10. Enders Nella-Steprock-Mountainburg-Linker	13,954	2	1,464	5	10	6.1	70	104	5.3
11. Wrightsville-Sallisaw-Leadvale	694	0	14	0	50	6.5	41	106	5.4
12. Leadvale-Taft	8,665	1	727	3	12	6.1	45	97	5.6
13. Enders-Mountainburg-Steprock-Nella-Linker	4,331	1	319	1	14	6.1	57	97	4.5
14. Spadra-Guthrie-Barling	840	0	26	0	32	6.0	59	71	6.1
15. Mountainburg-Linker-Enders	10,564	2	788	3	13	6.0	50	97	4.4
16. Muskogee-Wrightsville-McKamie-Pickwick	1,303	0	51	0	26	5.7	87	92	6.7
17. Carnasaw-Clebit-Sherless-Pirum	12,825	2	1,713	6	7	6.0	55	114	5.1
18. Ceda-Kenn-Avilla	4,106	1	976	3	4	6.1	50	99	4.4
19. Leadvale-Cane-Sallisaw	476	0	26	0	18	6.0	183	213	14.8
20. Yanush-Avant-Bigfork-Carnasaw-Bismarck	1,091	0	527	2	2	6.1	47	99	3.9
21. Calhoun-Overcup-Amagon	19,600	3	537	2	36	6.6	26	119	3.0
22. Kobel-Yancopin	17,866	3	544	2	33	6.4	28	119	3.0
23. Sharkey-Alligator	11,488	2	511	2	22	6.5	33	296	3.9

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	83,847	14	2,770	10	30	6.3	26	138	2.9
25. Amagon-Dundee-Sharkey	11,110	2	380	1	29	6.5	34	112	3.7
26. Commerce-Sharkey-Robinsonville	898	0	40	0	22	6.6	52	155	3.9
27. Sharkey	693	0	31	0	22	6.4	33	194	3.7
28. Tuckermann-Bosket	0	0	0	0	0	--	--	--	--
29. Commerce-Robinsonville-Crevasse	7,866	1	171	1	46	6.4	56	134	3.1
30. Sharkey-Dundee	95	0	6	0	16	6.2	48	105	7.0
31. Sharkey-Bowdre-Tunica	3,093	0	149	1	21	6.2	59	128	4.2
32. Perry-Portland-Rilla	28,969	5	767	3	38	6.6	32	222	2.5
33. Bruno-Crevasse-Coushatta-Norwood	166	0	59	0	3	6.2	36	83	5.3
34. Roxana-Roellen-Dardanelle-Crevasse	1,191	0	57	0	21	6.1	36	93	5.0
35. Rilla-Hebert-Perry	4,478	1	349	1	13	6.3	34	161	3.0
36. Severn-Kiomatia-Choska	143	0	12	0	12	6.1	90	98	5.7
37. Perry-Portland	81	0	6	0	14	6.0	55	140	6.1
38. Billyhaw-Perry-Portland	980	0	100	0	10	5.9	52	85	3.5
39. Severn-Kiomatia	377	0	6	0	63	7.2	21	246	1.3
40. Severn-Oklared-Billyhaw	310	0	19	0	16	7.1	31	76	9.2
41. Severn-Norwood-Moreland	1,041	0	186	1	6	6.3	109	85	7.9
42. Armistead-Gallion-Perry	1,909	0	169	1	11	5.8	57	81	5.1
43. Rilla-Caspiana-Billyhaw-Perry	71	0	7	0	10	6.4	51	201	12.8
44. Dewitt-Stuttgart	75,266	12	2,444	9	31	6.6	25	90	4.5
45. Ethel-Immanuel-Lagrue-Henry	85,745	14	1,735	6	49	6.3	25	99	2.9
46. Oaklimeter-Immanuel	217	0	10	0	22	6.5	42	54	4.7
47. Adaton-Sawyer	2	0	2	0	1	6.5	10	85	2.5
48. Wrightsville-McKamie-Acadia	484	0	18	0	27	6.0	45	82	6.1
49. Amy-Stough-Savannah	1,159	0	97	0	12	6.1	140	146	13.1
50. Sacul-Warnock-Darley-Bibb-Darden	81	0	14	0	6	5.7	26	99	3.1
51. Amy-Stough	1,687	0	254	1	7	6.1	48	82	3.7

continued

Table 3. Continued.

						Median			
SAN Soil association	**Acres sampled**	**% of total acres**	**No. of samples**	**% of total samples**	**Acres/ sample**	**pH**	**P**	**K**	**Zn**
							----------(ppm)----------		
52. Smithdale-Savannah-Sacul-Amy	2,729	0	245	1	11	5.0	57	80	3.1
53. Sacul-Sawyer-Savannah	1,000	0	327	1	3	6.1	50	104	4.4
54. Guyton-Amy	189	0	30	0	6	5.7	33	59	2.2
55. Sacul-Kullit-Bowie	220	0	11	0	20	5.3	53	86	1.7
56. Sacul-Eastwood-Darley	0	0	0	0	0	--	--	--	--
57. Wrightsville-Kolin	0	0	0	0	0	--	--	--	--
58. Sawyer-Sacul-Kipvin	102	0	3	0	34	5.4	6	32	1.2
59. Gladewater-Kaufman-Texark	0	0	0	0	0	--	--	--	--
60. Sawyer-Eylau-Sacul-Woodtell	1,739	0	129	0	0	6.0	37	73	3.7
61. Henry-Grenada-Calloway-Calhoun	73,436	12	1,708	6	0	6.8	26	87	3.2
62. Loring-Oaklimeter	1,025	0	141	0	0	6.6	42	136	4.9
63. Loring-Memphis-Collins	5,001	1	851	3	6	6.2	37	120	3.9
64. Brandon-Saffell-Memphis-Collins	10,953	2	301	1	36	6.4	32	104	5.8
65. Hillemann-Grubbs-Henry	930	0	19	0	49	7.0	17	85	2.0
66. Sumter-BIllstown-Japany	3,064	0	87	0	35	6.0	36	80	3.5
67. Peanutrock-Pikecity-Tiak-Antione	7,494	1	299	1	25	6.0	90	97	6.5
68. Tiak-Antione	322	0	36	0	9	6.0	41	85	3.1
69. Guytown-Ocklockonee-Sardis	365	0	44	0	8	6.2	56	66	1.8
70. Blevins-Tiak-Peanutrock	1,357	0	63	0	22	5.8	155	88	12.4
Sum or Average	619,091		28,601		18	5.8	51	106	4.8

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 2021 through 31 December 2021.

Previous crop	Acres Sampled	% of total acres	No. of samples	% of total samples	Acres/ sample
Corn	112,133	11	2,212	5	51
Cotton	26,016	3	999	2	26
Grain sorghum, non-irrigated	309	0	21	0	15
Grain sorghum, irrigated	1,569	0	65	0	24
Rice	153,263	15	3,324	7	46
Soybean	344,736	35	9,526	21	36
Wheat	6,116	1	211	0	29
Cool-season grass hay	4,452	0	293	1	15
Native warm-season grass hay	4,031	0	238	1	17
Warm-season grass hay	39,511	4	1,732	4	23
Pasture, all categories	128,368	13	6,142	14	21
Home garden	5,625	1	3,615	8	2
Turf	1,376	0	991	2	1
Home lawn	68,896	7	8,722	19	8
Small fruit	853	0	445	1	2
Ornamental	4,023	0	1,144	3	4
Miscellaneous[a]	89,696	9	5,150	11	17
Sum or Average	990,969		44,830		20

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

Table 5. The percentage of sampled acres as distributed within five soil-test levels and median soil chemistry 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 2021 through 31 December 2021.

	Soil pH[a]						Mehlich-3 soil phosphorus[b] (ppm)					
Geographic area	<5.4	5.4–5.7	5.8–6.2	6.3–6.9	>6.9	Md[c]	<16	16–25	26–35	36–50	>50	Md[c]
	------(% of sampled acreage)------						------(% of sampled acreage)-----					(ppm)
Ozark Highland	4	8	26	42	21	6.4	11	12	10	13	54	57
Boston Mountains	10	19	32	26	13	6.1	9	11	10	12	58	66
Arkansas Valley and Ridges, Eastern Part	13	21	31	26	9	6.0	15	13	11	11	50	50
Ouachita Mountains	13	18	31	30	8	6.1	6	14	14	14	51	52
Southern Mississippi River Alluvium	5	9	25	45	16	6.0	17	26	21	18	18	28
Arkansas River Alluvium	7	10	24	37	23	6.4	11	23	21	21	23	33
Red River Alluvium	17	21	25	23	13	6.0	10	9	10	11	60	67
Southern Mississippi River Terraces	8	12	21	30	29	6.5	19	33	25	15	8	25
Western Coastal Plain	17	19	30	24	9	6.0	15	12	10	15	49	50
Southern Mississippi Valley Loess	8	9	17	33	33	6.6	20	23	17	15	25	29
Cretaceous Western Coastal Plain	15	19	31	27	8	6.0	12	11	9	10	58	75
Average	11	15	27	31	16	6.2	13	17	14	14	42	48

	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	14	16	23	18	29	124	11	18	11	23	37	5.3
Boston Mountains	21	22	21	13	23	102	12	21	9	21	36	5.1
Arkansas Valley and Ridges, Eastern Part	22	23	24	14	17	97	12	21	10	25	33	4.9
Ouachita Mountains	16	22	27	19	16	106	7	23	14	28	28	4.7
Southern Mississippi River Alluvium	7	16	24	18	35	136	10	38	20	24	8	3.1
Arkansas River Alluvium	6	14	17	12	52	183	16	41	17	19	7	2.8
Red River Alluvium	27	29	22	9	14	84	15	15	7	25	38	5.6
Southern Mississippi River Terraces	10	37	36	10	7	93	13	27	13	35	11	3.8
Western Coastal Plain	30	22	20	12	17	88	18	22	11	20	29	3.9
Southern Mississippi Valley Loess	12	32	28	14	14	96	13	29	12	26	19	3.6
Cretaceous Western Coastal Plain	30	21	19	11	20	89	17	20	7	16	40	5.0
Average	18	23	24	14	21	109	13	25	12	24	26	4.3

[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 2021 through 31 December 2021.

	Soil pH[a]						Mehlich-3 soil phosphorus[b] (ppm)					
County	<5.4	5.4–5.7	5.8–6.2	6.3–6.9	>6.9	Md[c]	<16	16–25	26–35	36–50	>50	Md[c]
	--------(% of sampled acreage)--------						----------(% of sampled acreage)---------					(ppm)
Arkansas	17	12	18	27	26	6.3	19	29	23	17	13	27
Ashley	11	16	23	38	12	6.2	22	15	11	19	33	38
Baxter	2	6	20	34	38	6.7	11	11	14	14	51	52
Benton	5	7	20	39	29	6.6	4	9	11	14	62	70
Boone	2	6	31	43	17	6.4	2	7	10	15	67	83
Bradley	3	2	11	50	34	6.8	3	2	6	11	77	145
Calhoun	19	22	38	22	0	5.9	3	46	14	16	22	70
Carroll	1	7	31	39	22	6.4	5	0	5	6	84	146
Chicot	3	4	20	53	19	6.5	6	26	30	25	13	31
Clark	16	31	35	15	2	5.8	61	19	7	5	8	12
Clay	2	7	26	53	12	6.4	10	20	20	22	28	36
Cleburne	13	18	27	31	12	6.1	11	14	13	10	52	53
Cleveland	19	21	31	19	10	6.0	35	16	13	6	29	24
Columbia	30	25	24	18	3	5.7	9	9	9	15	57	64
Conway	11	22	28	30	10	6.1	15	10	8	10	57	59
Craighead	4	7	24	47	18	6.4	6	13	15	19	48	49
Crawford	9	20	30	26	15	6.1	16	17	17	13	37	35
Crittenden	4	6	16	45	29	6.6	14	27	24	21	15	29
Cross	2	4	17	41	36	6.7	8	17	18	22	35	40
Dallas	8	32	32	18	10	6.0	15	23	13	11	39	35
Desha	11	19	32	31	6	6.1	7	18	18	23	34	40
Drew	10	27	44	15	4	5.9	14	32	21	14	19	28
Faulkner	14	14	22	35	16	6.3	17	20	13	13	37	35
Franklin	8	29	36	18	8	6.0	10	12	12	16	51	51
Fulton	1	8	26	46	19	6.4	9	20	13	17	42	42
Garland	13	15	33	31	8	6.1	4	15	16	18	46	47
Grant	26	13	36	17	8	5.9	13	12	14	18	43	44
Greene	7	11	27	43	12	6.3	14	22	20	20	24	32
Hempstead	23	24	32	12	9	5.8	15	7	12	13	53	53
Hot Spring	17	27	27	19	11	5.9	29	12	5	10	44	42
Howard	11	25	30	25	8	5.9	2	0	2	5	92	188
Independence	8	15	26	34	17	6.3	12	17	13	14	44	43
Izard	10	14	29	33	14	6.2	7	16	13	19	46	48
Jackson	3	8	21	46	22	6.5	24	24	19	17	15	2
Jefferson	10	15	28	35	12	6.2	5	17	20	28	30	39
Johnson	16	20	31	28	5	6.0	15	14	11	15	46	44
Lafayette	13	18	27	29	13	6.1	6	13	6	8	67	79
Lawrence	3	9	20	42	26	6.6	27	36	18	10	9	22
Lee	4	10	27	46	13	6.4	5	15	22	31	27	39
Lincoln	2	9	9	21	59	7.2	6	20	24	22	27	35

continued

Table 6. Continued.

	Soil pH[a]						Mehlich-3 soil phosphorus[b] (ppm)					
County	<5.4	5.4–5.7	5.8–6.2	6.3–6.9	>6.9	Md[c]	<16	16–25	26–35	36–50	>50	Md[c]
	--------(% of sampled acreage)--------						----------(% of sampled acreage)---------					(ppm)
Little River	4	12	30	36	18	6.3	7	20	22	25	27	36
Logan	18	20	33	19	10	5.9	14	10	7	3	66	87
Lonoke	10	17	30	36	8	6.1	19	26	20	16	19	27
Madison	6	14	40	30	10	6.1	3	8	6	7	77	121
Marion	2	7	23	32	36	6.6	4	6	11	16	63	68
Miller	11	12	23	24	29	6.4	27	19	12	13	28	28
Mississippi	2	4	15	40	40	6.8	18	23	19	20	20	30
Monroe	1	3	12	43	41	6.8	27	31	20	13	9	23
Montgomery	18	23	24	30	5	5.9	6	8	12	8	67	107
Nevada	13	18	37	27	5	6.0	9	17	8	13	53	58
Newton	4	15	33	30	17	6.2	12	17	12	12	47	45
Ouachita	25	18	22	23	12	5.9	12	5	7	11	65	77
Perry	22	27	22	18	12	5.9	8	12	16	12	52	52
Phillips	3	6	18	50	24	6.6	6	17	18	21	38	42
Pike	15	18	23	30	13	6.1	3	10	5	15	67	103
Poinsett	3	5	15	43	35	6.7	7	18	20	24	30	38
Polk	23	28	30	15	5	5.7	6	10	7	6	72	105
Pope	16	16	24	25	18	6.1	11	9	9	10	62	81
Prairie	18	18	22	32	10	6.1	34	34	17	10	5	20
Pulaski	11	12	25	35	18	6.3	9	13	15	12	52	53
Randolph	4	10	32	41	14	6.3	17	26	24	19	14	29
Saline	10	17	29	35	9	6.2	6	13	16	22	44	44
Scott	16	19	28	17	19	5.9	12	12	6	10	61	101
Searcy	3	23	33	27	14	6.1	7	14	15	22	42	43
Sebastian	8	12	24	35	21	6.4	20	16	13	12	39	37
Sevier	14	19	33	27	7	6.0	16	12	7	8	57	69
Sharp	5	16	38	28	13	6.1	23	25	13	13	27	26
St. Francis	14	10	14	36	27	6.5	23	19	13	12	33	32
Stone	10	18	25	27	20	6.2	7	8	12	14	59	63
Union	8	17	30	27	18	6.2	17	8	9	16	51	52
Van Buren	9	21	38	23	9	6.0	12	15	13	13	47	48
Washington	4	5	19	50	22	6.6	11	9	9	14	57	58
White	11	15	29	36	10	6.2	13	14	12	12	49	49
Woodruff	2	6	23	49	20	6.5	15	23	20	18	24	31
Yell	12	28	33	17	9	5.9	10	8	4	8	70	92
Average	10	15	27	32	16	6.2	13	16	14	15	42	54

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	8	27	37	17	11	104	6	26	16	40	12	4.1
Ashley	19	28	19	16	19	98	25	25	11	25	13	3.0
Baxter	8	17	24	27	24	133	5	18	9	24	43	6.6
Benton	5	10	25	27	32	145	2	9	11	35	43	7.0
Boone	11	14	17	16	42	151	6	13	8	24	49	7.9
Bradley	10	24	31	15	21	102	3	18	5	23	52	8.1
Calhoun	16	24	27	19	14	94	19	22	11	30	19	3.6
Carroll	10	9	15	13	52	183	4	8	2	18	67	13.8
Chicot	2	5	8	9	75	289	7	27	28	33	5	3.6
Clark	34	43	17	5	2	70	33	53	7	3	4	1.8
Clay	5	18	32	24	20	121	7	29	22	36	7	3.7
Cleburne	25	24	20	11	20	93	14	25	11	21	29	4.0
Cleveland	45	18	21	10	6	6	29	15	11	16	29	3.3
Columbia	36	16	16	11	19	86	24	25	11	18	23	3.2
Conway	15	24	24	15	22	102	10	20	10	29	32	5.1
Craighead	3	10	21	25	40	155	7	34	24	27	9	3.4
Crawford	25	22	25	15	13	96	6	22	12	29	31	5.0
Crittenden	1	7	15	17	60	201	7	31	26	32	4	3.5
Cross	6	15	19	12	48	166	9	34	20	33	3	3.4
Dallas	29	34	24	5	8	79	23	27	10	15	26	3.0
Desha	6	16	23	15	40	145	9	27	21	38	5	3.7
Drew	25	33	16	12	14	81	11	29	22	28	9	3.5
Faulkner	19	24	25	15	17	100	16	26	11	21	26	3.7
Franklin	18	25	24	16	18	118	5	21	13	29	33	5.6
Fulton	12	21	26	15	26	116	13	28	15	23	21	3.6
Garland	14	27	32	17	10	99	5	27	18	30	20	4.1
Grant	28	23	19	8	22	90	13	20	12	29	26	4.7
Greene	10	23	31	22	14	110	15	40	20	20	5	2.9
Hempstead	25	28	22	11	13	84	19	12	11	26	32	4.8
Hot Spring	46	20	12	14	8	64	21	28	14	16	21	3.1
Howard	13	18	21	14	34	126	3	12	7	20	59	14.5
Independence	25	24	24	12	16	92	16	27	8	20	29	3.9
Izard	11	21	29	19	19	111	18	23	12	25	21	3.8
Jackson	7	20	37	22	14	113	19	43	15	17	6	2.6
Jefferson	8	20	24	17	30	2	10	30	17	28	15	3.6
Johnson	21	31	24	14	11	89	12	26	12	27	24	4.1
Lafayette	22	23	17	15	24	102	17	13	6	17	47	7.0
Lawrence	4	18	31	22	24	125	11	35	20	27	6	3.2
Lee	2	15	28	21	33	137	20	45	16	17	2	2.4
Lincoln	8	11	11	8	62	229	8	41	22	21	9	3.1

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)
Little River	2	14	37	23	24	126	18	43	17	19	3	2.6
Logan	27	25	20	9	20	86	10	18	9	26	39	6.2
Lonoke	9	25	32	15	19	107	22	41	14	17	5	2.4
Madison	15	16	18	16	36	136	7	11	6	22	55	9.0
Marion	5	16	28	19	32	131	2	12	12	26	49	7.3
Miller	22	16	15	9	37	117	32	35	8	11	15	2.0
Mississippi	1	5	17	26	51	177	3	35	33	23	6	3.4
Monroe	12	38	32	13	5	90	11	50	19	17	4	2.6
Montgomery	24	21	26	16	13	96	13	17	7	22	42	6.5
Nevada	33	26	20	11	10	79	17	17	8	21	37	5.4
Newton	23	17	25	12	24	108	19	33	9	15	23	2.8
Ouachita	42	30	16	4	8	69	13	15	5	30	38	6.1
Perry	18	29	28	8	18	96	6	29	11	27	28	4.5
Phillips	3	21	40	24	12	115	16	40	17	24	4	2.8
Pike	32	15	18	17	18	93	8	20	8	13	50	6.9
Poinsett	5	15	21	20	40	151	5	27	24	36	8	3.8
Polk	31	22	18	14	15	83	14	16	7	22	40	6.0
Pope	17	23	25	15	20	103	7	21	8	18	46	7.3
Prairie	13	36	34	8	8	91	43	27	12	15	3	1.8
Pulaski	14	22	23	14	27	112	7	18	12	20	43	6.0
Randolph	11	22	23	13	32	118	14	34	15	28	9	3.2
Saline	8	16	26	22	27	130	5	25	19	33	18	4.1
Scott	25	18	25	12	19	98	2	15	6	18	59	11.0
Searcy	22	22	29	16	12	98	16	42	8	17	16	2.8
Sebastian	13	21	33	18	15	106	5	10	10	28	47	7.5
Sevier	34	17	15	9	25	88	17	18	5	17	42	5.8
Sharp	24	20	24	14	19	101	32	29	9	17	12	2.3
St. Francis	10	25	29	15	21	110	14	33	12	21	19	3.3
Stone	23	20	19	14	24	102	15	23	10	21	32	4.3
Union	39	23	19	14	5	79	13	18	15	18	36	5.2
Van Buren	28	25	19	11	17	84	23	22	14	17	24	3.2
Washington	13	18	25	18	26	120	9	15	11	25	40	5.9
White	28	25	26	11	10	86	16	23	10	23	28	4.1
Woodruff	11	31	34	18	6	98	19	32	14	26	10	3.0
Yell	23	14	20	15	28	117	3	12	7	28	49	7.9
Average	17	21	24	15	23	111	13	25	13	23	26	4.7

[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 2021 through 31 December 2021.

	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	5	11	25	41	19	6.4	10	22	23	22	23	33
Cotton	5	8	27	44	15	6.4	21	12	11	21	35	40
Grain sorghum, non-irrigated	19	24	29	24	5	6.0	19	10	29	24	19	34
Grain sorghum, irrigated	2	14	58	17	9	6.0	9	22	38	22	9	32
Rice	6	11	21	37	25	6.5	24	31	21	15	9	24
Soybean	3	8	21	40	28	6.5	18	31	23	17	11	26
Wheat	8	8	32	40	11	6.3	9	23	21	23	24	33
Cool-season grass hay	8	18	29	33	12	6.2	13	16	16	18	38	40
Native warm-season grass hay	16	28	32	20	5	5.8	17	16	10	14	42	38
Warm-season grass hay	11	21	31	29	9	6.0	12	13	11	12	52	55
Pasture, all categories	10	18	34	31	7	6.1	12	13	11	12	52	55
Home garden	5	7	16	33	39	6.7	4	5	5	7	78	128
Turf	7	14	30	37	12	6.2	16	5	7	9	63	72
Home lawn	12	14	26	33	15	6.2	8	16	17	20	39	41
Small fruit	25	16	22	26	11	5.9	6	11	11	11	62	69
Ornamental	11	10	18	32	29	6.5	10	10	11	13	56	58
Average	10	14	28	32	16	6.2	13	16	16	16	39	49

	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	5	27	35	18	14	106	9	29	15	36	11	3.9
Cotton	4	23	24	25	25	130	24	37	14	22	3	2.5
Grain sorghum, non-irrigated	29	14	10	5	43	106	33	19	14	29	5	3.0
Grain sorghum, irrigated	8	45	31	6	11	89	34	37	17	12	0	1.9
Rice	10	25	27	13	26	110	14	42	17	22	5	2.8
Soybean	7	26	32	14	21	109	16	34	16	27	7	3.0
Wheat	16	21	24	10	29	113	21	36	14	22	7	2.7
Cool-season grass hay	33	28	19	10	11	79	20	31	10	23	16	2.9
Native Warm-season grass hay	42	23	15	9	11	69	22	24	9	19	26	3.5
Warm-season grass hay	37	22	17	11	13	77	15	21	8	22	35	4.9
Pasture, all categories	20	20	21	15	25	108	12	20	10	23	35	5.0
Home garden	10	15	22	18	36	139	4	9	6	18	63	12.4
Turf	35	25	20	9	11	77	6	17	18	29	30	4.8
Home lawn	7	20	29	22	21	120	5	23	16	36	20	4.5
Small fruit	11	21	34	16	19	111	11	20	9	20	40	5.4
Ornamental	15	22	30	18	15	106	7	11	8	20	53	8.7
Average	18	24	24	14	20	103	16	26	12	23	23	4.5

[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.

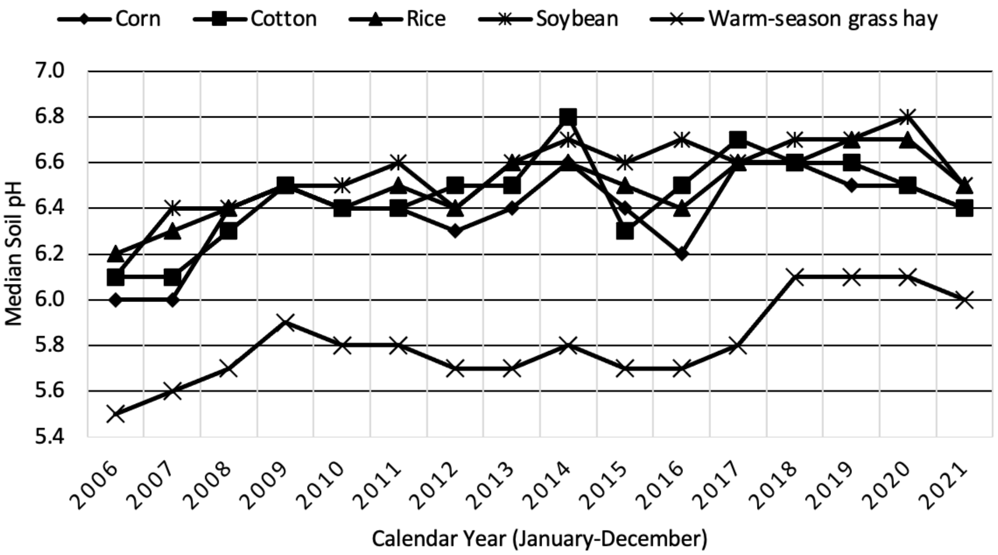

Fig. 1. Sixteen-year trend from 2006–2021 of median pH for Arkansas soils previously cropped to corn, cotton, rice, soybean, and warm-season grass hay.

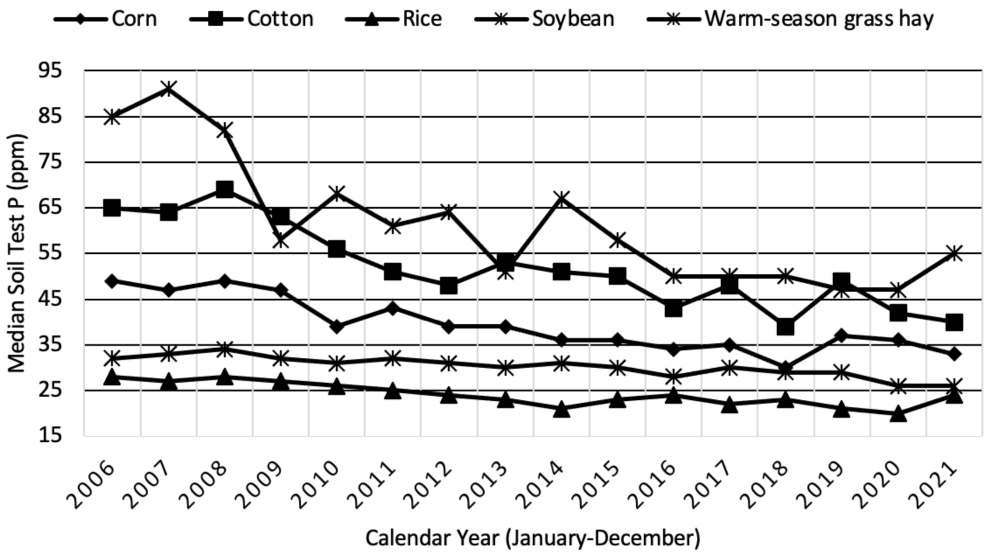

Fig. 2. Sixteen-year trend from 2006–2021 of median M3-P for Arkansas soils previously cropped to corn, cotton, rice, soybean, and warm-season grass hay.

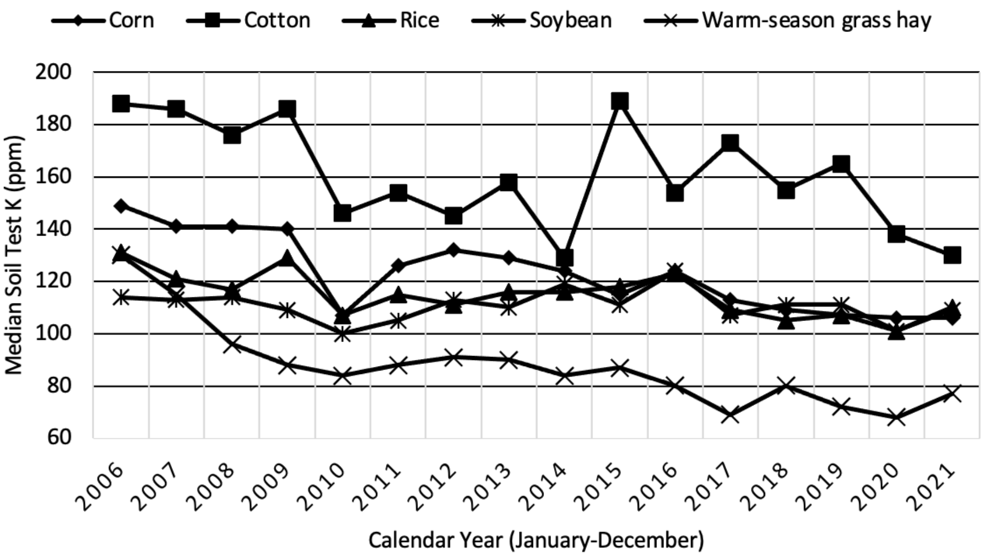

Fig. 3. Sixteen-year trend from 2006-2021 of median M3-K for Arkansas soils previously cropped to corn, cotton, rice, soybean, and warm-season grass hay.

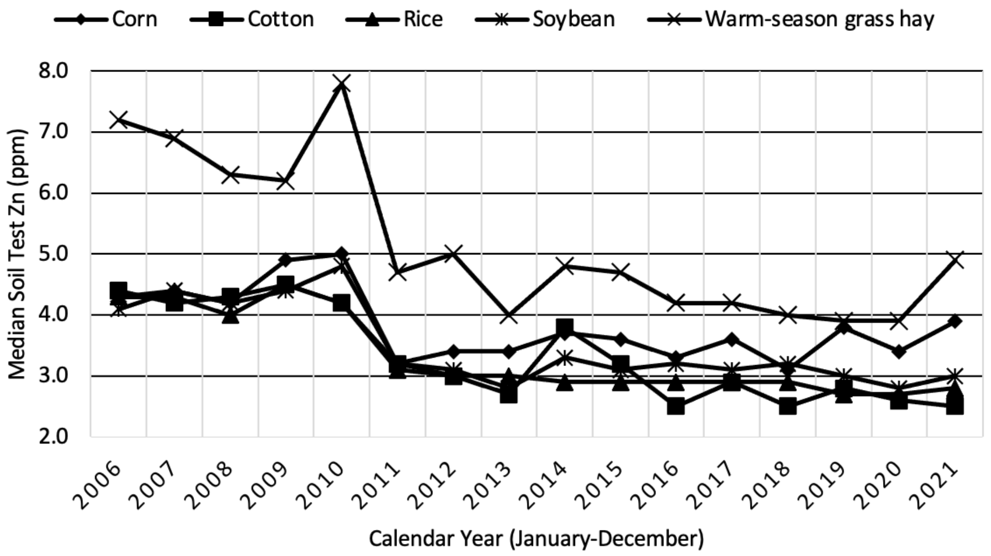

Fig. 4. Sixteen-year trend from 2006-2021 of median M3-Zn for Arkansas soils previously cropped to corn, cotton, rice, soybean, and warm-season grass hay.

Sulfate Loss in Runoff from Arkansas Discovery Farms Research Sites

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Abstract

Nutrient management is an essential function of successful agricultural production. Field-applied nutrient loss via surface runoff poses challenges to Arkansas farmers and producers. While the majority of research regarding nutrient runoff loss has mainly dealt with nitrogen (N) and phosphorus (P), runoff loss of nutrients such as sulfur (as sulfate, SO_4^{2-}) are studied to a lesser extent. In May 2022, the Arkansas Discovery Farms Program (ADF) began research quantifying the concentrations and land area losses of sulfate-sulfur (SO_4-S) collected in edge-of-field runoff samples from 8 ADF locations. These ADF sites are composed of 6 row crop and 2 forage operations. Statistical analysis of preliminary data comparing collected edge-of-field runoff samples by ADF location showed that the row crop systems in Light and Dumas, Arkansas had significantly higher SO_4-S concentrations in edge-of-field runoff samples than all other ADF sites. In terms of SO_4-S losses by land area, Newport, Dumas, Light, and Elkins had significantly higher losses than the other ADF sites. The remaining ADF locations varied in their respective significant differences as well, underscoring the effect of each individual farm's approaches to crop and nutrient management. Statistical analysis of total runoff per acre showed Newport being significantly higher than all other ADF locations. The addition of non-growing season edge-of-field runoff data generated from annual soil sampling events and evaluations of field-applied SO_4-S fertilizer efficiency will provide a clearer view of SO_4-S runoff aspects and its activity in the soil under a variety of cropping systems.

Introduction

Studies regarding the surface runoff potential of applied and soil-inherent nutrients have focused on nitrogen (N) and phosphorus (P). However, other nutrients can also be lost from agricultural fields via surface runoff. While N and P have been broadly investigated concerning surface runoff events, the fate of soil and fertilizer-applied sulfur (S) from edge-of-field runoff events have been examined to a lesser degree in regard to economic and environmental concerns.

Plants consume and utilize S in the form of the sulfate ion (SO_4^{2-}, hereafter abbreviated SO_4-S; McMahon et al., 2007). Sulfate is soluble in the soil, and the discharge of accessible soil SO_4-S relies on microbial activity to be intercepted and assimilated by plant root exudates (Brady and Weil, 2008). Sulfate can also adsorb onto soil particles which can release additional stores of SO_4-S over time (Stewart and Sharpley, 1987). Due to the mobile nature of SO_4-S, any SO_4-S not taken up by plants would seem to be vulnerable to migration (e.g., leaching and runoff) out of the soil system. However, some research has shown that increases in SO_4-S in runoff may be attributed to dry SO_4-S accumulation (Sharpley et al., 1991) and inherent SO_4-S already present in the soil that masks SO_4-S discovery in runoff samples (Zielinski et al., 2006).

Even though crop fertilization programs mostly involve N, P, and potassium (K), SO_4-S is an important constituent of many fertilizer formulations. As such, S fertilization should be a strategic concern in any agricultural production system's nutrient management plan. By measuring the amounts of SO_4-S lost in runoff water and from the soil, a correlation may be made between SO_4-S fertilizers along with future soil testing methods and recommendations (Stewart and Sharpley, 1987).

The Arkansas Discovery Farms Program (ADF) has recently started monitoring SO_4-S runoff from experimental farm sites throughout Arkansas. These farms exemplify a myriad of agricultural interests ranging from row crop farming to forage production. Therefore, the current objectives of this study are to compare the concentrations and land area losses of SO_4-S in edge-of-field surface runoff from 8 ADF experimental locations and to determine differences in total runoff per acre between selected sites.

Procedures

Research data in this report was collected at 8 ADF locations from 2 May to 19 September 2022. Experimental site information is presented in Table 1. Existing ADF sites already equipped with edge-of-field monitoring equipment (Teledyne ISCO, Lincoln, Nebraska) were used to monitor SO_4-S loss in runoff. After a runoff event caused by rainfall or irrigation, flow-weighted runoff water samples were thoroughly mixed and filtered with a 0.45-micron filter with no acid and stored cold (EPA Method 300.0). These SO_4-S sampling procedures were in accordance with sampling guidelines by the United States Environmental Protection Agency (USEPA, 2016). The date, flow data provided from the ISCO sampler, and the type of sample (ISCO or grab) were recorded and entered into a project sampling log for future reference. The samples were transported to an accredited water quality laboratory for SO_4-S analysis. Additional SO_4-S grab samples were collected from 2 tailwater reservoirs at Stuttgart, along with a holding pond and ephemeral creek at Elkins.

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Statistical analysis was performed in SAS 9.4 by employing a generalized linear mixed model (PROC GLIMMIX) using a gamma distribution and a natural logarithm link comparing SO_4-S concentrations and losses in runoff from individual ADF sites and the 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.).

Results and Discussion

Analysis of SO_4-S edge-of-field runoff concentrations by ADF location showed Dumas and Light having similar SO_4-S concentrations that were significantly ($P \leq 0.05$) greater than all other ADF sites (Table 2). The Elkins, Delaplaine, and Cherry Valley sites had similar and intermediate SO_4-S concentrations that were greater than the Newport, Stuttgart, and Wedington sites. The analysis of SO_4-S loss per unit of land area showed that Newport, Dumas, Elkins, and Light had growing season losses ranging from 1.1 to 1.9 lb SO_4-S/ac that were significantly greater than the SO_4-S losses from the Cherry Valley and Wedington sites (Table 2). The Wedington sight is a pasture-raised beef and sheep farm and had the lowest SO_4-S loss, whereas the Elkins location is a combined poultry and forage operation. The close proximity of poultry houses to sampling sites at the Elkins farm and the subsequent application of poultry litter to its surrounding fields can lead to increased nutrient loading, which is reflected in the significant differences in SO_4-S concentrations and land area losses between these two sites.

A preliminary analysis of total runoff per acre showed Newport having significantly higher runoff than all the other ADF sites (Table 2). Elkins, Light, Dumas, and Cherry Valley all had similar total runoff values and were greater than Wedington. As a result of ISCO malfunctions at the Delaplaine and Stuttgart sites, flow data were not collected, and total runoff analyses were not performed.

Practical Applications

The results of this report show significant differences in SO_4-S concentrations and land area losses in edge-of-field runoff among selected ADF research locations. These locations represent agricultural systems such as row crop farming as well as livestock and poultry/forage production. Any quantification and analysis of SO_4-S runoff loss and total runoff volumes should consider different farming strategies concerning nutrient management, crop selection, and the type of production system. Soil testing for SO_4-S at these ADF sites, along with detailed nutrient management information about each ADF location, will present additional clarity into SO_4-S runoff dynamics.

Acknowledgments

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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 2022, 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	Soybean/Rice	89	Foley-Bonn
Dumas	Desha	4	Cotton	111	Herbert
Elkins	Washington	3	Crabgrass/Bermudagrass	29	Cherokee
Light	Greene	2	Rice	62	McCrory
Newport	Jackson	3	Rice	63	Egam
Stuttgart	Arkansas	2	Corn	150	Tichnor/ Dewitt
Wedington	Washington	3	Crabgrass/Bermudagrass/ Johnsongrass[g]	269	Pembroke

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

Table 2. Arkansas Discovery Farms (ADF) 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	7.0 b	14	0.4 b	14	0.3 b	14
Delaplaine	7.0 b	28	N.A.‡	N.A.‡	N.A.‡	N.A.‡
Dumas	25.6 a	20	1.7 a	20	0.3 b	20
Elkins	10.6 b	29	1.2 a	13	0.4 b	13
Light	27.1 a	10	1.9 a	8	0.4 b	8
Newport	2.4 c	24	1.1 a	24	1.9 a	24
Stuttgart	3.3 c	19	N.A.‡	N.A.‡	N.A.‡	N.A.‡
Wedington	2.9 c	12	0.0 c	7	0.0 c	7

† Values within a column having different lowercase letter are significantly different ($P \leq 0.05$).

‡ Flow values for Delaplaine and Stuttgart are not available for calculating SO_4-S land area losses and total runoff at this time.

Bermudagrass Forage Yield and Soil Nutrient Availability Response to Phosphorus and Potassium Fertilization

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Abstract

Hay production removes vegetative material and its compositional nutrients from the field. If soil nutrients are not replenished with adequate fertilizer rates, nutrient deficiencies will develop, affecting forage yields and quality. Field studies were initiated in 2019 and repeated in 2020, 2021, and 2022 in Batesville and Fayetteville, Ark., to monitor bermudagrass (*Cynodon dactylon* L.) yield responses to phosphorus (P) and potassium (K) fertilization. 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, following harvest 1, and following harvests 1 and 2. In K-rate trials, 0, 70 (35 × 2), 150 (50 × 3), 225 (75 × 3), 300 (100 × 3), and 375 (125 × 3) lb K_2O/ac were applied as muriate of potash, using previously defined application timings. Soil nutrient availability and bermudagrass yield were assessed in 2022. Soil-test K results at both sites reflect the expected influence of annual fertilizer rate with rates greater than forage K removal increasing soil-test K and vice versa. Fertilizer-K rates affected forage yields, with rates ≥70 and 150 lb K_2O/ac producing maximum yields, which were 72 and 83% greater than the no-fertilizer-K control for the season total forage production at Batesville and Fayetteville, respectively. Soil-test P and K increased with increasing fertilizer-P and -K rates at both locations. In Batesville, P-fertilized plots produced greater forage yield in one of the three harvests (26% yield increase on average) and for season-total forage biomass production (19% yield increase on average). Sub-optimal P and K fertilization result in yield reduction, while high fertilizer rates build up soil-test levels and likely increase nutrient removal.

Introduction

In Arkansas, there are 1.3 million acres of hay production, with an additional 3.2 million acres of pasture (USDA-NASS, 2017). Thus, decisions regarding soil nutrient management in forage production will affect more acres than any other agricultural commodity crop in the state. Among the essential nutrients for proper plant growth, 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).

Surveys indicate that the majority of 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 from each site, exporting great quantities of nutrients, especially P and K, each year. Furthermore, hayland acres are commonly not fertilized annually and, therefore, may produce forage yields that are likely low or that may decline across 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 K or P fertilization may vary according to the forage species, soil, and field management history (Adjei et al., 2001), which requires additional studies to evaluate forage yield responses and nutrient removal when subjected to different soils, nutrient availability, and fertilizer-P and -K rates.

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

Procedures

Field studies were established on Arkansas Agricultural Experiment Station (AAES) properties in the spring of 2019 and repeated in 2020, 2021, and 2022 to evaluate the effects of P and K fertilization on bermudagrass hay yields, nutrient removal, and soil nutrient contents. Trials were located in Fayetteville, Ark., at the Milo J. Shult Agricultural Research and

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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. Visual inspection of each site in spring 2019 determined both locations exhibited uniform stands of bermudagrass. Each selected site was managed uniformly with no history of fertilization experiments with varying fertility rates. Records indicate that 'Greenfield' bermudagrass was sprigged at the SAREC site in 2012 and that 'Hardie' bermudagrass was sprigged at the LFRS site in 1984. Trials were repeated in each location in 2022, with the plots receiving identical fertilizer-P and -K rate treatments from 2019, 2020, and 2021. 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), but relevant soil Mehlich-3 extractable P and K values from 2019, 2020, and 2021 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 to 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, following the first harvest, and following the second harvest. This trial was conducted at two sites, and environmental differences affected the timing of fertilizer applications. Therefore, fertilizer applications during green-up, following the first harvest, and following the second harvest occurred on 19 April and 29 April; 28 June and 17 June; and 7 September and 25 August 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 179 lb N/ac.

In the P trials, fertilizer-P was applied over two to three applications to reach the cumulative season-total rates. Triple superphosphate was applied at rates of 0, 30 (×1), 60 (30 × 2), 90 (30 × 3), 120 (40 × 3), and 150 (50 × 3) lb P_2O_5/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.

Soil-test results from 2021 indicated that Mehlich-3 extractable Mg and S were decreasing to sub-optimal levels at both locations, and, therefore, blanket applications of 155 lb/ac of magnesium sulfate (9.8% of Mg and 12.9% of S) were applied at green-up in all trials in 2021, for a season total of 19 and 20 lb of Mg and S/ac, respectively. Additionally, the fertilizer-P trial at Batesville received 1750 lb/ac of pelletized lime in 2021 to maintain soil pH at adequate levels for bermudagrass plant growth, and the trials in Fayetteville received 600 lb/ac of pelletized lime in the Spring of 2022.

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 disclosed 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 yield. The total hay yield was calculated by summing dry matter yield 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. Plant tissue analysis has not been completed for all harvests, and therefore, the nutrient concentrations and total P and K removal in harvested hay are not presented in this report.

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, Inc., Cary, N.C.). Forage yield data from 2022 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, separate ANOVA was conducted and reported for each location. Means were separated using Fisher's protected least significant difference (LSD) ($P < 0.05$). 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 fourth year of fertilizer-K and -P rates applied to the same plots in Fayetteville trials and the fourth and second year of fertilizer-K and -P rates, respectively, applied in Batesville. Since the Batesville fertilizer-P trial was reestablished in 2021 and soil samples were collected before fertilizer application in 2022, soil-test P results presented in Table 2 reflect only one year of fertilizer-P treatment application.

Potassium Fertilization

Mehlich-3 extractable K was significantly ($P < 0.05$) affected by fertilizer-K rates in Batesville and Fayetteville (Table 2). A clear pattern is detectable in the 2022 soil-test results at both locations, indicating that soil-test K is increasing as the fertilizer-K rate increases. The 2022 soil-test results show that the K level among fertilizer-K treatments at both locations was either Low (0 and 70 lb K_2O/ac), Medium (150 lb K_2O/ac), Optimum (225), or Above Optimum (300 and 375 lb K_2O/ac).

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). Overall, the greatest yields observed either as individual harvests or accumulated season yields occurred for treatments receiving ≥150 lb K_2O/ac in Fayetteville and ≥70 lb K_2O/ac in Batesville, except for the third harvest, where 70 lb K_2O/ac in Fayetteville and ≥150 lb K_2O/ac in Batesville maximized hay yields. The relatively low forage yields for the third harvest (especially in Fayetteville) were related to drought during 2022. We observed that the fertilized treatments, on average, resulted in 79 and 83% yield increases compared to the no-fertilizer-K treatment at Fayetteville and Batesville, respectively. This behavior indicates that adequate fertilizer-K management is a substantial factor for profitable forage production.

Phosphorus Fertilization

The mean Mehlich-3 extractable P concentration of 27 ppm (Table 1) in the fertilizer-P trial established in 2021 in Batesville was near the lower boundary of the Medium (26–35 ppm) soil-test P category. After the first year of fertilizer-P application, soil-test results significantly ($P < 0.05$) differed at this location, with the highest soil-test P occurring at the 120 lb P_2O_5/ac rate, which did not differ from the 150 lb P_2O_5/ac treatment. Soil-test P among the P-rate treatments is now in the Low (0 lb P_2O_5/ac), Medium (30 lb P_2O_5/ac), Optimum (60 and 90 lb P_2O_5/ac), and Above Optimum (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 all above the Optimum soil-test P level (36–50 ppm) and show significant ($P < 0.05$) differences from the cumulative effect of the annual fertilizer rates applied in the last three years (Table 2). The lowest soil-test P values were observed in the 0 and 30 lb P_2O_5/ac treatments, 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.

Soil-test P is at the Above Optimum level in the Fayetteville P trial, and therefore, no significant forage yield response to fertilizer-P treatments was observed at this site (Table 4). In contrast to the Fayetteville site, the bermudagrass forage yield at Batesville was significantly ($P < 0.05$) affected by fertilizer-P rate for the first harvest and the season-total hay yield. For the first harvest, fertilizer rates ≥30 lb P_2O_5/ac produced maximum yields with an average of 4778 lb forage/ac, which is about 26% greater than the no-fertilizer-P control. It is worth noting that near-significant numerical yield differences were observed for the third harvest. Similar to the first harvest, fertilizer rates ≥30 lb P_2O_5/ac also showed maximum forage yield for the season-total biomass production (average of 12,001 lb forage/ac, which is a 19% increase in relation to the no-fertilizer-P control). These results show that sub-optimal P supply impacts bermudagrass growth, resulting in significantly lower forage yields. Greater yield differences are expected among fertilizer-P treatments as this trial continues.

Practical Applications

The 2022 harvest season is the fourth 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). Current findings of these experiments indicate that soil-test K has changed greatly from 2019 (Low) to 2022 (Low to Above Optimum) in response to the fertilizer-K treatments, which is reflected in the forage yield. Sub-optimal P supply (via soil or fertilization) impacted the bermudagrass growth and resulted in lower forage yield in one of three harvests performed in Batesville and the season's total biomass production. While greater yield differences are expected among fertilizer-P treatments as the Batesville P trial continues, the fertilizer-P trial in Fayetteville has an Above Optimum soil-test level (>50 ppm P), and no yield responses have been observed to additional P application, but soil-test P values are increasing with the higher fertilizer-P rates. 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. Continuing these studies in the long term is critical to better understand the consequences of sub-optimal P and K fertilization rates in forage production systems and to fine-tune fertilizer-P and -K recommendations for profitable bermudagrass hay production offered by the University of Arkansas System Division of Agriculture.

Acknowledgments

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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, and 2022.

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	N/A	-[‡]	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
	K	2019	5.4	72	68	739	45	12	7	203	191	6.2	2.2	0.3
		2020	N/A	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
Batesville	P	2019	5.7	29	66	979	43	16	9	109	309	0.5	0.6	0.3
		2020	N/A	-[‡]	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
	K	2019	5.6	32	65	947	33	18	8	120	325	0.5	0.6	0.3
		2020	N/A	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

[†] 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.

N/A = data not available.

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

	Fayetteville Potassium Trial				Batesville Potassium Trial			
Seasonal Total K_2O rate[‡]	**2019**	**2020**	**2021**	**2022**	**2019**	**2020**	**2021**	**2022**
(lb K_2O/ac)	------------- **Mehlich-3 K (ppm)** -------------				------------- **Mehlich-3 K (ppm)** -------------			
0	67	46 d	49 e	62 e	65	74 cd	50 d	63 e
$70^{\times 2}$	66	53 d	58 e	78 e	62	60 d	58 d	72 e
$150^{\times 3}$	63	80 c	100 d	114 d	64	101 bc	94 c	111 d
$225^{\times 3}$	63	83 c	133 c	165 c	65	94 bcd	124 b	161 c
$300^{\times 3}$	73	109 b	160 b	211 b	68	123 ab	201 a	216 b
$375^{\times 3}$	75	140 a	187 a	259 a	65	160 a	226 a	280 a
***P*-value**	0.3446	<0.0001	<0.0001	<0.0001	0.6741	0.0007	<0.0001	<0.0001
C.V. (%)	N/A	N/A	16.9	12.9	N/A	N/A	17.7	11.0
	Fayetteville Phosphorus Trial				**Batesville Phosphorus Trial**			
P_2O_5 rate[‡]	**2019**	**2020**	**2021**	**2022**	**2019**	**2020**	**2021[§]**	**2022**
(lb P_2O_5/ac)	------------- **Mehlich-3 P (ppm)** -------------				------------- **Mehlich-3 P (ppm)** -------------			
0	100	94 bc	97 c	83 d	27	19	22	22 d
$30^{\times 1}$	92	88 c	96 c	85 d	29	22	28	32 cd
$60^{\times 2}$	99	102 abc	113 b	107 c	27	21	30	38 bc
$90^{\times 3}$	93	107 ab	121 b	127 b	29	21	25	38 bc
$120^{\times 3}$	97	109 ab	148 a	151 a	30	25	31	54 a
$150^{\times 3}$	92	111 a	143 a	156 a	30	21	23	47 ab
***P*-value**	0.6608	0.0344	<0.0001	<0.0001	0.7193	0.1015	0.1819	0.0042
C.V. (%)	N/A	N/A	10.8	10.6	N/A	N/A	24.5	29.7

[†] 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. 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 and P 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.

N/A = data not available.

Table 3. Bermudagrass hay yields in response to K fertilization in Fayetteville and Batesville locations during the 2022 growing season.[†]

	Potassium Trial							
	Fayetteville				Batesville			
Seasonal Total 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	2,024 c	837 c	545 bc	3,407 d	2,698 b	1,717 b	669 d	5,084 b
$70^{\times 2}$	3,119 b	1,434 b	676 a	5,229 c	4,420 a	3,176 a	1,159 c	8,755 a
$150^{\times 3}$	3,833 ab	1,830 a	569 abc	6,233 ab	4,645 a	3,662 a	1,684 a	9,991 a
$225^{\times 3}$	4,493 a	1,919 a	475 c	6,888 a	4,527 a	3,579 a	1,558 ab	9,664 a
$300^{\times 3}$	3,374 b	1,718 a	653 ab	5,744 bc	4,088 a	3,315 a	1,310 ab	8,714 a
$375^{\times 3}$	3,782 ab	1,882 a	660 ab	6,325 ab	4,649 a	3,130 a	1,615 ab	9,394 a
***P*-value**	<0.0001	<0.0001	0.0258	<0.0001	0.0013	<0.0001	<0.0001	<0.0001
C.V. (%)	22.8	14.3	19.3	14.2	19.1	21.7	28.6	19.4

[†] 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 hay yields in response to P fertilization from Fayetteville and Batesville locations during the 2022 growing season.[†]

	Phosphorus Trial							
	Fayetteville				Batesville			
Seasonal Total 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	4,643	2,075	508 bc	7,227	3,785 b	3,268	3,011	10,063 b
$30^{\times 1}$	4,613	1,949	447 c	7,009	4,687 a	3,747	3,336	11,769 a
$60^{\times 2}$	4,723	1,898	521 bc	7,142	4,535 a	3,760	3,475	11,770 a
$90^{\times 3}$	4,560	1,938	599 ab	7,096	4,907 a	3,903	3,463	12,273 a
$120^{\times 3}$	4,216	1,970	665 a	6,852	4,845 a	3,885	3,351	12,081 a
$150^{\times 3}$	4,704	2,107	530 bc	7,342	4,918 a	3,648	3,547	12,113 a
***P*-value**	0.5438	0.5657	0.0025	0.8115	0.0197	0.4300	0.0682	0.0390
C.V. (%)	17.6	11.4	22.7	12.0	12.1	15.9	8.1	9.8

[†] 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.

Cotton Biomass Accumulation and Yield in an Irrigated Arkansas Production System

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Abstract

The goals of this research project are to determine the dry matter production and yield of two modern cotton cultivars (Deltapine 2038 and NexGen 4936) grown in a furrow-irrigated system that is typical of eastern Arkansas production. The study was replicated at three different site years: in 2021 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS), and in 2022 at the Lon Mann Cotton Research Station and at the Rohwer Research Station (RRS). The 2021 site year was planted on a Zachary silt loam, while the 2022 Lon Mann Cotton Research Station site year was planted on a Convent silt loam, with the 2022 Rohwer Research Station site year on a Sharkey and Desha silt loam. Treatments included two different rates of fertilizer designed to apply 100% and 125% of current University of Arkansas Soil Test Laboratory fertilizer rate recommendations for nitrogen (N), phosphorus (P), and potassium (K) based on soil test nutrient levels where applicable. Fertilizer treatments were applied preplant and at early squaring. For the 100% rate, the sum of the fertilizer treatments was applied as follows: 2021 LMCRS 70 lb P_2O_5, 60 lb K_2O, 110 lb N; 2022 LMCRS 50 lb P_2O_5, 95 lb K_2O, 110 lb N; 2022 RRS 50 lb P_2O_5, 40 lb K_2O, 110 lb N. The sum of the fertilizer treatments applied for the 125% rate were as follows: 87.5 lb P_2O_5, 75 lb K_2O, 137.5 lb N; 2022 LMCRS 62.5 lb P_2O_5, 119 lb K_2O, 137.5 lb N; 2022 RRS 62.5 lb P_2O_5, 50 lb K_2O, 137.5 lb N. Preliminary results show no difference between either the cultivars or the fertilizer treatments. Total averaged aboveground biomass for the first sample time of the year (10 days after emergence) ranged from 11 lb/ac to 33 lb/ac, while the final sample time (at the start of the defoliation period) ranged from 1594 lb/ac to 2722 lb/ac. Lint yields averaged across cultivars and fertilizer treatments within each site year ranged from 427 to 2249 lb/ac.

Introduction

Beginning in the 1990s in production agriculture, there was a sharp increase in the implementation of new technology, including the use of transgenic crops such as cotton (*Gossypium hirsutum* L.). Originally, genetically engineered cotton was produced to help combat yield losses from bollworm infestation, which led to the pest becoming functionally eradicated from the United States. In 2021, Arkansas producers harvested 475,000 acres, down 9 percent from 2020 (UASDA, 2022). Production in the state totaled 1,235,000 bales in 2022, with an average yield of 1248 lb/acre, up 5.8% from 2020 (USDA-NASS, 2022a).

Cotton exhibits both an indeterminate and perennial growth habit, which presents producers with unique challenges not seen in other row crops grown in Arkansas. Plant emergence generally occurs 4 to 14 days after planting (DAP), with the first true leaf emerging roughly a week after seedling establishment, with this first true leaf signaling the beginning of vegetative growth. Leaves on the main stem are the first vegetative structures to appear, and they are formed on the nodes. A new node is created roughly every 3 days, with nodes forming especially during early season growth. At the beginning of every fruiting branch, a fruiting bud (square) begins to form, and the portion of the branch between the square and the main stem begins to lengthen. The first square on the plant will be visible at 35 DAP, followed by a flower bloom appearing 21 days after the square is created. The flower will begin its cycle as white, turning pink, and finally red, with the color dictated by fertilization, before falling off after 7 days. After pollination, bolls will begin to form and take 50 days after pollination to open under optimal growing conditions. Cotton exhibits an indeterminate growth pattern and can experience unrestricted growth unless controlled by growth regulators to help prevent excessively tall and heavy vegetative growth that does not necessarily contribute to yield.

Boll formation can be affected by dry matter accumulation and partitioning, which in turn affects the quantity and ratio of nutrients left to be reincorporated into the soil at the end of the season to be utilized by a successive crop. The research presented here is needed to determine how a potential increase in cotton biomass may change the overall partitioning of biomass and nutrients in the cotton plant. The objective of this research is to determine the total and partitioned aboveground biomass accumulated at six different key growth stages and the cotton yield in two different modern cotton cultivars grown in an Arkansas furrow-irrigated cotton production system.

Procedures

In 2021, plots were established at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) in Marianna, Ark., on 16 June, with the field being a Zachary silt loam (Fine-silt, mixed, active, thermic Typic Albaqualfs; Soil Survey Staff, 2018). In 2022, plots were established at the LMCRS on 19 May on a Convent silt loam (Coarse-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts; Soil Survey Staff, 2018).

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Plots were established at the Rohwer Research Station (RRS) at Rohwer, Ark., on 1 June 2022 on soil mapped as Sharkey (Very-fine, smectitic, thermic Vertic Hapludolls; Soil Survey Staff, 2018) and Desha silt loams (Very-fine, smectitic, thermic Chromic Epiaquerts; Soil Survey Staff, 2018). Whole field composite soil samples (*n* = 10) were collected from the 0-6 in. depth before planting and were analyzed by the University of Arkansas System Division of Agriculture's Agricultural Diagnostic Laboratory in Fayetteville, Ark.

The average soil test values for 2021 LMCRS were 24 ppm Mehlich-3 P, 107 ppm Mehlich-3 K, and soil pH (1:1 v:v soil: water mixture) of 6.6, with the LMCRS 2022 site averaging 26 ppm Mehlich-3 P, 88 ppm Mehlich-3 K, and soil pH of 6.8. Soil test values for 2022 RRS averaged 31 ppm Mehlich-3 P, 141 Mehlich-3 K, and a soil pH of 7.1. The recommended N, P_2O_5, and K_2O rates from the soil analysis were used to develop two fertilizer regimes.

The first fertilizer treatment (referred to as 100%) consisted of the standard rate and timing suggested by the University of Arkansas System Division of Agriculture's Cooperative Extension Service based on the soil test results. The 100% treatment resulted in preplant application of nutrients as follows: 2021 LMCRS 36 lb N/ac, 70 lb P_2O_5/ac, 60 lb K_2O/ac., 2022 LMCRS 36 lb N/ac, 50 lb P_2O_5/ac, 95 lb K_2O/ac., 2022 RRS 36 lb N/ac, 50 lb P_2O_5/ac, 40 lb K_2O/ac.

The second fertilizer treatment referred to 125% of the standard CES recommendation resulted in a preplant application of 36 lb N/ac, 70 lb P_2O_5/ac, 60 lb K_2O/ac at 2021 LMCRS; 45 lb N/ac, 62.5 lb P_2O_5/ac, 119 lb K_2O/ac for 2022 LMCRS; and 45 lb N/ac, 62.5 lb P_2O_5/ac, 50 lb K_2O/ac for 2022 RRS. The preplant fertilizer treatments were broadcast onto a flat, stale seedbed and incorporated into the raised beds (established on 38-in. row spacing) that were formed to aid in the furrow irrigation. The remainder of the season-total N rates of 74 lb N/ac for 100% and 92.5 lb N/ac for 125% was applied at early squaring and incorporated using irrigation within 3 days of application.

Included in the trial were two cultivars, Dekalb Deltapine 2038 (DP 2038, Bayer CropScience, Monheim, Germany) and Americot NexGen 4936 (NG 4936, Americot, Lubbock, Texas). Cotton was planted 0.5-0.75-in. deep at 42,000 seeds/ac. The emergence dates were 4 July 2021 for 2021 LMCRS, 30 June 2022 for 2022 LMCRS, and 11 June 2022 for 2022 RRS. The experimental design was a two (fertilizer regimens) by two (cultivars) factorial treatment structure arranged in a randomized complete block design with four replications. The field histories include 2021 LMCRS being previously cropped to soybean (*Glycine max* Merr.), 2022 LMCRS previously cropped to corn (*Zea mays*), and 2022 RRS previously cropped to grain sorghum (*Sorghum bicolor*); all three fields laid fallow through the winter before being planted with cotton. The cotton was grown using furrow irrigation on an as-needed basis determined by soil moisture and rainfall.

The sampling for the project included sampling aboveground biomass from 3 ft of each row at six different times in the growing season: 10 days after emergence (DAE), first square, first white flower, cutout, first open boll, and the start of the defoliation period. The sampled plants were placed in burlap bags and transported to Fayetteville, Ark., where the plants were then partitioned into separate vegetative and reproductive parts: leaves, stems, squares, flowers, burrs (including immature bolls), lint, and seeds based on growth stage. Once partitioned, these subsamples were dried for 72 hours at 60 °C or until they reached a constant weight and moisture level. The dried subsamples were removed from the dryer and weighed. Total and subsample aboveground biomass was determined based on the dry weights and sample collection area and reported as biomass/ac. Following defoliation, the center two rows of each plot were harvested with a small-plot cotton picker, and the seedcotton yield was converted into lb lint yield/ac for statistical analysis.

Data analysis was completed using JMP 16. The "Fit Model" function was used to analyze the total aboveground biomass, subsample aboveground biomass, and lint yield data. The experimental design for the total aboveground biomass accumulation was a two-by-two factorial arrangement, with cultivar being the first factor and fertilizer treatment as the second factor, with each sample time analyzed independently from one another. The experimental design for the subsample aboveground biomass was the same as the total biomass, while the lint yield was analyzed the same as for the biomass accumulation, but with only one harvest time for each site-year. For the purposes of this report, these parameters were analyzed within each site-year. An analysis of variance was used to determine the significance of the main effects and their interaction, and mean separation was performed using Fisher's protected least significant difference with a *P*-value of 0.05.

Results and Discussion

The statistical analysis indicated that there were no significant main effects of cultivar or fertilizer regimen or interaction between fertilizer regimen and cultivar on aboveground biomass or lint yield. The lack of statistical significance for either of the main effects or their interactions indicated that there were no differences in the biomass accumulation across all treatments, and therefore, the mean aboveground biomass accumulation for each sample time for each site year has been provided in Table 1.

The biomass values for each of the partitioned plant parts for each sample time and site year are listed in Table 2, with the values averaged across all treatments. These mean biomass values are averaged over cultivars and fertilizer regimens within a sample time for each site year. The results indicate that aboveground biomass accumulation by cotton on a silt loam soil follows a sigmoidal pattern of increase and peaks near the defoliation period.

For the defoliation sample timing for 2021 LMCRS, the stems contained the largest amount of biomass at 2397 lb/ac, followed by the bolls with 1594 lb/ac, leaves at 1283 lb/ac, and finally, squares at 14 lb/ac. For 2022 LMCRS, the portioned boll sample was the largest aboveground plant component with a biomass weight of 4786 lb/ac, followed by stems with 2481 lb/ac, and leaves weighing a total of 899 lb/ac. For 2022 RRS, the stems again had the largest accumulation of biomass weighing 5381 lb/ac, followed by bolls at 3987 lb/ac, leaves at 2169 lb/ac, and squares with 64 lb/ac.

The total average lint yield separated by site year was 427 lb/ac for 2021 LMCRS, 2249 lb/ac for 2022 LMCRS, and 911 lb/ac for 2022 RRS. The wide variation of lint yields for each site year is likely due to trial establishment date and management. The 2021 LMCRS study site did not emerge until 4 July, which is well past the optimum planting window for cotton in Arkansas. The late planting date resulted in a lower accumulation of biomass and, consequently lint yield. The projected state average cotton lint yield is estimated to be 1219 lb/ac (USDA-NASS, 2022b).

Practical Applications

These results indicate that the current fertilizer recommendation guidelines as put forth by the Cooperative Extension Service for N, P_2O_5, and K_2O for furrow-irrigated cotton are, at minimum, adequate for aboveground biomass accumulation and that increasing fertilizer rates above those recommendations do not increase biomass accumulation or yield on a silt loam soil. The results suggest that modern cotton cultivars can produce near-maximal yield using the current fertilizer rates as they are recommended. Future research may focus on replicating this study on different soil textures (clays and sands) with reduced fertilizer rates, or looking at changes in application timing and rates to either improve yields or increase efficiency of nutrient management for modern cotton varieties.

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USDA-NASS. 2022b. United States Department of Agriculture National Agricultural Statistics Service. Arkansas Cotton County Estimates.

Table 1. The total aboveground biomass averaged across all treatments for each site year and corresponding to sample collection timing.

	Average Aboveground Biomass		
Growth Stage	**2021 LMCRS**	**2022 LMCRS**	**2022 RRS**
	----------------------------------	(lb/ac)	----------------------------------
10 DAE	22	35	12
1st Square	192	137	178
1st White Flower	416	403	575
Cutout	662	1290	1075
1st Open Boll	1551	2479	1961
Defoliation	1594	2722	2648

Abbreviations: LMCRS = Lon Mann Cotton Research Station, RRS = Rohwer Research Station, DAE = days after emergence.

Table 2. The aboveground biomass of each partitioned plant part averaged across all treatments, separated by each site year, corresponding to the sample collection timing.

		Average Aboveground Biomass		
Growth Stage		**2021 LMCRS**	**2022 LMCRS**	**2022 RRS**
		-------------------------------------(lb/ac)-------------------------------------		
10 DAE	Leaves	32	18	16
	Stems	12	51	7
1st Square	Leaves	343	220	304
	Stems	215	169	220
	Squares	19	7	9
1st White Flower	Leaves	707	636	1264
	Stems	837	848	1162
	Squares	110	92	155
	Flowers	10	36	47
	Burrs	N/A[a]	N/A	163
Cutout	Leaves	1193	1593	1575
	Stems	1353	2499	1914
	Squares	55	64	63
	Flowers	21	86	12
	Burrs	688	2208	945
1st Open Boll	Leaves	1530	1188	2062
	Stems	2286	2408	3220
	Squares	63	N/A	9
	Flowers	9	N/A	N/A
	Burrs	1595	3840	2062
Defoliation	Leaves	1283	899	2160
	Stems	2397	2481	5381
	Squares	14	N/A	64
	Bolls	1594	4786	3987

[a] N/A is used as a place holder for partitioned samples that did not exist on the plant for that sample time.

Abbreviations: LMCRS = Lon Mann Cotton Research Station, RRS = Rohwer Research Station, DAE = days after emergence.

Impact of Nitrogen Fertilization Rate on One-Year-Old ‘Ouachita’ Blackberry Yield and Tissue Nutrient Concentration

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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, 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. Nitrogen fertilization rate × 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 lb N/ac rate. Our first-year observations agree with previous research findings that blackberry primocanes are impacted more immediately by in-season N application compared to floricanes. This trial will be continued through 2024 to study the impact of N rate on yield, 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 recommended 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, Fla.) were planted in a Linker fine sandy loam (Fine-loamy, siliceous, semiactive, thermic Typic Hapludults; Soil Survey Staff, 2022) in May of 2021 at the University of Arkansas System Division of Agriculture's 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/hour 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 26 April 2022 and continuing until 11 August 2022. 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 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 ppm NH_4-N.

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The experiment consists of 6 N rate treatments with four replicates resulting in 24 total plots spread evenly across the three rows. Each plot consisted 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 29 April 2022 after N fertilizer application began and continued until 1 September 2022, 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 System Division of Agriculture's Diagnostic Laboratory (Fayetteville, Ark.).

Bi-weekly blackberry fruit harvest began on 16 June 2022 and continued through 14 July 2022. 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.

Data were analyzed in SAS (SAS Institute Inc, Cary, N.C.) using Proc Glimmix and response variables mean separation was performed using Tukey's honestly significant difference for post-hoc analysis. Treatment effects, sampling date, and their interaction were assessed for 10 sampling dates for the petiole NO_3-N data. Significant sampling date by N fertility rate interactions were analyzed using the slice function in SAS to identify N fertility rate treatment differences at individual sampling dates. At the time of writing this report, only two sampling dates for leaf total N concentration had been received, and as such sampling date effect was not evaluated. The figure presented was created via JMP Pro 16 (SAS Institute Inc, Cary, N.C.).

Results and Discussion

Nitrogen fertilization rate did not impact ($P > 0.05$) marketable yield, percent cull, total yield, average berry weight, or white drupe occurrence for one-year-old 'Ouachita' blackberry during our trial in 2022 (Table 1). A lack of a response of in-season N application on floricane yield and fruit quality has been noted (Strik, 2017b) because floricane fruiting laterals and cane growth are determined in the previous season during primocane growth. In our 2021 trial, a uniform N rate was applied to all primocanes, which likely resulted in uniform floricane yields during the 2022 harvest season.

Primocane leaf total-N concentration was not significantly different across N rates (Table 2). However, these results are currently based on data from only two early season sampling dates and will be updated once final results for all sampling dates are received. Primocane petiole NO_3-N concentration was significantly affected by the sampling date × N fertilization rate interaction (Table 2). Generally, higher N fertilization rates had higher petiole NO_3-N concentrations but only at some sampling dates. On five dates (27 April, 6 June, 22 June, 20 July, and 18 August 2022), there were significant differences ($P < 0.05$) in petiole NO_3-N among the N fertilization rates (Fig 1). How the N fertilization rate impacted primocane petiole NO_3-N concentration was complicated and did not have a uniform trend across all sampling dates. A general trend of higher petiole NO_3-N concentration in primocanes was observed for higher N rates compared to lower N rates. For example, primocane petiole NO_3-N concentration for the 150 lb N/ac rate was significantly higher than the 0 lb N/ac rate except on 18 August, on which date the 120 lb N/ac rate was significantly higher than the 0 lb N/ac rate (Fig 1). Floricane leaf total-N concentration was impacted by N fertilization rates, however only the 120 lb N/ac rate (3.04%) was significantly higher than the 0 lb N/ac rate (2.76%), while all other rates were similar (Table 2). However, these results are currently based on data from only two sampling dates and will be updated once results for all sampling dates are received. Floricane petiole NO_3-N was not significantly impacted by N fertilization rates, sampling date, or a sampling date × N fertilization rate interaction ($P > 0.05$; Table 2). 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 floricanes nutrient concentration is primarily determined in the previous year. Thus, we anticipate that differing rates of N fertilizer may correspond to differences in floricane leaf total-N or petiole NO_3-N concentration in 2023.

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 (2023). Simultaneously, the second year of our trial will begin in the Spring of 2023, 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, berry weight, and white drupe occurrence on 'Ouachita' blackberry in Clarksville, Arkansas during 2022.

N Rate	Marketable Yield[†]	Cull	Total Yield	Average Berry Weight	White Drupe
(lb N/ac)	(kg per plot)	(%)	(kg per plot)	(g)	(%)
0	33.31	31.69	44.78	5.94	12.5
30	36.02	31.62	49.54	6.21	15.3
60	32.76	33.08	46.21	6.18	16.0
90	34.44	34.11	48.50	6.29	15.7
120	32.89	33.71	45.53	6.21	13.5
150	36.35	28.66	48.22	6.25	15.7
P-value	*0.5157*	*0.0806*	*0.3709*	*0.5846*	*0.8139*

[†] 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 post-hoc analysis.

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

	Primocane		**Floricane**	
	Leaf	**Petiole**	**Leaf**	**Petiole**
Effects	**N**[†]	**NO_3-N**	**N**	**NO_3-N**
N Rate (lb N/ac)	**(%)**	**(mg/kg)**	**(%)**	**(mg/kg)**
0	3.32	1050	2.76 b	828
30	3.30	1086	2.93 ab	734
60	3.36	1111	3.00 ab	755
90	3.27	1172	2.84 ab	825
120	3.51	1230	3.04 a	847
150	3.42	1217	3.01 ab	1131
P-value	0.8853	0.0248	0.0142	0.2573
Sampling Date				
P-value	NA[‡]	<0.0001	NA	0.1320
Sampling Date x Fertilization Rate				
P-value	NA	<0.0001	NA	0.1964

[†] 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.

[‡] Only two sampling dates of data were available at the time of analysis; the listed values are the average of the data available from those two sampling dates. Sampling date was not analyzed.

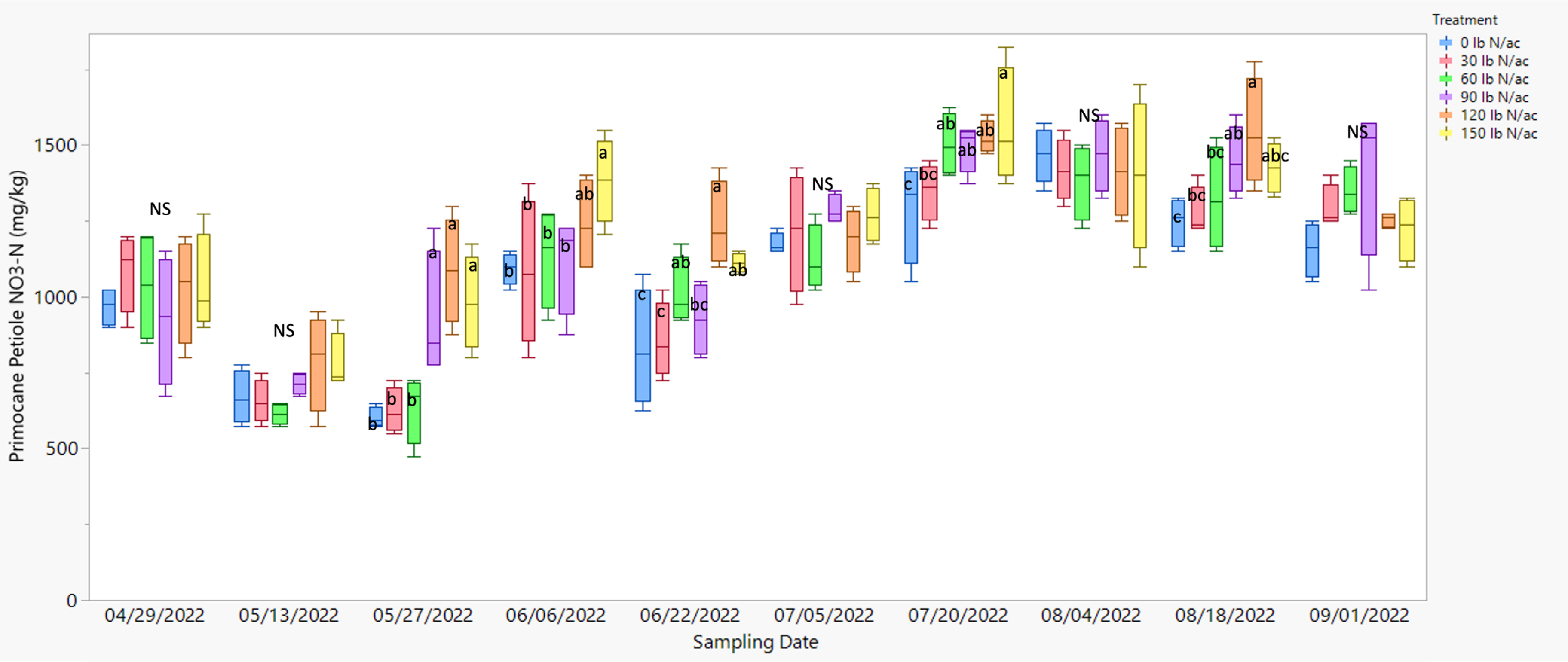

Fig. 1. Effect of N fertilization rate (lb/ac) on primocane petiole NO_3-N concentration at each sampling date in 'Ouachita' blackberry in Clarksville, Arkansas, from April 2022 to September 2022.

Validation of Potassium Management Strategies in Arkansas Soybean

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Abstract

Recent advancements in soil testing and plant analysis have expanded potassium (K) management in soybean [*Glycine max* (L.) Merr.] from traditional preplant applications based simply on soil test results to also include profit-maximizing K rates using the economic potash rate calculator and in-season diagnosis of hidden hunger using tissue tests. The objective of this research was to validate K management strategies available for soybean, including traditional preplant applications, a reduced preplant rate according to the economic potash rate calculator, in-season granular fertilizer-K applications, in-season foliar fertilizer-K applications, and split fertilizer-K applications. The research was conducted as a randomized complete block design in 2022 on a Henry silt loam with Very Low soil-test K (STK). The site experienced dry weather and delayed irrigation, resulting in visual K deficiencies 15 days after R1 stage (DAR1), confirmed by trifoliolate leaf samples collected at 15 DAR1. The deficiencies were remediated by irrigation and in-season applications of granular fertilizer K. Regardless of the granular fertilizer-K rate, the addition of a foliar K source applied 2 gal/ac (4.6 lb K_2O/ac) at 30 DAR1 did not significantly increase grain yield. Additionally, there was no significant yield difference when the same rate of granular fertilizer-K was applied all preplant compared to one-half preplant and one-half 15 DAR1. However, treatments that received additional in-season granular fertilizer-K applications did numerically outyield those which did not. Finally, the yield-maximizing K rate based on soil test values and the profit-maximizing K rate based on fertilizer and grain prices at the time of planting resulted in similar yields. Therefore, both the traditional yield-maximizing K rate and the reduced profit-maximizing K rate are successful management approaches when applied all at preplant or as split applications to include in-season granular fertilizer-K applications.

Introduction

Potassium (K) deficiency is one of the most important yield-limiting factors in Arkansas soybean [*Glycine max* (L.) Merr.] production. Traditional K management involves a full-season, yield-maximizing rate of fertilizer-K applied prior to planting. Fertilization using this approach relies on recent soil samples taken at a 0-to 4-in. depth and analyzed with the Mehlich-3 extractant (Zhang et al., 2014). Previous correlation and calibration research established the yield-maximizing fertilizer rate based on the soil-test K (STK) values (Slaton et al., 2010). The build and maintain philosophy is currently used for the University of Arkansas System Division of Agriculture's soybean fertilizer recommendations, resulting in rate recommendations that meet the needs of the crop and include additional fertilizer intended to build the STK in the lower categories and maintain adequate STK levels in optimum soils (Olson et al., 1982). However, when considering the profitability of K fertilization, these uniform rate recommendations were often higher than profit-maximizing rates (Popp et al., 2020). Recently, an economic potash rate calculator was established to consider not only the STK value but also the current prices of grain and potash fertilizer and the anticipated yield potential (Popp et al., 2020). These crop inputs are used to compute a profit-maximizing fertilizer-K rate for preplant K management. The potash rate calculator allows producers to compare the yield-maximizing fertilizer-K rate recommendation to the profit-maximizing fertilizer-K rate recommendation and make the best decision for specific field situations.

While the preplant fertilizer recommendations are reliable, in-season K deficiencies may still occur and result in yield loss, especially if preplant rates are reduced or if there is a lack of available capital. These K deficiencies often show no visible symptoms, known as hidden hunger, or symptoms may not appear until very late in the season. Therefore, proactive and routine tissue sampling is the best way to monitor nutrient status and identify potential hidden hunger before significant yield loss is unavoidable. The recent development of a dynamic critical K concentration curve for soybean improves the diagnostic ability for in-season deficiencies by providing an exact critical concentration of leaf-K required to maintain 95%, 85%, and 75% relative grain yield goals at any given point during the reproductive growth (Slaton et al., 2021). Depending on the severity of the deficiency, an in-season application of granular potash may correct the deficiency and minimize the yield loss (Slaton et al., 2020). The critical window to correct deficiencies is 20 days after R1 (DAR1) for severe K deficiencies and extends out to 44 DAR1 for moderate K deficiencies (Slaton et al., 2020). Information from in-season tissue analysis and the ability to interpret the results increases opportunities for in-

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season applications of granular K, as either a split application or a corrective application. While it is not recommended to use a foliar source of K fertilizer to correct a deficiency, there is a large interest in this fertilization strategy for its potential to be included as a tank mix with other pest management field applications. The objectives of this study were to validate multiple K management strategies available for soybean, including traditional preplant applications, reduced preplant rate according to the economic potash rate calculator, in-season granular applications, in-season foliar applications, and split applications.

Procedures

Field research was conducted in 2022 at the University of Arkansas System Division of Agriculture's Northeast Rice Research and Extension Center near Jonesboro, Ark. The site was selected for the uncommonly low STK (<60 ppm) measured in the Henry silt loam soil (Coarse-silty, mixed, active, thermic Typic Fragiaqualfs). One composite soil sample consisting of an average of eight subsamples was taken from each block just prior to planting at the 0-to 4-in. depth. The soil was oven-dried, ground, and submitted to the Agricultural Diagnostic Lab (Fayetteville, Ark.) for analysis of pH (1:2 v/v soil/water mixture; Sikora and Kissel, 2014) and Mehlich-3 extractable nutrients (Zhang et al., 2014). The mean soil test values measured 40 ppm phosphorus (P) and 58 ppm K, with a soil pH of 5.2. In order to ensure that P was not limiting, 40 lb P_2O_5/ac as triple superphosphate (0-46-0) was broadcast on the soil surface and was not incorporated prior to planting. The Delta Grow 49XF22 (Delta Grow Seed Co., England, Ark.) variety was planted at a seeding rate of approximately 130,000 seed/ac on 18 May 2022. General crop management followed the current University of Arkansas System Division of Agriculture Cooperative Extension Service's production recommendations for stand establishment and pest control in soybean (Ross, 2000).

The experiment was designed as a randomized complete block design with four replications of each treatment. Individual plots were 4 rows (30-in. row spacing) wide and 30 ft long. Treatments included applications at various timings and rates of granular muriate of potash (0-0-60) and Delivered K Plus (3-0-20) (Innvictis Crop Care, LLC) as the foliar fertilizer-K source (Table 1). Treatments were structured to consider both the yield-maximizing preplant rate based on the soil test results (160 lb K_2O/ac; Slaton et al., 2013) and the profit-maximizing preplant rate (128 lb K_2O/ac) based on the economic potash rate calculator using the grain ($15.50/bu.) and potash fertilizer ($815/ton) prices at planting (Popp et al., 2020). These recommended season total rates of 160 and 128 lb K_2O/ac were also halved and applied at reduced rates of 80 lb K_2O/ac and 64 lb K_2O/ac at preplant. The management strategy of split applications included preplant rates as the halved recommended rates which were then also followed by the same half rate applied in-season at 15 DAR1. Similarly, the management strategy of a reduced rate followed by an in-season tissue test to determine the in-season management was included following the reduced preplant rates of 64 and 80 lb K_2O/ac. The aforementioned treatments, which received halved preplant rates, were found to be K deficient by trifoliolate tissue samples collected at 15 DAR1 and subsequently received an additional corrective application of 50 lb K_2O/ac at 30 DAR1. Additionally, foliar fertilizer-K applications at the first pod (R3) growth stage were considered. Foliar fertilizer-K applications followed preplant rates of 0, 80, 128, and 160 lb K_2O/ac at a foliar rate of 2 gal/ac (4.6 lb K_2O/ac) applied at 30 DAR1. Finally, an untreated control was included to complete the 12 total treatment combinations (Table 1). Furrow irrigation was used to incorporate in-season granular treatments immediately after application, and additional irrigation events were determined based on soil moisture sensor data.

At 15 DAR1, a composite sample of 12 trifoliolate leaves was taken from the uppermost fully expanded trifoliate leaves within the middle two rows of every plot. The leaves were dried, ground, and digested with concentrated HNO_3 and 30% H_2O_2 (Jones and Case, 1990) and analyzed by ICP-AES to determine K concentration at the Fayetteville Agricultural Diagnostic Lab. At maturity, the middle two rows were harvested, and the grain yields were adjusted to 13% moisture for statistical analysis. Relative grain yield was calculated by comparing the measured yield from each replicate to the highest yielding treatment average, multiplied by 100 to convert to a percent; then each value was capped at 100%. The relative grain yield was analyzed by K management strategy as a randomized complete block design using a mixed effect model. Means separation was conducted using student's *t*-test and least squares means, while direct treatment comparisons were considered as contrasts. All analysis was completed in JMP Pro 16 at an alpha value of 0.10.

Results and Discussion

The field pH measured from 5.2 to 5.3 among blocks, all below the recommended 5.5, which may have resulted in yield loss (Slaton et al., 2013). Grain yields were relatively low, ranging from 13 to 41 bu./ac. The uncommonly low STK and droughty conditions during the early reproductive growth stages resulted in severe visual K deficiencies at 15 DAR1 in the treatments that had not yet received any potash fertilizer, which was confirmed by trifoliolate tissue tests (Fig. 1). Immediately following the in-season potash fertilizer treatment applications at 15 DAR1, furrow irrigation was initiated, and the plant uptake of K was facilitated, alleviating the visual deficiency symptoms. Additional trifoliolate samples collected at 30 and 45 DAR1 confirmed that some treatments resulted in adequate K nutrition while others remained yield-limited (Fig. 1). Overall, fertilizer-K applications did result in a significant yield response ($P = 0.09$), with treatment rate, timing, and source affecting the outcome (Fig. 2).

The rate of granular potash fertilizer did affect the relative grain yield measured, with the numerically highest relative grain yield of 92% achieved with 114 lb K_2O/ac, which was a combination of one-half of the season total potash rate based on the potash rate calculator applied preplant and an additional corrective application of 50 lb K_2O/ac applied at 30 DAR1 (Fig. 2). However, no statistical differences were found between the highest-yielding treatment and that which received 80 lb K_2O/ac preplant, although the 80 lb K_2O/ac preplant resulted in a

20% reduction in relative grain yield and was not statistically different from the untreated control (Fig 2). Overall, the two highest-yielding treatments received a split application of potash, with 64 lb K_2O/ac applied at preplant and an additional in-season application during reproductive growth. In-season applications were successful at remediating yield loss, both at 15 and 30 DAR1. While most situations would benefit from earlier corrective applications, this site showed a strong yield response to the in-season applications of granular fertilizer-K at 30 DAR1, likely because the crop was drought stressed at 15 DAR1 and K was not the greatest yield-limiting factor at that time. The drought stress inhibited K uptake and was relieved with furrow irrigation at 18 DAR1, allowing the crop to maximize K uptake when additional granular fertilizer-K was applied at 30 DAR1 and incorporated with another irrigation event.

Two contrasts were considered to compare the application timing of the yield-maximizing K rate (160 lb K_2O/ac) based on STK and the profit-maximizing K rate (128 lb K_2O/ac) based on grain and fertilizer prices during the 2022 planting season. Each of these treatments was applied at a full rate preplant and compared to a split application of one-half preplant followed by one-half 15 DAR1. No differences were found between these application timings either at the full rate ($P = 0.7963$) or at the economic rate ($P = 0.5520$). An additional contrast was considered between the yield-maximizing K rate and the profit-maximizing K rate when both were applied preplant and again no significant differences ($P = 0.8199$) were found. Therefore, the economic potash rate calculator successfully reduced the rate recommendation (reducing the fertilizer cost by $21.70/ac) without significantly reducing the yield and can be applied as either a full preplant rate or a split between a preplant and an in-season application.

Fertilizer source was also considered, with contrasts conducted to compare the rates of 0, 80, 128, and 160 lb K_2O/ac applied as granular potash with and without additional foliar fertilization applied 30 DAR1. No significant yield differences were found between any of these treatments ($P = 0.3878$, $P = 0.7410$, $P = 0.4996$, $P = 0.9161$), respectively. Therefore, the addition of foliar fertilizer at the beginning pod growth stage (R3) did not result in a yield increase and should not be relied on to correct a K deficiency. Foliar K products are not successful at correcting K deficiencies because of the low rate needed to avoid leaf burn. The 2 gal/ac rate used (based on label recommendations) provided only 4.6 lb K_2O/ac, a fraction of that which can be applied as granular potash and soil incorporated with irrigation or rainfall. While foliar fertilizers do have their place in soybean production to apply micronutrients, Delivered K (3-0-20-13S) included 0.1% boron, 0.2% manganese, and 0.05% zinc and still resulted in no significant yield increases. Therefore, caution is advised when using foliar fertilizer products in soybean, as yield increases have been reported to be inconsistent and rarely profitable (Haq and Mallarino, 2005).

Practical Applications

Successful K management in soybean begins with a sound soil sampling and soil testing program to provide a season-total fertilizer-K rate recommendation, which may be adjusted using the economic potash rate calculator using current grain and fertilizer prices. Regardless of the season-total K rate selected, the application may be split into a reduced preplant rate followed by an in-season application of granular fertilizer K. However, water must be readily available to the crop and applied in a timely manner (i.e., irrigation in the occasion of no rainfall) to incorporate in-season, soil-applied fertilizer K and facilitate plant uptake of K to correct or prevent further deficiency. If droughty conditions persist, the crop may experience K deficiency due to reduced diffusion and K uptake. Fortunately, when soil moisture is sufficient, soybean will scavenge for K, and if adequate plant-available K exists, yield loss can be limited (Slaton et al., 2020). Successful in-season K management should rely on granular fertilizer K, as a single foliar application of K may not supply enough K to alleviate moderate to severe K deficiency (Haq and Mallarino, 2005).

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Table 1. Treatment structure for various combinations of fertilizer-K applied at preplant and in-season at 15 or 30 days after R1 (DAR1). Broadcast applications were made of granular muriate of potash (0-0-60) or applied as a foliar fertilizer (3-0-20-13S).

		In-Season		
Treatment Structure	**Preplant**	**15 DAR1**	**30 DAR1**	**Season Total**
	----------------------------lb K_2O/ac----------------------------			
No-K control	-	-	-	0
Foliar	-	-	4.6[a]	4.6
½ soil test recommendation (rec.)	80	-	-	80
½ soil test rec. + foliar	80	-	4.6[a]	84.6
Soil test rec.	160	-	-	160
Soil test rec. + foliar	160	-	4.6[a]	164.6
Split soil test rec.	80	80	-	160
½ soil test rec. + corrective granular	80	-	50	130
Economic rec.	128	-	-	128
Economic rec. + foliar	128	-	4.6[a]	132.6
Split economic rec.	64	64	-	128
½ economic rec. + corrective granular	64	-	50	114

[a] Applied as a foliar fertilizer source at the 2 gal/ac rate (4.6 lb K_2O/ac).

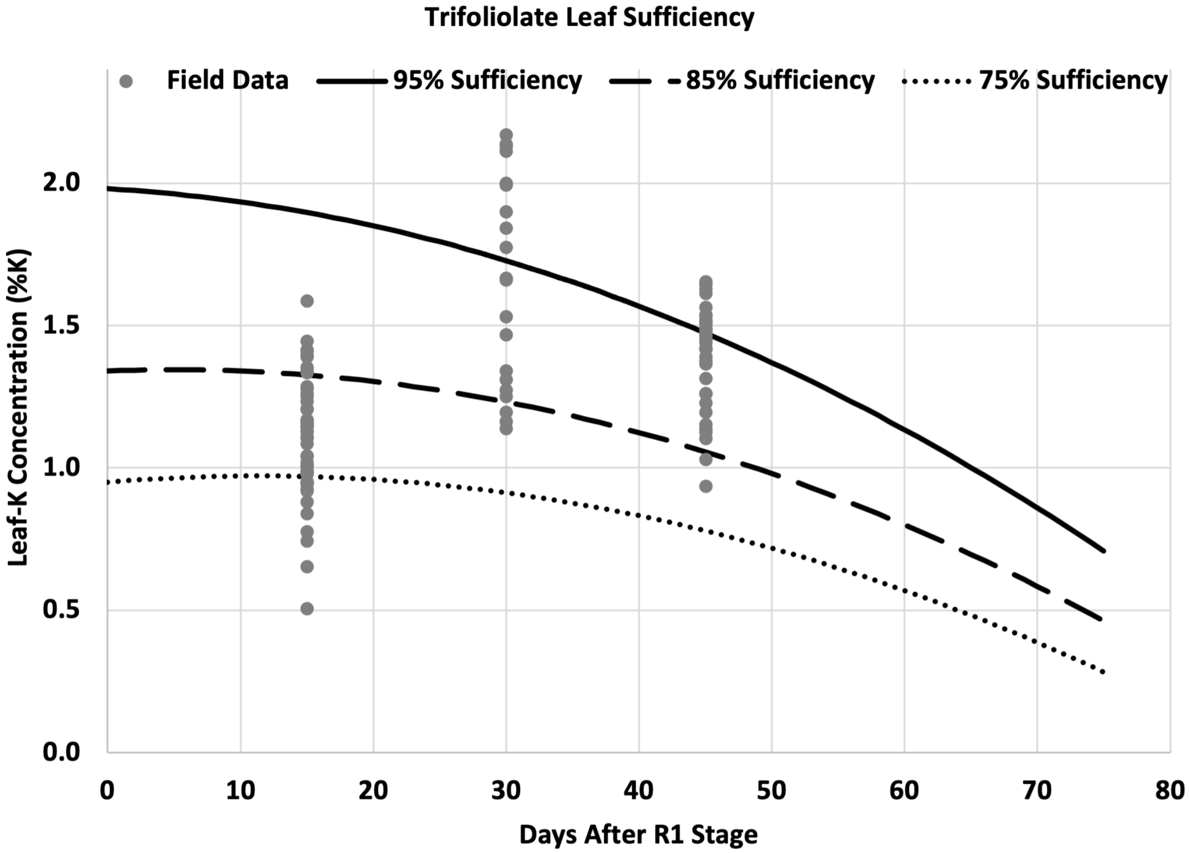

Fig. 1. Soybean trifoliolate leaf-K concentration data collected at 15, 30, and 45 days after R1 stage (DAR1) compared to the dynamic critical K concentration curve with the 95%, 85%, and 75% sufficiency thresholds represented as black lines (Slaton et al., 2021).

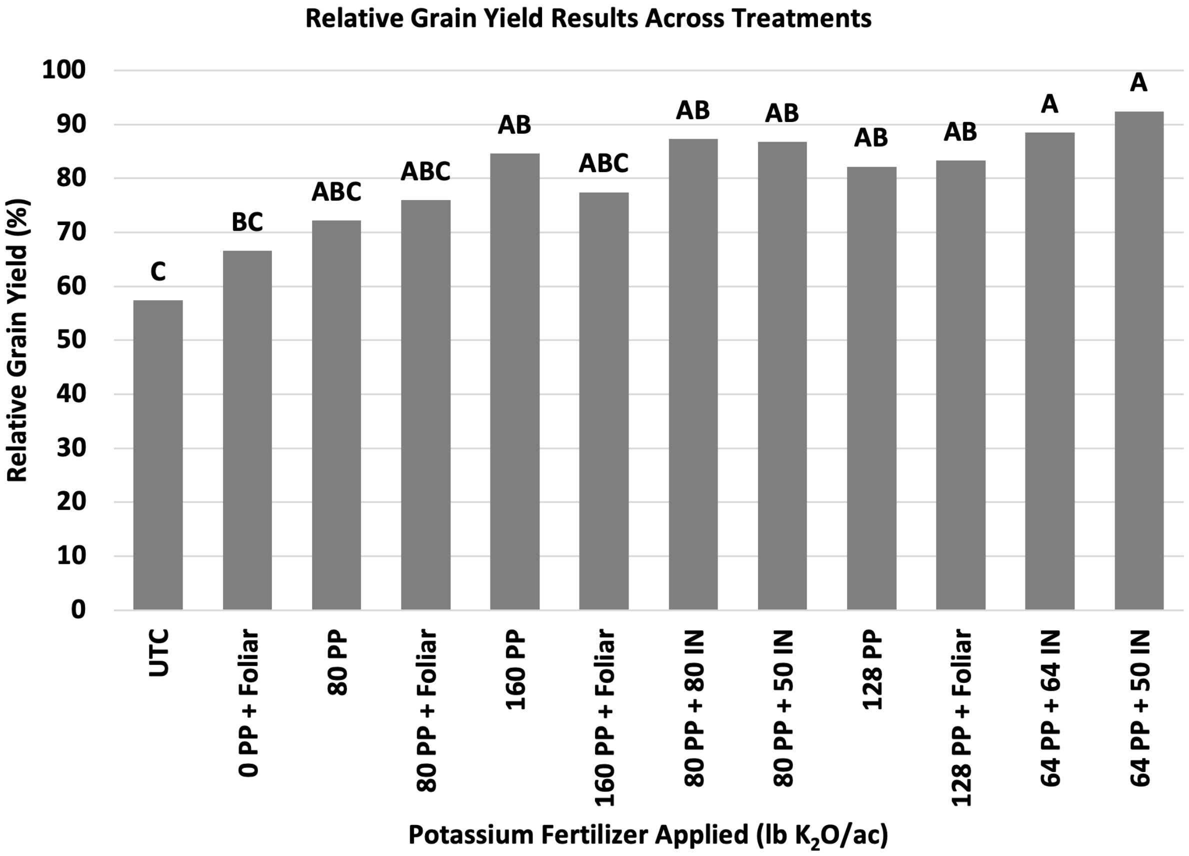

Fig. 2. Soybean relative grain yield results across all treatment combinations, abbreviated as UTC as untreated control, PP for preplant, and IN for in-season applications. All foliar applications were applied at 2 gal product/ac (4.6 lb K_2O/ac) at 30 days after first flower (DAR1). In-season applications of 80 or 64 lb K_2O/ac were applied at 15 DAR1, while those at 50 lb K_2O/ac were applied at 30 DAR1. Treatments with the same lowercase letter are not significantly different according to the student's *t*-test least significant difference at $\alpha = 0.1$.

Preliminary Assessment of the Precision Agriculture Landscape in Arkansas

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Abstract

Producers' approaches to precision agriculture (PA) vary widely depending on their background and unique production factors. Technology use and perceptions of benefits may also be affected by previous experiences, operation size, and level of integration into the farm management decision-making process. Investigating Arkansas stakeholder views of PA is needed to characterize the range of management practices and perceptions related to PA in Arkansas, form a common vision for PA, and inform the direction of land-grant research, extension, and teaching programs in PA. Research was conducted in 2022 to assess the perceptions of PA goals, identify educational needs, and determine drivers of technology adoption in Arkansas. A survey was developed in Qualtrics XM® to collect quantitative data from field crop farmers, crop consultants, and county extension agents. The survey was advertised at field days, production meetings, and using social platforms. Data were collected electronically using an online survey accessed through a QR code and on paper. Responses and data collected between 6 August 2022 and 1 December 2022 were cleaned and summarized. Results showed that the respondents had a proper understanding of the goals of PA despite some confusion with the PA tools available to meet the PA goals. Moreover, the respondents tended to focus more on technology integration at the operational level rather than at the decision-making level. The concerns most important to respondents were those that already affect profitability and are easy to quantify. Results also showed that decision-making regarding technology adoption is a complex process hindered by many economic and social barriers. Future research will investigate specific technology adoption dynamics and the stakeholders' approach to soil testing for the characterization of in-field variability in Arkansas.

Introduction

Precision agriculture (PA) is a farm management concept that relies on recent technological advances and data-driven recommendations to optimize input use and increase farm profitability (Pierce and Nowak, 1999; Zhang et al., 2002). Optimal input use and maximum profitability are achieved when the input application parameters—rate, time, and placement—match the crop needs. However, crop needs may vary in a field or cropping system because of spatiotemporal changes in field conditions, weather, and management history, making it difficult to identify and execute the best management strategies (Cahn et al., 1994; Kravchenko et al., 2005). Modern practices do not account for all sources of variability, and PA can help minimize losses from suboptimal input applications with improved scouting techniques, higher levels of equipment performance and accuracy, fine-tuned recommendations, and reduced errors from increased automation (Toriyama, 2020). Precision agriculture adoption is a gradual process that starts with the use of grid sampling, guidance technologies, and yield mapping (Pierpaoli et al., 2013). Other technologies, such as precision planting and spray technology, automatic section control, depth and downforce control, hybrid planters, and variable-rate technologies, may also be adopted to improve equipment performance and input placement (Bhakta et al., 2019). Emphasis is often given to variable-rate technologies that can be used to vary input application rates within a field (Clark and McGuckin, 1996).

Increased profitability from optimized input use is the goal of PA, but many producers do not meet the anticipated benefits as technology adoption does not ensure optimal use. An increasing body of literature demonstrates that technology adoption changes more than just how operations are performed, and the continued advancement of PA will require complete integration at both the strategic and operational levels (Bhakta et al., 2019; Bullock et al., 2007; Guo et al., 2015). The more advanced the technology, the greater the impact on the producers' management decision process and the greater the potential for increased management complexity (Lee et al., 2021). The current University of Arkansas System Division of Agriculture crop recommendations are based on the yield goal, specific soil parameters (e.g., soil properties, soil test results), and other relevant production parameters. They were created to maximize average profitability across production environments and have proven to work under whole-field and operator-driven management (Dahnke and Olson, 1990; Morris et al., 2018). However, as PA continues to advance, the same recommendations are being increasingly applied to smaller management units or integrated within automated operation management systems without evidence that they optimize site-specific input use and maximize profitability (Bullock et al., 2007). Research that evaluates the applicability of the current crop recommendations in the context of PA and develops new or updated guidelines is needed to overcome the limitations of current management practices and optimize technology use.

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Fortunately, PA is not limited to variability management, and technology can also be used to characterize field conditions, monitor crop development, and quantify equipment performance (Fulton and Port, 2018; Reis et al., 2021; Schepers and Francis, 1998). The collected data may be analyzed to assess the efficacy of current management practices and update the scope of the current crop recommendations providing that the data mining and modeling efforts are guided by a systemic understanding of crop production systems (Tantalaki et al., 2019). Findings may be used to educate stakeholders about the importance of optimizing technology use to maximize benefits and develop decision-support systems that deliver appropriate crop recommendations for PA (Bouma et al., 1999). Appropriate crop recommendations for PA should be adapted to the producers' unique production strategy, goal, environments, and available resources (Adams et al., 2000; Sudduth et al., 1997). Moreover, educational efforts dedicated to the promotion of PA adoption as a critical component of farm management should be adapted to the stakeholders' vision and perception of PA, as well as their previous experiences with technology (Cisternas et al., 2020). Regular and continued communication between stakeholders and researchers is needed to identify emerging needs, build and maintain trust, facilitate on-farm implementation of research results, and maximize benefits from innovation and technological development in local and regional agricultural communities (Raturi et al., 2022). Nevertheless, little information is available to help tailor the land-grant efforts regarding PA development to the stakeholder needs in Arkansas. The objective of this study was to conduct a preliminary assessment of the PA landscape in Arkansas.

Procedures

Data were collected using a survey developed in Qualtrics XM®. The targeted audience was field crop farmers, crop consultants, and county agents with experience in field crops in Arkansas. The questions listed in Table 1 were included in the survey. Question 1 was asked to define the respondents' perceptions of PA. Question 1 was open-ended, and the data were collected as text. Questions 2 to 7 were asked to describe the respondents' perceptions of the goal of PA and their concern for Arkansas agriculture in 2050, identify the respondents' priorities and educational needs regarding PA, and determine the drivers of new technology adoption in the state. Questions 2 to 7 were quantitative, and the data were collected using a 5- or 6-point Likert-type scale to reduce the amount of time needed to complete the survey, increase data reliability, and help increase survey response rates (Marshall, 2005). The response categories were Agree, Somewhat Agree, Neither Agree nor Disagree, Somewhat Disagree, and Disagree for questions 2, 3, 4, and 7. The response categories were Comfortable, Somewhat Comfortable, Neither Comfortable nor Uncomfortable, Somewhat Uncomfortable, and Uncomfortable for question 5. The response categories were Very Important, Important, Moderately Important, Slightly Important, Not Important, and It Depends for question 6. Demographic questions were asked to describe the respondents' population based on profession, age range, and experience. Respondents were also asked to provide their names and email addresses to help identify duplicate answers.

Before the survey was finalized, questions were reviewed by experts in precision agriculture; crop and soil science; and agricultural education, communication, and technology to help ensure relevance and proper interpretation by stakeholders. Institutional Review Board approval for this study—protocol 2207412722—was received on 5 August 2022, and the survey has been advertised at field days, production meetings, and using social platforms. Data collection is ongoing, and the responses gathered so far were provided by the respondents' electronically using online surveys accessed through a Quick Response (QR) code or on paper. Hardcopies of the survey questions were distributed during in-person interactions with the respondents when preferred to the electronic alternative. The responses gathered using hardcopies were digitalized a posteriori by completing the electronic survey on behalf of the respondents. The collected data were downloaded from Qualtrics XM®, anonymized, and aggregated using R/R Studio (R Core Team, 2022; R Studio Team, 2022) to protect the respondents' identities. Incomplete responses were removed to increase data quality. The amount of time used to complete the survey was also considered a data quality metric.

The data collected from question 1 were cleaned to improve uniformity. All words were capitalized, updated to correct typos, and grouped to emphasize identical meanings. For instance, the words efficient, efficiency, and 100% were all represented by the word efficiency. The clean data were then summarized by associating the cited words with the number and percentage of respondents who listed them. The data collected from questions 2 to 7 were summarized by computing the percentage of answers provided for each of the Likert-type scale response categories. The demographic data were also summarized to describe the percentage of respondents by profession, age range, and experience level. Descriptive summaries are a method of choice for the identification of trends within quantitative survey data (Marshall and Jonker, 2010).

Results and Discussion

Results were provided for the 20 responses collected between 6 August 2022 and 1 December 2022. Half the respondents were county extension agents with 0 to more than 25 years of experience (Table 2). The other half was divided between crop consultants with 0 to 25 years of experience and farmers with more than 25 years of experience. The word that was most often associated with PA was efficiency (Table 3). The words that were second most often associated with PA were accuracy, technology, and global positioning system (GPS). Efficiency is the ratio between the number of resources used to perform an operation and the total number of resources provided (Grisso et al., 2004). Accuracy defines the degree to which machinery or equipment performance conforms with the operator's expectations. Technology and GPS are tools used to perform agricultural operations in the context of PA. Therefore, the words that were most often associated with PA relate to how agricultural operations are performed and machinery or equipment performance. Many of the least cited words also referred to operational planning and execution with a focus on specific field operations (e.g., irrigation, planting), equipment performance (e.g., precise, reliability), and PA equipment or tools (e.g., equipment, drones, autonomous). A few of the least cited words referred to the goal of PA (e.g., profit, sustainable, stewardship, solutions, improvement), barriers to adoption (e.g., expensive), and the PA data (e.g., data, yield maps, math, grid sampling).

All respondents agreed or somewhat agreed that optimizing input use, improving operation timeliness, improving environmental stewardship, and technology use in farming are goals of PA (Table 4). All except one (5%) respondent agreed or somewhat agreed that improving field data management, increasing farm profitability, and managing within field variability are goals of PA. Most respondents tended to agree that improving field data management is a goal of PA, while only slightly more than half the respondents agreed that increasing farm profitability and managing within-field variability are goals of PA. Increasing yield and resilience to climate change were the least recognized goals of PA. No respondents disagreed or somewhat disagreed that increasing yield is a goal of PA, with responses divided between the Agree, Somewhat Agree, and Neither Agree nor Disagree categories. The least amount of consensus was obtained for increasing resilience to climate variability. Half the respondents agreed or somewhat agreed that increasing resilience to climate variability is a goal of PA; the other half neither agreed nor disagreed or somewhat disagreed. Optimizing input use is described as the overarching goal of PA in literature, which can be achieved through increased profitability, operation timeliness, environmental stewardship, and resilience to climate change and variability (Thompson et al., 2019; Paustian and Theuvsen, 2017). Improved field data management, technology use in farming, and managing in-field variability are tools and methods available to achieve the overarching and specific goals. Increasing yields is often misconstrued as the predominant goal of PA; rather, the goal of PA is to optimize production. Optimization is finding the right balance between inputs and outputs, and PA aims to optimally manage areas with different production capabilities rather than achieve increased uniformized yields. The respondents recognized the overarching and specific goals of PA, except for increasing resilience to climate variability. They also recognized that PA is not only about increasing yields. However, respondents may have difficulty differentiating between the goals of PA and the means available to achieve these goals.

None of the options provided in question 4 were unanimously recognized as a concern for Arkansas agriculture in 2050 (Table 5). All but one respondent agreed or somewhat agreed that pest management, soil health issues, and water quality are concerns for Arkansas agriculture. Most respondents agreed that pest management is a concern. Approximately half of the respondents agreed that soil health issues and water quality were a concern. Most respondents agreed or somewhat agreed that the cost of inputs, land tenancy, and unfavorable governmental regulations are concerns. The other respondents neither agreed nor disagreed. Increased weather unpredictability, rapid technological development, and water scarcity were least recognized as concerns for Arkansas agriculture and had the smallest consensus. All options provided in question 4 have been recognized in the literature as concerns for Arkansas agriculture in 2050 (Reba et al., 2013; Malhi et al., 2021). The concerns most recognized by the respondents that are easier to identify or quantify are concerns that already directly affect the profitability of farm operations in Arkansas.

All respondents agreed or somewhat agreed that proper equipment calibration and making sense of the PA data are important for the successful implementation of PA (Table 6). Most respondents agreed or somewhat agreed that expertise using technology and computer skills are important for the proper implementation of PA. The smallest consensus was obtained for the strong agronomic foundation as four (20%) respondents neither agreed nor disagreed or somewhat disagreed that a strong agronomic foundation is needed for the proper implementation of PA. Furthermore, most respondents were comfortable or somewhat comfortable using computers and tablets (Table 7). Slightly more than half the respondents were comfortable or somewhat comfortable analyzing data. The respondents were least comfortable scouting stress and precision technologies. Respondents acknowledged that equipment calibration, data analytics skills, experience working with precision technologies, a strong agronomic foundation, and computer skills are all needed for the successful implementation of PA. However, many respondents did not feel comfortable performing these tasks, and there is a need for educational programs that will help address this gap in expertise.

More than 75% of respondents considered that ease of use, integration with existing equipment, technical support from the manufacturer, data ownership considerations, initial cost, the time before payoff, risk level, and availability of extension guidelines for use with the new technology are important or very important criteria when considering the adoption of new technology (Table 8). Less consensus was obtained for support from crop insurance policies and recommendations from peers, producers, crop consultants, and county extension agents. Many respondents also answered that the importance of the different criteria might depend on the situation. Furthermore, more than 75% of respondents agreed or somewhat agreed that time before payoff, initial cost, complexity of use, data ownership, lack of training, software overload, lack of compatibility with equipment, and economic risk are barriers to PA adoption (Table 9). Less consensus was obtained for the lack of extension recommendations, data management, and bad (previous) experiences with technology. The least number of respondents agreed or somewhat agreed that the lack of extension recommendations is a barrier to PA adoption. These results demonstrated that technology adoption is a complex process driven by many economic and social factors. Moreover, many of the factors accounted for in the decision-making process are significant barriers to adoption in Arkansas.

Practical Applications

Data collection for this survey is ongoing. Additional efforts are being dedicated to at least doubling the number of respondents and diversifying demographics among producers and crop consultants. Assuming that similar trends are obtained from the final dataset, the following takeaways will be drawn from this study:

- While stakeholders have a good understanding of the goals of PA, confusion may exist between the components of optimized crop management and the means and methods available to achieve optimized crop management.
- There is a wide range of perceived comfort levels in performing important tasks related to PA among stakeholders.
- There are complex economic and social barriers to precision agriculture adoption in Arkansas.

The continued advancement of PA has become a critical advancement of long-term food and water security in Arkansas, and land-grant universities could help overcome the barriers to technology adoption and optimum use with research and educational programs that focus on:

- Providing stakeholders with the skills needed to overcome the barriers to technology adoption and improve technology use.
- Facilitating integration of precision technologies in the management decision-making process.
- Increase collaborations between stakeholders.

Results from this study provided a preliminary assessment of the PA landscape in Arkansas. Future research will investigate specific technology adoption dynamics and the stakeholders' approach to soil testing for the characterization of in-field variability in Arkansas.

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Table 1. Questions included in the survey distributed to field crop farmers, crop consultants, and county agents with experience in field crops in Arkansas.

Number	Formulation
1	What three keywords come to mind when you hear PA?
2	Do you consider each of the following options a goal of PA? ● Technology use in farming ● Manage within field variability ● Increase yields ● Optimize inputs ● Improve operation timeliness ● Improve field data management ● Increase farm profitability ● Improve environmental stewardship ● Increase resilience to climate variability
3	Do you consider each of the following options to be a concern for Arkansas agriculture in the next 30 years? ● Water scarcity ● Water quality ● Soil health issues ● Increased weather unpredictability ● Pest management ● Rapid technological development ● Cost of inputs and land tenancy ● Unfavorable governmental regulations
4	Do you consider the following skills to be important for the successful implementation of precision agriculture? ● Strong agronomic foundation ● Proper equipment calibration ● Expertise using technology ● Computer skills ● Making sense of the data
5	How comfortable are you in performing the following tasks? ● Scout for stress ● Calibrate equipment ● Use technology ● Use computers and tablets ● Analyze data
6	Do you consider the following criteria to be important when considering the adoption of a new technology? ● Initial cost ● Time before payoff ● Risk level ● Ease of use ● Farmer recommendation ● Crop consultant recommendation ● County agent recommendation ● Technical support from manufacturer ● Integration with existing equipment ● Extension guidelines for use with the new technology ● Data ownership considerations ● Support from crop insurance policies
7	Do you consider the following options barriers to precision agriculture technology adoption in Arkansas? ● Initial cost ● Time before payoff ● Economic risk ● Complexity of use ● Lack of training ● Lack of extension recommendations ● Bad (previous) experiences ● Lack of compatibility with equipment ● Data management ● Software overload ● Data ownership

Table 2. Demographic distribution of respondents by profession. Summary of data collected between 6 August 2022 and 1 Dec 2022.

Profession	Age range	Experience	Respondents
			(%)
Field Crop Farmer	> 55	> 25 years	20
Crop Consultant	26 to 55	0 to 25 years	30
County Extension Agent	26 to 65	0 to > 25 years	50

Table 3. Summary of responses to the question: what three keywords come to mind when you hear precision agriculture? The results were summarized based on the number of times keywords were cited by the respondents.

Citations	Keywords
8 (40%)	Efficiency
4 (20%)	Accuracy; GPS; Technology
3 (15%)	Profit
2 (10%)	Data, Drones, Equipment, Expensive, Irrigation, Savings, Sustainable, Yield
1 (5%)	Agronomy, Autonomous, Available, Fertility, Greenfield, Grid Sampling, Grids, Ground Forming, Herbicide, Improvement, Knowledge, Markets, Math, Planting, Precise, Reliability, Software, Solutions, Stewardship, Yield Maps

Table 4. Summary of responses to the question: Do you consider each of the following options a goal of precision agriculture?

	A[a]	SA	N	SD	D
	-------- (% total number of respondents) --------				
Optimize inputs	85	15	0	0	0
Improve field data management	85	10	5	0	0
Improve operation timeliness	75	20	0	0	5
Improve environmental stewardship	65	35	0	0	0
Technology use in farming	60	40	0	0	0
Increase farm profitability	60	35	5	0	0
Manage within field variability	50	45	5	0	0
Increase resilience to climate variability	40	10	40	10	0
Increase yields	35	45	20	0	0

[a] A = Agree; SA = Somewhat Agree; N = Neither Agree nor Disagree; SD = Somewhat Disagree; D = Disagree.

Table 5. Summary of responses to the question: Do you consider each of the following options to be a concern for Arkansas agriculture in the next 30 years?

	A[a]	SA	N	SD	D
	---------- (% total number of respondents) ----------				
Pest management	65	30	5	0	0
Cost of inputs and land tenancy	60	20	20	0	0
Soil health issues	55	40	5	0	0
Unfavorable governmental regulations	55	30	15	0	0
Increased weather unpredictability	50	25	20	5	0
Rapid technological development	50	20	25	0	5
Water quality	45	50	5	0	0
Water scarcity	35	40	20	0	5

[a] A = Agree; SA = Somewhat Agree; N = Neither Agree nor Disagree; SD = Somewhat Disagree; D = Disagree.

Table 6. Summary of responses to the question: Do you consider the following skills to be important for the successful implementation of precision agriculture?

	A[a]	SA	N	SD	D
	---------------(% total number of respondents)---------------				
Proper equipment calibration	100	0	0	0	0
Making sense of data	80	20	0	0	0
Expertise using technology	65	25	5	5	0
Strong agronomic foundation	60	20	10	10	0
Computer skills	55	35	10	0	0

[a] A = Agree; SA = Somewhat Agree; N = Neither Agree nor Disagree; SD = Somewhat Disagree; D = Disagree.

Table 7. Summary of responses to the question: How comfortable are you in performing the following tasks?

	C[a]	SC	N	SU	U
	------- (% total number of respondents) -------				
Use computers and tablets	60	25	5	10	0
Calibrate equipment	35	30	10	10	15
Analyze data	30	45	10	15	0
Scout for stress	20	30	30	10	10
Use technology	15	25	20	35	5

[a] C = Comfortable; SC = Somewhat Comfortable; N = Neither Comfortable nor Uncomfortable; SU = Somewhat Uncomfortable; U = Uncomfortable.

Table 8. Summary of responses to the question: Do you consider the following criteria to be important when considering the adoption of a new technology?

	VI[a]	I	MI	SI	NI	ID
	------- (% total number of respondents) -------					
Ease of use	70	20	0	0	0	10
Integration with existing equipment	65	30	5	0	0	0
Technical support from manufacturer	60	35	5	0	0	0
Data ownership considerations	60	30	5	0	0	5
Initial cost	55	40	0	0	0	5
Time before payoff	55	35	0	0	0	10
Extension guidelines for use with the new technology	50	30	15	5	0	0
Farmer recommendation	45	25	5	5	0	20
Risk level	40	40	10	0	0	10
Crop consultant recommendation	35	35	25	0	0	5
County agent recommendation	15	40	15	15	0	15
Support from crop insurance policies	40	30	25	5	0	0

[a] VI = Very Important; I = Important; MI = Moderately Important; SI = Slightly Important; NI = Not important; ID = It Depends.

Table 9. Summary of respondents' response to the question: Do you consider the following options barriers to precision agriculture technology adoption in Arkansas?

	A[a]	SA	N	SD	D
	-------------- (% total number of respondents) --------------				
Time before payoff	75	15	10	0	0
Initial cost	65	35	0	0	0
Complexity of use	60	25	15	0	0
Data ownership	55	35	5	5	0
Lack of training	55	30	5	10	0
Software overload	55	20	25	0	0
Bad experiences	55	20	15	5	5
Lack of compatibility with equipment	50	35	15	0	0
Data management	50	25	25	0	0
Economic risk	45	40	15	0	0
Lack of extension recommendations	25	40	20	10	5

[a] A = Agree; SA = Somewhat Agree; N = Neither Agree nor Disagree; SD = Somewhat Disagree; D = Disagree.

Preliminary Assessment of Gamma-Ray Spectrometer Data Accuracy for Proximal Sensing of Soil Potassium in Arkansas

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Abstract

Adequate management of soil fertility is the backbone of Arkansas agriculture production. Optimal soil sampling strategies are needed to properly assess crop needs and optimize fertilizer use. However, the optimal sampling strategy may vary between fields because of spatial changes in soil properties and management history. Single-parameter proximal soil sensing can be used to characterize in-field variability in specific soil fertility metrics, including soil potassium (K). Yet, sensor data accuracy is likely to vary between fields limiting on-farm use. The objective of this study was to assess the performance of a commercial gamma-ray spectrometer for proximal sensing of soil K. Sensor data and grid samples were collected in four fields representing a wide range of soil properties and management practices. The grid soil samples were collected in approximately 100 locations within each field and analyzed for soil-test K. The field sizes ranged from 25 to 50 ac, and the sampling depths were 4 and 6 in. Data analysis was conducted to compare the sensor K values to the soil-test K values and assess sensor performance. The sensor accurately described the distribution of soil K in half the fields but did not accurately represent spatial dynamics in soil K. Further research is needed to identify the drivers of sensor performance and predict data accuracy as a function of soil properties and management history.

Introduction

Soil testing is widely used in Arkansas to measure in-field changes in soil pH and nutrients (DeLong et al., 2022). Most field samples are collected using a 2.5- or 5.0-ac grid sampling strategy without evidence that the chosen spatial resolution appropriately describes in-field variability. Suboptimal sampling spatial resolutions may result in inaccurate measurement of variability and assessment of crop needs (Poncet et al., 2022). Accurate assessment of crop needs through optimized soil sampling strategies is needed to optimize fertilizer application parameters and maximize profitability (Johnston and Bruulsema, 2014). However, the optimal sampling strategy may vary within and between fields because of spatial changes in soil properties, weather, and management history (Mulla and McBratney, 2001). Until recently, the optimum soil sampling strategy could only be determined a posteriori from soil data collected at very high spatial resolution. While this process is commonly used in research, implementation on-farm would be impractical. Fortunately, recent developments in proximal sensing have created new opportunities for optimized soil sampling and soil fertility management (Adamchuck and Rossel, 2010; Gruijter et al., 2010).

Proximal sensor data are collected in proximity or in contact with the soil to estimate specific soil properties or combinations of soil properties (Rossel et al., 2011). Geophysical methods for proximal soil sensing are most widely used to quantify in-field changes in soil physio-chemical properties and locate soil boundaries (Adamchuk et al., 2011). More particularly, electromagnetic induction and electrical resistivity have become the methods of choice to map site-specific changes in field conditions (Corwin and Plant, 2005). Electromagnetic induction uses alternating electric currents to determine the soil electrical conductivity, a measure of the soil's ability to transport electric charges (Serrano et al., 2010). Electrical resistivity uses a differential electric current to determine the soil capacity, a measure of the soil's ability to attenuate the flow of electric charges (Corwin and Lesch, 2003). Electrical resistivity is most often used to estimate the apparent soil conductivity, defined as the inverse of soil electrical resistivity. The proximal sensing data collected using electromagnetic induction or electrical resistivity provide a confounded measurement of soil salinity which may be affected by multiple soil properties, including texture, bulk density, organic matter, water content, and ionic composition (Grisso et al., 2005). The relative importance of each parameter may vary between and within fields, and the collected data cannot be used to map any one soil parameter (Mueller et al., 2003).

Today, an increasing body of literature investigates the use of non-destructive analytical techniques for proximal soil sensing to overcome the limitations of electromagnetic induction and electrical resistivity (Lobsey et al., 2010). For instance, gamma-ray spectroscopy is being increasingly used to determine soil pH and plant-available nutrients (Mahmood et al., 2013). Gamma-ray spectroscopy is a rapid, non-invasive method that uses passive measurements of the soil natural gamma radioactivity and modeling to quantify in-field changes in individual soil fertility metrics. The gamma-ray spectrometer (GRS, or sensor) data are collected at high resolution to attempt to describe in-field changes in key soil fertility metrics. However, sensor performance may vary between fields. Proper assessment of sensor performance and the factors affecting the collected data's accuracy are critical components of any effort that aims to facilitate the integration of single-parameter

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proximal soil sensing into the producers' decision-making process for optimized soil sampling and fertility management (Heggemann et al., 2017).

The University of Arkansas System Division of Agriculture's Soil Testing Laboratory only provides fertilizer recommendations for potassium (K), phosphorus, zinc, and liming recommendations for pH. The strongest yield responses to soil fertility management are observed following K fertilizer and lime applications (Slaton et al., 2006). Therefore, optimization of soil K and pH measurements using single-parameter proximal soil sensing could have the most significant positive impact on farm profitability. The objective of this study was to assess the GRS data accuracy in four production fields in Arkansas. The scope of this project was limited to soil K.

Procedures

Data Collection and Processing

Proximal soil sensing and ground-truth data were collected from four fields located in Conway (fields A and C), St. Francis (field B), and Drew (field D) counties, Arkansas (Table 1). The experimental locations were selected to represent a range of typical soil physical properties and management history for Arkansas silt-loam soils. Field size ranged from 25 ac in field B to 50 ac in field D. The dominant soil series were Gallion, Calhoun, Roxana, and Herbert/Rilla in fields A, B, C, and D, respectively. The previous crops were corn (*Zea mays*), soybean (*Glycine max*), or cotton (*Gossypium hirsutum*). Fields A and C were managed using cover crop and no-till practices. Fields B and D were managed using conventional tillage, raised beds, and furrow irrigation. Pivot irrigation was used in Field A. No irrigation was used in Field C. Different crop rotations were used in each field.

In each field, GRS measurements of soil K were collected in the spring of 2022 using a SoilOptix® commercial sensor (SoilOptix Inc, Tavistock, Ontario, Canada). The raw sensor data were collected along equidistant, parallel passes oriented in the maximum direction of elongation of fields A to C and along the established raised beds in field D. The distance between two consecutive passes was 40 ft as recommended by SoilOptix Inc. The distance between the GRS and the soil was 3 ft. Individual GRS sensor measurements were recorded at a frequency of five hertz and georeferenced using real-time kinematic positioning accuracy (±1 in. within a field).

Soil samples were collected using grid sampling and submitted to the Marianna Soil Test Laboratory for soil pH determination in a 1:2 (v/v) soil-to-water mixture and Mehlich 3 extraction for available nutrients. The grid sampling resolution ranged from 4 samples/ac in field B to 2 samples/ac in field D (Table 2). In each grid sampling location, soil samples were collected at the 4- and 6-in. depths using the custom-manufactured cone probe described by Drescher et al. (2021). Each 4- and 6-in sample was composed of 12 and 8 subsamples collected within 15 ft from the sampling locations, respectively. The GRS measurements and soil samples were collected on the same day in each field. Additional soil samples were collected in 1 location per 8 ac or a minimum of four locations per field for GRS data calibration using the same protocol as for grid sampling. The additional sampling locations were identified using the SoilOptix Inc proprietary data collection software. Visual assessments of surface residue cover were taken at the time of data collection. There were no surface residues in field B, a moderate amount of surface residues in field D, and a high amount of surface residues in fields A and C. The GRS data were collected after tillage and before bed establishment in field B and before tillage along the raised beds from the previous year in field D.

The raw GRS data and soil test results from the additional sampling locations were provided to SoilOptix Inc for processing. The GRS data were processed separately for each field. Empirical calibration and interpolation were performed using the SoilOptix® 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 K values in each grid sampling location were calculated as the average of the processed GRS data found within a 15-ft radius from the grid sampling location.

In-field changes in soil-test K and sensor K values were quantified using boxplots. Separate boxplots were created by field and depth. The mean soil-test K and sensor K values were added to each boxplot. The median and mean values provided a measure of central tendency (Manikandan, 2011a; Manikandan, 2011b). The 95% confidence intervals (CI) around the median soil-test K and sensor K values were represented using notches (McGill et al., 1978). The 95% confidence intervals (CI) around the mean soil-test K and sensor K values were represented using error bars. There was a 95% chance that the true median and mean values fell within the associated 95% CI (O'Brien and Yi, 2016). Two 95% CI that did not overlap indicated that the associated two values were statistically different from each other at a significance level of $P = 0.05$. The difference between the mean and median soil-test K or sensor K values in each boxplot provided a measure of skewness or asymmetry (McCluskey and Lalkhen, 2007). When the 95% CI of the mean did not overlap with the 95% of the median in a boxplot, the corresponding soil-test K or sensor K data were significantly skewed. When the mean was statistically greater than the median, the corresponding data were skewed toward greater soil-test K values. The boxplot length and interquartile range provided a measure of variability (Xie et al., 2017). The greater the boxplot length and interquartile range, the stronger the spatial variability in soil-test K or sensor K. The middle 50% of soil-test K or sensor K values fell within the interquartile range. Two other measures of variability—referred to as the 75% and 90% ranges—were created to identify the middle 75% and 90% soil-test K or sensor K values. The coefficient of variation values associated with each boxplot were also computed to show the extent of soil-test K and sensor K variability in comparison to the mean.

Central tendency, skewness, and variability defined the distribution of soil-test K and sensor K values by field and depth. The distributions of soil-test K values were compared between fields and sampling depths to characterize true field conditions. The distributions of sensor K values were compared to the distribution of soil-test K values by field and sampling depth to assess sensor performance. Sensor performance was first described as the sensor's ability to represent the distribution of soil-test K values in a field at a given sampling depth. Sensor performance was satisfactory if the 95% CI for the mean and median values of the sensor K values overlapped with the 95% CI for the mean and median values of the soil-test K, respectively, and if the coefficient of variation for sensor K was within 10% from the associated coefficient of variation for soil-test K. The interquartile, 75% and 90% range values for the sensor K and soil-test K values were also compared to characterize the sensor's ability to measure variability across the distribution of soil-test K values in a field for a given sampling depth. The sensor provided an accurate estimation of the middle 50% of soil-test K values if the difference between the soil-test K and sensor K interquartile ranges was within ±5 ppm. The sensor provided an accurate estimation of the middle 75% and 90% of soil-test K values if the difference between the soil-test K and sensor K 75% and 90% ranges was within ±10 ppm. Poor sensor estimation of the middle 75% or 90% of soil-test K values indicated that the sensor failed to characterize the tails of the soil-test K distribution.

Furthermore, linear regression analysis was computed to model the sensor K values as a function of their corresponding soil-test K values in fields where the GRS accurately described the distribution of soil-test values. A non-spatial linear regression was computed using the ordinary least squares (OLS) method to estimate the model parameters and the global Moran's I statistics to investigate the degree of spatial autocorrelations among the model residuals (Xiong et al., 2019). The assumption of spatial independence was not validated if the *P*-value associated with the computed global Moran's I statistics was significant at the $P = 0.05$ significance level. In that case, spatial autocorrelations were accounted for using linear spatial lag and spatial error regression models (Anselin, 2009). The spatial lag model assumes that the GRS measurement in one location averages the soil-test K values from neighboring locations. The spatial error model assumes that the GRS measurement error in one location depends on the measurement error in neighboring locations. The best linear regression model minimized the Akaike's Information Criterion (AICc). The accuracy of the best model in each grid sampling location was quantified as the ratio of the best regression model residuals to their corresponding soil-test K values. The higher the ratio value, the more accurate the model characterization of soil K. Results for a field were summarized using a boxplot. The accuracy of the best model was satisfactory, provided the slope parameter was statistically different from zero at $P = 0.05$, the 95% confidence interval around the median of the residual to soil-test K ratio values includes 0, and more than 95% of the residual to soil-test K ratio values were smaller than 15%. The first metric ensured that there were significant correlations between sensor K and soil-test K values. The second metric ensured that the sensor K values were not biased. The third metric ensured appropriate goodness of fit for the model.

Results and Discussion

Ground-Truth Characterization of Soil K

The soil-test K values at the 4- and 6-in. sampling depths ranged from 105 to 259 ppm and 86 to 267 ppm in field A, 42 to 89 ppm and 36 to 88 ppm in field B, 71 to 342 ppm, and 63 to 308 ppm in field C, and 67 to 307 ppm and 83 to 294 ppm in field D (Fig. 1). The median soil-test K values at the 4- and 6-in. sampling depth were 152 and 136 ppm in field A, 59 and 52 ppm in field B, 124 and 113 ppm in field C, and 120 and 114 ppm in field D. The mean soil-test K values at the 4- and 6-in. sampling depths were 156 and 145 ppm in field A, 60 and 53 ppm in field B, 134 and 130 ppm in field C, and 132 and 126 ppm in field D. The 95% CI around the median and mean soil-test K values for each field and sampling depth combination overlapped. Therefore, there was no statistical difference between the median and mean soil-test K values in a field at a given sampling depth, and the soil-test K data were not skewed. The coefficient of variation for soil-test K values at the 4- and 6-in sampling depths were 30.3% and 34.3% in field A, 10.7% and 10.6% in field B, 47.4% and 53.9% in field C, and 44.2% and 40.8% in field D. The interquartile range values for soil-test K at the 4- and 6-in. sampling depths were 45 and 47 ppm in field A, 14 and 14 ppm in field B, 57 and 53 ppm in field C, and 36 and 31 ppm in field D. The middle 75% range for soil-test K values at the 4- and 6-in. sampling depths were 66 and 86 ppm in field A, 25 and 24 ppm in field B, 91 and 96 ppm in field C, and 69 and 56 ppm in field D. The middle 90% range for soil-test K values at the 4- and 6-in. sampling depths were 90 and 104 ppm in field A, 34 and 35 ppm in field B, 122 and 164 ppm in field C, and 150 and 147 ppm in field D. The central soil-test K values and magnitude of in-field variability were smallest in field B. The central soil-test K values were greatest in field A, and the magnitude of in-field variability in soil-test K was greatest in field C, closely followed by field D. Differences in the distribution of soil-test K values existed between sampling depths within a field, but the 95% CI around the mean and median overlapped meaning that there was no significant stratification.

GRS Data Accuracy: Descriptive Comparisons to Soil-Test K

The sensor K values at the 4- and 6-in. depth ranged from 103 to 130 ppm and 130 to 176 ppm in field A, 32 to 95 ppm and 25 to 93 ppm in field B, 117 to 147 ppm, and 116 to 137 ppm in field C, and 67 to 295 ppm and 100 to 213 ppm in field D (Fig. 2 and 3). The median sensor K values at the 4- and 6-in. depth were 120 and 148 ppm in field A, 62 and 61 ppm in field B, 130 and 126 ppm in field C, and 126 and 130 ppm in field D. The mean sensor K values at the 4- and 6-in. depth were 118 and 150 ppm in field A, 62 and 60 ppm in field B, 131 and 126 ppm in field C, and 136 and 136 ppm in field D. The 95% CI around the median and mean sensor K values for each field and sampling depth combination overlapped. There were no statistical differences between the median and mean sensor K values within a field at a given sampling depth, and the GRS provided an accurate measurement of the skewness of soil-test K values. The coefficient of variation for soil-test K values at the 4- and 6-in. sampling depths were 6.0% and 10.1% in field A, 13.0% and 12.7% in field B, 6.7% and 4.6% in field C, and 48.6% and 24.0% in field D. The interquartile range values for sensor K at the 4- and 6-in. sampling depths were 7 and

12 ppm in field A, 18 and 17 ppm in field B, 8 and 6 ppm in field C, and 49 and 24 ppm in field D. The middle 75% range for sensor K values at the 4- and 6-in. sampling depths were 13 and 22 ppm in field A, 30 and 29 ppm in field B, 15 and 10 ppm in field C, and 98 and 49 ppm in field D. The middle 90% range for sensor K values at the 4- and 6-in. sampling depths were 21 and 35 ppm in field A, 42 and 40 ppm in field B, 20 and 14 ppm in field C, and 178 and 88 ppm in field D. The 95% CI for the mean and median sensor K values overlapped with the 95% CI for mean and median soil-test K values at the 4-in. sampling depths in fields B, C, and D, and at the 6-in. sampling depth in fields A and C. The coefficient of variation for sensor K was within 10% of the associated coefficient of variation for soil-test K at the 4-in. sampling depth in fields B and D, and at the 6-in. depth in fields B. Therefore, the sensor performance was satisfactory at the 4-in. sampling depth in fields B and D. Moreover, the interquartile, 75% range, and 90% range for the sensor K values at the 4-in. sampling depth were within ±5, ±10, and ±10 ppm of the corresponding ranges for the soil- test K values in field B, but not in field D. This means that the GRS provided a better estimation of the soil-test K distribution tails in field B than field D.

GRS Data Accuracy: Regression Modeling

Significant spatial autocorrelations were found within the OLS regression model residuals for both fields at the 4-in. sampling depth (Table 3). The spatial dependencies found within the data were best modeled using a spatial lag linear regression model. The estimated model intercept values were 31.3 ppm in field B and 5.0 ppm in field D. The estimated model slope values were 0.29 in field B and 0.49 in field D. Both estimated slope values were statistically different from zero, which demonstrated that there were statistically significant positive relationships between sensor K and soil-test K values in fields B and D at the 4-in. sampling depth. The performance metrics ratio values ranged from -58.8% to 47.1% in field B and –48.4% to 0.84% (Fig. 4). The 95% confidence interval around the median ratio values ranged from -3.4% to 5.9% in field B and –8.1% to 3.0% in field B. These intervals included zero, and the GRS provided an unbiased measurement of the spatial distribution of soil test values in fields C and D. On the other hand, the middle 85% of the ratio values ranged from -28.6% to 26.9% in field B, and –27.1% to 30.4% in field D. The middle 85% range was greater than the acceptable ±15% and the GRS did not accurately represent the spatial distribution of soil test values in fields C and D.

Practical Applications

The commercial GRS used in this study provided an accurate measurement of the distribution of soil-test K values in 2 of 4 fields at the 4-in. sampling depths but did not accurately represent spatial dynamics in soil K. In these two fields, the collected data could have been used to determine the optimum uniform K fertilizer application rate or quantify the K fertilizer amounts needed for variable-rate K fertilizer application. However, the collected GRS data could not have been used to replace soil sampling for the purpose of variable-rate K fertilizer application. Assuming that the results from this study are reproducible - meaning that the sensor is reliable - gamma-ray spectroscopy could be used to assess the overall field soil K level and quantify the magnitude of in-field changes in soil K under some, but not all, field conditions. Research is being conducted to identify the drivers of non-spatial GRS performance and predict sensor data accuracy rather than determine it *a posteriori*. To do so, additional sensor and ground-truth data are being collected to increase the dataset size and identify the factors most likely to affect the sensor performance. Analysis of the data will allow for the formulation of hypotheses regarding the drivers of sensor performance, and validation data will be collected to test these hypotheses. The methods used in this study can be applied to other single-parameter proximal sensing tools, and future applications of this research will not be limited to gamma-ray spectroscopy. Outcomes may include the development of a decision-support tool that will facilitate the integration of gamma-ray spectroscopy or other single-parameter proximal soil sensing tools into the producers' decision-making process to optimize soil sampling and fertilizer management practices in Arkansas.

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Table 1. Experimental locations and relevant management history.

Field	Area	County	Soil Series	Previous Crop	Management Practices
	(ac)		(% area, ac)		
A	40	Conway	• Gallion (70.3%) • Roxana (29.7%)	Corn	• Cover crop • No-till • Pivot irrigation • Corn–Soybean rotation
B	25	St. Francis	• Calhoun (100%)	Soybean	• No cover crop • Conventional tillage, annual • Raised beds • Furrow-irrigation • Corn–Soybean rotation
C	40	Conway	• Moreland (24.3%) • Roellen (24.9%) • Roxana (50.8%)	Soybean	• Cover crop • No-till • Not irrigated • Soybean monoculture
D	50	Drew	• Hebert (45.5%) • Perry (0.4%) • Rilla (54.1%)	Cotton	• No cover crop • Conventional tillage, annual • Raised beds • Furrow-irrigation • Cotton–Corn rotation

Table 2. Data collection protocol and field notes.

Field	n[a]	Data Collection	Relevant Notes
A	100	01/26/2022	Visual assessment of surface residue cover: high
B	101	04/09/2022	Visual assessment of surface residue cover: none Data collected after tillage and before bed establishment
C	95	01/31/2022	Visual assessment of surface residue cover: high
D	100	02/15/2022	Visual assessment of surface residue cover: moderate Data were collected along the raised beds from previous year

[a] *n* = number of grid sampling locations.

Table 3. Results from regression analysis to assess the spatial sensor data accuracy.

		Global Moran's I		Regression Model AICc[a] Values			Best Model
Field	Depth	Statistic	P[b]	OLS	Spatial Lag	Spatial Error	P_{Slope}[c]
B	4 in.	0.26	0.05	792.6	785.5	789.2	$P = 0.01$
D	4 in.	0.55	0.05	994.1	954.4	964.1	$P < 0.001$

[a] AICc = Akaike's Information Criterion.

[b] P = Significance level of the Global Moran's I statistic.

[c] P_{Slope} = Significance level of the best model intercept parameter.

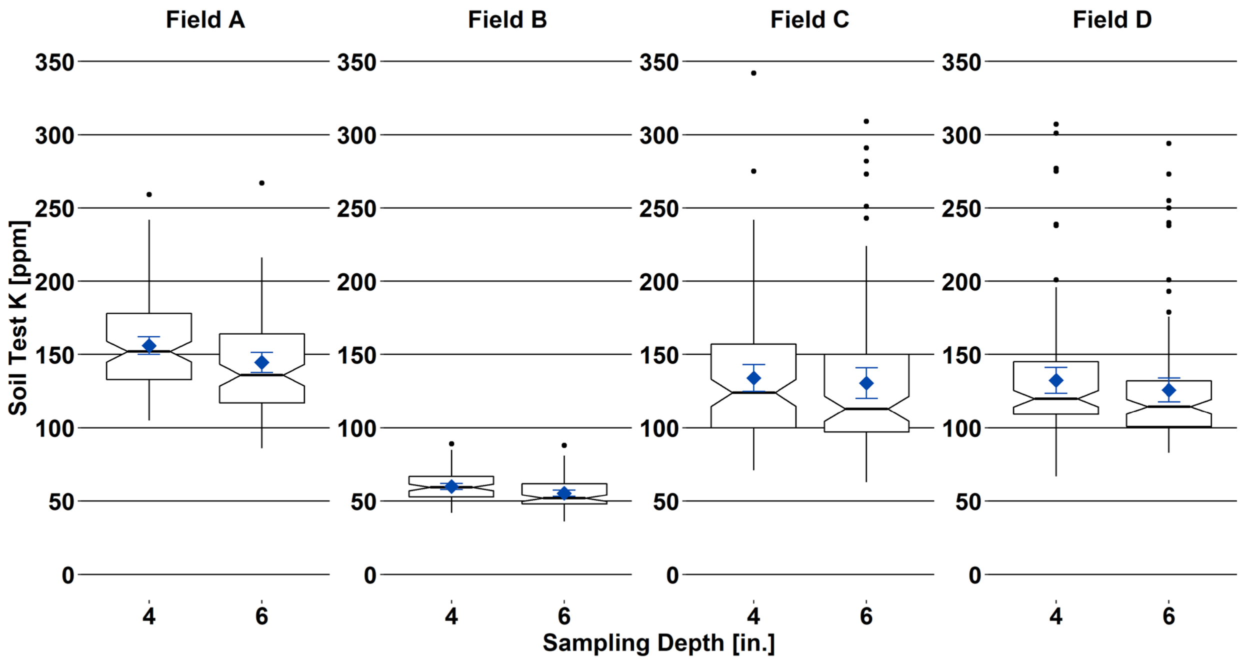

Fig. 1. Distribution of soil-test K values by experimental location and sampling depth. The notches represent the 95% confidence intervals around the median soil-test K values. The blue diamond symbols represent the mean soil-test K values. The blue vertical error bars represent the 95% confidence interval around the mean soil-test K values.

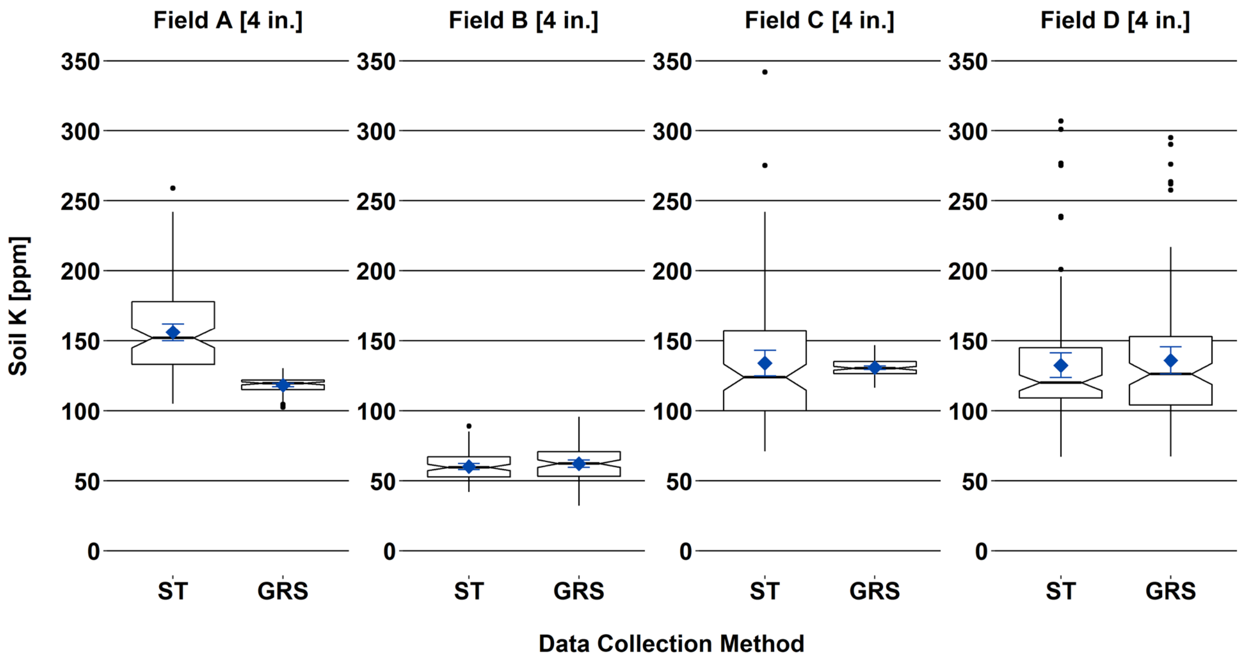

Fig. 2. Distribution of soil-test K (ST) and sensor K (GRS) values by experimental location of the 4-in. sampling depth. The notches represent the 95% confidence intervals around the median soil-test K and sensor K values. The blue diamond symbols represent the mean soil-test K and sensor K values. The blue vertical error bars represent the 95% confidence interval around the mean soil-test K and sensor K values.

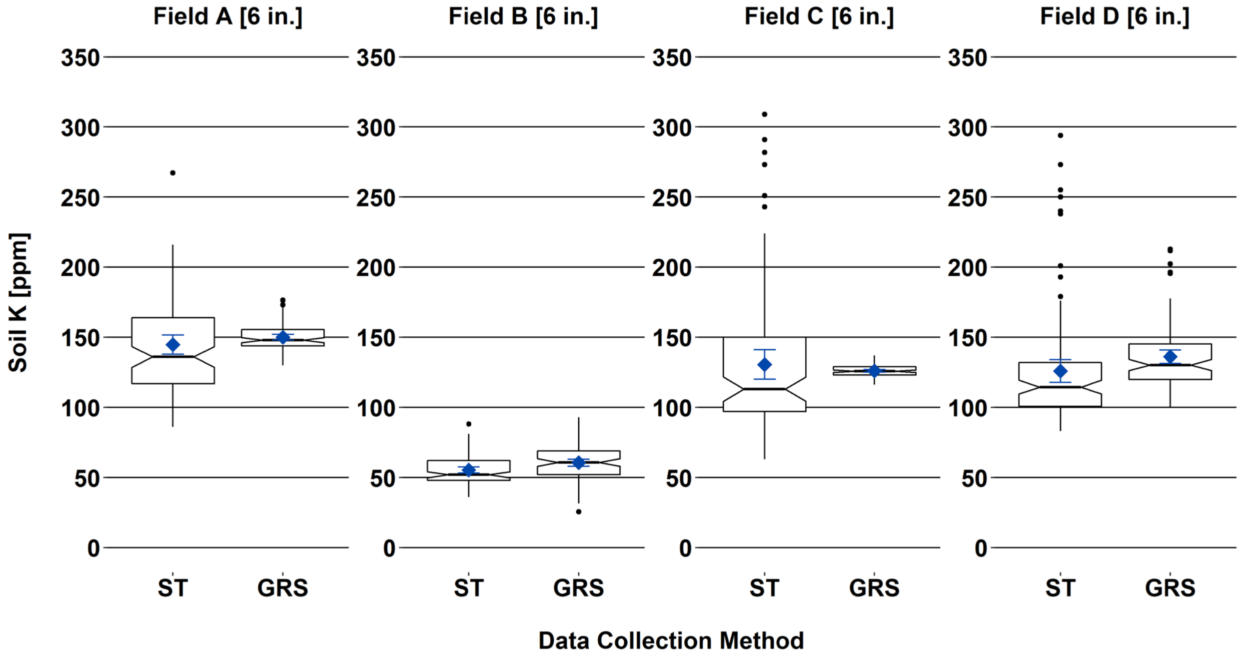

Fig. 3. Distribution of soil-test K (ST) and sensor K (GRS) values by experimental location of the 6-in. sampling depth. The notches represent the 95% confidence intervals around the median soil-test K and sensor K values. The blue diamond symbols represent the mean soil-test K and sensor K values. The blue vertical error bars represent the 95% confidence interval around the mean soil-test K and sensor K values.

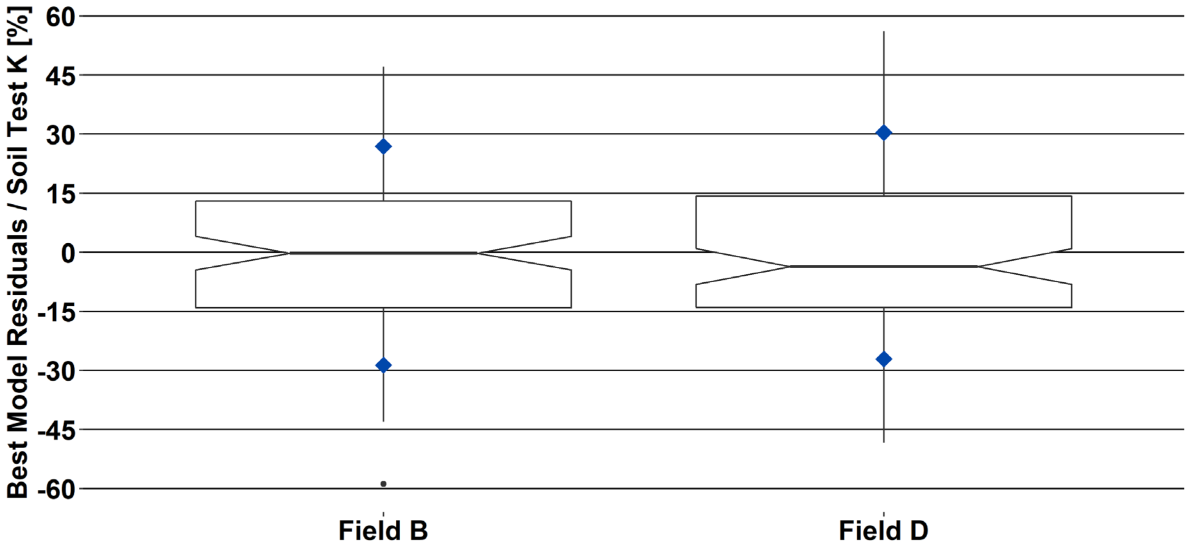

Fig. 4. Goodness-of-fit of the best linear regression models computed for fields B and D at the 4-in. sampling depth. The goodness-of-fit in each grid sampling location was quantified with the ratio of the best model residual to soil-test K. The overall model goodness-of-fit was assessed by looking at the distribution of the computed ratio values within a field. The notches represent the 95% confidence intervals around the median ratio values. The blue diamond symbols represent the range of ratio values that contain 85% of the grid sampling locations.

Cover Crop and Phosphorus and Potassium Application Rate Effects on Soil-Test Values and Soybean 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 6 results of a field trial examining the influence of cover crop and fertilizer-P and -K application on soybean (*Glycine max*) 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 2021 and termination in spring 2022. The fifth annual fertilizer-P and -K treatment applications were made to fertilizer treatment subplots, and soybean was planted following cover crop termination. Cereal rye (*Secale cereal*) biomass (921–1573 lb/ac) contained the equivalent of 9–15 lb P_2O_5 and 30–47 lb K_2O/ac, while biomass from winter fallow treatments (613–822 lb/ac) contained the equivalent of 5–7 lb P_2O_5 and 21–29 lb K_2O/ac. Dry matter and nutrient accumulation were generally greater with cereal rye than in winter fallow treatments, but fertilizer rate only affected dry matter and nutrient accumulation in 1 trial, where the control resulted in greater accumulation than where K was applied. Cover crop generally did not influence spring soil-test values, but fertilizer rates were consistently reflected in soil-test values following 4 annual applications, with values increasing as rates increased. Fertilizer rate also significantly affected grain yield in one K-rate trial, where 60 lb K_2O/ac produced greater soybean yield than treatments where 180 lb K_2O/ac or no fertilizer-K were applied. Soybean yield in the other trials was not affected by either the main-effect treatments or their interaction

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 (*Zea mays*)/soybean (*Glycine max*) 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 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 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 from 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 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) describe the initial soil properties and the soil-test and cash crop responses to cover crop and fertilizer rates across the first 5 years of this project. This report summarizes the year 6 results focused on examining the effect of cover crop and fertilizer-P and -K rates on soybean yield and select soil-test properties and the influence of cover crop on changes in selected

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soil chemical properties 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 Calloway (54%), Loring (28%), and Memphis (1%) silt loam and Marvell fine sandy loam (16%) soils (Slaton et al., 2018). Mean soil properties for the no-P or no-K fertilizer control treatments of each trial in 2022 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, initial fertilizer treatment application in the spring of 2018, a cotton crop in the 2018 growing season, soybean in 2019, corn in 2020, and cotton in 2021. Following cotton harvest in fall 2021, cover crop treatments were established by drill seeding cereal rye (80 lb/ac; 6-in. row spacing) on 11 November at RRS and 10 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 2 December 2021 at RRS and 3 December 2021 at LMCRS. Additional soil samples were collected on 22 April 2022 at RRS and 29 April 2022 at LMCRS to examine the influence of cover crop growth and sample time on selected soil chemical properties and soil health parameters. 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 Agricultural Research and Extension Center, Fayetteville, Ark. Soil health samples were collected (8, 1.25-in. diameter cores/composite) in spring 2022 from the 40 lb P_2O_5/ac and 120 lb K_2O/ac treatments in each cover crop treatment in all trials and submitted to Cornell University for analysis using the Basic Soil Health Analysis Package (BSHAP, Moebius-Clune et al., 2016).

Tissue samples of cereal rye and winter fallow weeds were also collected immediately before termination 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. Samples were dried to constant moisture, ground to pass a 1-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 both locations.

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 fifth 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 11 May and 18 May 2022, respectively, and soybean (Delta Grow 49XF22) was planted on 12 May at LMCRS. Fertilizer treatments were applied on 4 May, blanket P and K were applied on 5 May, and soybean (Delta Grow 49XF22) was planted on 9 May 2022 at RRS.

The soybean at each location received recommended pest control based on the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations. Soybean was harvested on 12 October at LMCRS and on 15 October 2022 at RRS. Soybean grain yield was measured by harvesting the 2 middle rows of 117-ft and 125-ft long sections in the middle of each plot at LMCRS and RRS, respectively. Following soybean harvest, cereal rye was planted on 3 November 2022 at LMCRS and on 1 November 2022 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 2021 minus spring 2022). 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 soybean yield data using the MIXED procedure of 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

Fertilizer-P rate did not influence aboveground dry matter accumulation or nutrient uptake in either of the P trials, but dry matter accumulation and biomass P content were greater from cereal rye relative to winter fallow at both locations (Table 2). Similarly, compared to native vegetation in winter fallow, cereal rye had greater aboveground dry matter and K uptake in the K trial at RRS, while fertilizer-K rate did not affect these parameters (Table 3). Cereal rye in these trials produced up to 1573 lb/ac of aboveground dry matter and contained as much as 39 and 6.6 lb/ac of K and P, respectively, while winter fallow treatments resulted in 48 to 67% of the dry matter and 41 to 55% of the nutrient content, relative to cereal rye. In the K trial at LMCRS, however, cover crop did not affect aboveground dry matter or K content, but the no-fertilizer-K control averaged 37% more dry matter and 24% greater K content than treatments receiving 60–180 lb K_2O/ac, which did not differ from each other (Table 4). Although unexpected, the increased growth and nutrient uptake without fertilizer-K may be related to yields of the previous crop as fertilizer-K significantly improved cotton yield in this trial in 2021 (Smartt et al., 2022), potentially removing more nutrients from the soil and resulting in limitations of other essential nutrients. The mean aboveground nutrient content of cereal rye was equivalent to as much as 15 lb P_2O_5 and 47 lb K_2O/ac, indicating substantial nutrient uptake can occur from fall and winter cover crop growth.

Soil organic matter in the spring was influenced by cover crop in both fertilizer-K trials ($P < 0.10$; data not shown). At LMCRS, SOM was greater with cereal rye (1.71%) than in the winter fallow treatment (1.55%). Similarly, SOM at RRS was 1.37% with cereal rye and 1.28% in winter fallow. Additionally, SOM of the K trial at RRS was affected by fertilizer-K rate, where 60 lb K_2O/ac resulted in greater SOM (1.40%) than applications of 120 or 180 lb K_2O/ac, which did not differ and averaged 1.28% SOM. Soil organic matter was not significantly influenced by cover crop treatment or fertilizer rate in the P trials.

Soil-test P in the spring was significantly affected by fertilizer-P rate in both P trials, where soil-test P increased with each increasing fertilizer-P rate but was not affected by cover crop treatment or its interaction with P rate (Table 5). Compared to spring 2021 soil samples, soil-test P in the LMCRS P trial increased by about 1, 7, 11, and 14 ppm in the no-fertilizer-P control and 40, 80, and 120 lb P_2O_5/ac treatments, respectively (Smartt et al., 2022). Soil-test P in the RRS P trial, relative to 2021, decreased by about 3 and 2 ppm in the no-fertilizer-P control and 40 lb P_2O_5/ac treatments, respectively, while soil-test P increased by 5 and 16 ppm at application rates of 80 and 120 lb P_2O_5/ac. From cover crop planting in the fall to termination in the spring, changes in soil-test P were not affected by cover crop, P rate, or their interaction but increased by averages of 4.7 and 3.5 ppm in the LMCRS and RRS P trials, respectively (Table 5). These increases in soil-test P are consistent with 2021 results, where increases of 4.1 and 3.7 ppm were observed at LMCRS and RRS, respectively.

Spring 2022 soil-test K in the K trial at LMCRS ranged from 76 to 188 ppm and was influenced by cover crop, where soil-test K was 5 ppm greater with cereal rye, relative to winter fallow, and fertilizer-K rate (Table 6). Soil-test K in the K trial at RRS in spring 2022 ranged from 69 to 175 ppm and increased significantly with each increasing fertilizer-K rate but was not affected by cover crop treatment or its interaction with K rate. Relative to spring 2021 soil samples, soil-test K in the RRS K trial decreased by 8 and increased by 14, 22, and 33 ppm at application rates of 0, 60, 120, and 180 lb K_2O/ac, respectively (Smartt et al., 2022). The same application rates at LMCRS resulted in soil-test K increases of 8, 32, 58, and 50 ppm, respectively, from 2021 to 2022. Soil-test K from cover crop planting in the fall to spring termination decreased numerically by an average of 10 ppm at LMCRS but was not affected by cover crop, fertilizer-K rate, or their interaction (Table 6). At RRS, however, the interaction of cover crop and fertilizer-K rate significantly influenced change in soil-test K from fall to spring. Soil-test K decreased by over 43 ppm in the winter fallow treatment with 180 lb K_2O/ac, which was greater than any other treatment combination, with an intermediate change at 120 lb K_2O/ac with winter fallow and the least change when 0 or 60 lb K_2O/ac were applied with winter fallow. Changes in soil-test K did not differ based on fertilizer-K rate within the cereal rye treatments, which decreased by an average of 26 ppm and were all similar to the intermediate change resulting from 120 lb K_2O/ac in the winter fallow treatment. With nearly twice as much K in spring aboveground dry matter of cereal rye, soil-test K is expected to decrease more relative to winter fallow, which was the trend when 0 or 60 lb K_2O/acre was applied. Greater than expected decreases in soil-test K at higher application rates in winter fallow treatments at RRS must not be related to differences in K uptake by plants over the winter but indicate a different mechanism of K loss that needs to be studied further (perhaps a flush of excess K from the soil system).

The cumulative influence of cover crop treatment on soil health parameters measured in 2022 was minor (Table 7). Aggregate stability and active carbon were 34% and 12% greater, respectively, with cereal rye, relative to the winter fallow treatment in the K-rate trial at LMCRS, while no significant differences were observed in the other 3 trials. Fertilizer rates were not evaluated for soil health parameters.

Soybean grain yield averaged 60 bu./ac in the P-rate trial at LMCRS but was not significantly affected by fertilizer-P rate, cover crop treatment, or their interaction (Table 8). The probability of a response to fertilizer-P was low since the treatment soil-test P values are at an Optimal level (26–50 ppm) for soybean. Similarly, there was no cotton yield response to fertilizer-P in 2021 when soil-test P of the non-P-fertilized control was 25 ppm (Smartt et al., 2022). At the RRS, soil-test P of the no-P control was 32 ppm (Optimum level), and grain yield was not significantly affected by P rate, cover crop, or their interaction (Table 8). The RRS yields are the mean of replicates 1 and 2 as the growth of soybean in all P rate treatments growing in the no- cover crop (winter fallow) portion of replicate 3 was stunted and affected by root-knot nematodes. Whether the distribution of nematode injury was related to the cover crop treatments in the P trial is unknown.

Fertilizer rate significantly affected soybean grain yield in the K trial at LMCRS, where 60 or 120 lb K_2O/ac rates produced greater yields than the non-K-fertilized control (Table 9). The application of 180 lb K_2O/ac resulted in a yield lower than the 60 lb K_2O/ac treatment but similar to the other two treatments. Cover crop treatment or its interaction with fertilizer-K rate did not affect soybean grain yields. A yield response to fertilizer-K was expected at LMCRS, where soil-test K of the control (76 ppm) was in the middle of the Low category (61–90 ppm). A similar response was observed in this trial in 2021, where fertilizer-K, regardless of rate, increased cotton yield by 25% relative to the non-K-fertilized control. Due to severe damage to the soybean crop by root-knot nematodes in more than one-half of the plots, soybean grain yield data were not statistically analyzed for the K-rate trial at RRS. In the K rate trial, root-knot nematode damage did not appear to differ between cover crop treatments. Means from the remaining 1 or 2 replications of each treatment are provided for the record (Table 9), but interpretations should be made with caution.

Practical Applications

Aboveground dry matter sampled in spring 2022 and nutrient uptake of that biomass were consistently greater with cereal rye, relative to winter fallow, but cover crop treatment generally had little effect on soil-test values or soybean grain yields in these trials. Low biomass accumulation of the cereal rye, along with proliferation of weeds in the winter fallow plots, likely reduced the relative difference in influence of the cover crop treatments. The effect of cover crop treatment has been stronger in previous years, especially when cereal rye growth is good and weeds are less abundant in the winter fallow treatment. Soil-test P of the no-P control treatment is in the Optimum category at both locations and slowly decreasing over time, increasing the likelihood of yield responses in the future. Soil-test K is in the Low category in both trials, where a yield response to fertilizer-K is likely. Although yields cannot be interpreted for the K trial at RRS due to nematode damage, the trial at LMCRS was responsive to K in 2022. Although cover crop treatment did not substantially affect measured soil and plant parameters in these trials in 2022, 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 should put on substantial biomass and will likely have a greater influence on the 2023 summer crop. Additionally, future plans have been discussed to utilize a legume or a mixture including legumes to enhance cover crop growth for a potentially stronger influence on the cropping system if funding continues.

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Table 1. Mean soil pH, organic matter (SOM), and Mehlich-3 extractable nutrients in the 0–6-in. 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 2022.

	LMCRS		RRS	
Soil property	**P trial**	**K trial**	**P trial**	**K trial**
Soil pH	7.3	7.3	6.6	6.5
P (ppm)	26	42	32	37
K (ppm)	127	76	174	69
Ca (ppm)	1135	1151	739	725
Mg (ppm)	333	303	118	109
S (ppm)	7.6	6.9	6.6	6.6
Fe (ppm)	172	185	275	286
Mn (ppm)	123	117	104	107
Cu (ppm)	1.1	1.2	0.7	0.7
Zn (ppm)	3.5	4.2	3.6	3.4
B (ppm)	0.4	0.4	0.4	0.4
SOM (%)	1.4	1.6	1.4	1.3

Table 2. Influence of the cover crop 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 2022 in the sixth 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).

Cover crop	Dry matter		Tissue P		P content	
treatment	**LMCRS**	**RRS**	**LMCRS**	**RRS**	**LMCRS**	**RRS**
	---------- (lb/ac) ----------		------------ (%) ------------		---------- (lb/ac) ----------	
Winter fallow	613 b[†]	693 b	0.348	0.391	2.1 b	2.7 b
Cereal rye	921 a	1418 a	0.428	0.469	3.8 a	6.6 a
	------------------------ (*P*-value) ------------------------					
Cover crop	0.0773	0.0140	0.1879	0.1076	0.0158	0.0073
P rate	0.9915	0.6885	0.3539	0.1450	0.5543	0.7985
Interaction	0.9955	0.3965	0.8424	0.2277	0.9977	0.5145
C.V. (%)	14.9	22.6	9.1	10.8	12.1	19.8

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

Table 3. Influence of the cover crop 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 2022 in the sixth year of the fertilizer-K rate trial at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS).

Cover crop treatment	Dry matter	Tissue K 0[†]	60	120	180	K content
	(lb/ac)	------------------------------ (%) ------------------------------				(lb/ac)
Winter fallow	749 b[‡]	2.80 A[§]	2.98 A	2.76 AB	2.45 C	20.1 b
Cereal rye	1573 a	2.41 C	2.46 C	2.56 BC	2.47 C	38.8 a
	-------------------- (*P*-value) --------------------					
Cover crop	0.0270	---------------------------- 0.3114 ----------------------------				0.0169
K rate	0.4981	---------------------------- 0.0858 ----------------------------				0.6936
Interaction	0.2790	---------------------------- 0.0692 ----------------------------				0.6267
C.V. (%)	18.3	------------------------------ 6.3 ------------------------------				18.2

[†] Annual application rates of 0, 60, 120, and 180 lb K_2O/ac.

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

[§] Different uppercase letters next to means indicate significant differences in cover crop/K rate treatments ($P \leq 0.10$).

Table 4. Influence of the cover crop 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 2022 in the sixth year of the fertilizer-K rate trial at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS).

Annual K rate	Dry matter	Tissue K	K content
(lb K_2O/ac)	(lb/ac)	(%)	(lb/ac)
0	1235 a[†]	2.66	31.7 a
60	959 b	2.72	25.9 b
120	878 b	2.91	25.3 b
180	867 b	2.97	25.5 b
	---------------------- (*P*-value) ----------------------		
Cover crop	0.2410	0.4546	0.3415
K rate	0.0009	0.3539	0.0190
Interaction	0.1365	0.9496	0.4257
C.V. (%)	12.8	11.8	12.7

[†] Different lowercase letters next to means within a column indicate significant differences ($P \leq 0.10$).

Table 5. Influence of the cover crop (CC) main-plot effect, the fertilizer-P rate subplot effect, and their interaction on soil-test P in spring 2022, before annual fertilizer-P treatment application, and the difference in soil-test P between cover crop establishment in fall 2021 and termination in spring 2022 in the sixth 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	26.7	26.0	26.3 d[‡]	32.0	31.7	31.8 d	-4.7	-3.2	-4.0	-1.5	-2.2	-1.8
40	35.7	33.0	34.3 c	49.3	42.0	45.7 c	-6.0	-3.8	-4.9	-3.6	-2.9	-3.2
80	43.7	42.3	43.0 b	69.7	62.7	66.2 b	-5.8	-6.9	-6.4	-3.9	1.3	-1.3
120	52.0	44.7	48.3 a	101.3	89.0	95.2 a	-4.1	-2.9	-3.5	-11.5	-3.6	-7.6
CC mean	39.5	36.5	--	63.1	56.3	--	-5.2	-4.2	--	-5.1	-1.9	--
P rate	<0.0001			<0.0001			0.1785			0.3953		
Cover crop	0.5071			0.3530			0.6900			0.4711		
Interaction	0.4842			0.6443			0.6239			0.6743		
C.V. (%)	10.4			13.4			48.0			191		

[†] Fertilizer-P rate treatments were applied for the first time in 2018. These data reflect the cumulative effect of four annual applications.

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

Table 6. Influence of the cover crop (CC) main-plot effect, the fertilizer-K rate subplot effect, and their interaction on soil-test K in spring 2022, before annual fertilizer-K treatment application, and the difference in soil-test K between cover crop establishment in fall 2021 and termination in spring 2022 in the sixth 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	66	85	76 c[‡]	72	67	69 d	20.2	11.2	15.7	13.6 C[§]	23.6 BC	18.6
60	127	115	121 b	110	105	108 c	5.7	16.1	10.9	16.2 C	24.8 BC	20.5
120	168	180	174 a	145	137	141 b	7.9	7.1	7.5	28.1 B	30.9 B	29.5
180	187	189	188 a	171	179	175 a	3.9	7.1	5.5	43.2 A	23.2 BC	33.2
CC Mean	137 b	142 a	--	124	122	--	9.4	10.4	--	25.3	25.6	--
K rate	<0.0001			<0.0001			0.1690			0.0202		
Cover crop	0.0600			0.1114			0.6565			0.9521		
Interaction	0.5604			0.7534			0.2343			0.0209		
C.V. (%)	13.9			10.4			78.3			30.1		

[†] Fertilizer-K rate treatments were applied for the first time in 2018. These data reflect the cumulative effect of four annual applications.

[‡] Different lowercase letters next to means within a site indicate significant differences for that factor ($P \le 0.10$).

[§] Different uppercase letters next to means indicate significant differences ($P \le 0.10$).

Table 7. Influence of the cover crop main-plot effect on selected soil properties measured by Cornell's Basic Soil Health Analysis Package in spring 2022 in the sixth year of fertilizer-P and -K rate trials at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) and Rohwer Research Station (RRS).

Location/ cover crop treatment	Aggregate stability	Aggregate stability rating	Active carbon	Active carbon rating	Overall soil quality score
	(%)		(ppm)		
LMCRS P trial					
Winter fallow	6.5	6.7	197	3.1	48
Cereal rye	6.9	6.9	245	5.0	48
Cover crop *P*-value	0.7307	0.7772	0.2310	0.2149	0.7418
C.V. (%)	18.6	13.0	15.7	32.3	2.2
RRS P trial					
Winter fallow	7.0	9.2	276	11.7	54
Cereal rye	7.0	9.2	287	12.6	53
Cover crop *P*-value	1.000	0.9821	0.6639	0.7088	0.8020
C.V. (%)	25.3	17.5	9.5	21.9	5.3
LMCRS K trial					
Winter fallow	6.1 b[†]	6.4 b	297 b	8.3 b	52
Cereal rye	8.2 a	8.0 a	334 a	11.5 a	54
Cover crop *P*-value	0.0516	0.0354	0.0158	0.0138	0.3675
C.V. (%)	8.6	5.0	1.8	4.6	4.0
RRS K trial					
Winter fallow	7.8	10.5	293	13.2	56
Cereal rye	8.1	10.2	306	14.8	52
Cover crop *P*-value	0.9290	0.9171	0.6528	0.6523	0.2379
C.V. (%)	35.7	30.3	10.2	26.6	5.9

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

Table 8. Soybean grain yield as affected by annual fertilizer-P rate, cover crop (CC), and their interaction during the sixth 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 2022.

Annual P rate[†]	LMCRS			RRS[‡]		
	Winter fallow	Cereal rye	Rate mean	Winter fallow	Cereal rye	Rate mean
(lb P_2O_5/ac)	**(bu./ac)**					
0	59.4	60.5	60.0	50.5	44.7	47.6
40	59.0	61.3	60.1	55.2	48.9	52.1
80	60.5	59.4	60.0	53.0	49.7	51.4
120	58.0	59.2	58.6	52.1	52.4	52.2
CC Mean	59.2	60.1	--	52.7	48.9	--
P rate	0.5982			0.3779		
Cover crop	0.6829			0.2542		
Interaction	0.6022			0.6442		
C.V. (%)	3.7			7.8		

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

[‡] The RRS yields are the mean of 2 replicates due to nematode damage in rep 3.

Table 9. Soybean grain yield as affected by annual fertilizer-K rate, cover crop (CC), and their interaction during the sixth 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 2022.

Annual K rate[‡]	LMCRS			RRS[†]		
	Winter fallow	Cereal rye	Rate mean	Winter fallow	Cereal rye	Rate mean
(lb K_2O/ac)	**(bu./ac)**					
0	53.7	54.2	54.0 c[§]	32.6	47.8	40.2
60	57.8	56.8	57.3 a	49.2	48.3	48.7
120	57.2	55.0	56.1 ab	42.4	52.9	47.7
180	54.9	55.3	55.1 bc	52.2	50.8	51.5
CC Mean	55.9	55.3	--	44.1	50.0	--
K rate	0.0470				--	
Cover crop	0.6554				--	
Interaction	0.5416				--	
C.V. (%)	3.3				--	

[†] Severe nematode damage at RRS prevented the collection of grain yield data from more than half of the trial plots. Means are provided but should be interpreted with caution.

[‡] Fertilizer 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 within a site indicate significant differences ($P \leq 0.10$).

Cotton Response to Topdress Nitrogen Fertilizer When Grown in a Cotton-Peanut Rotation: Year 2

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

Abstract

Field research in northeastern Arkansas continued to evaluate N fertilizer management for cotton (*Gossypium hirsutum*) in rotation with peanut (*Arachis hypogaea*). The on-farm study was conducted in a 40-ac commercial Mississippi County field with sandy, alluvial soils [Routon-Dundee-Crevasse complex (Typic Endoqualfs)]. It was the 2nd year of cotton in rotation following peanut. Fertilizer applications and yield assessments were made with the cooperating producer's equipment. A base rate of 80 lb N/ac was broadcast applied to all plots in the week of first squares, 34 days after planting (DAP), followed by topdress applications of 0, 25, 40, or 55 lb N/ac made at first flowers (58 DAP), which resulted in total-N rates of 80, 105, 120, and 135 lb N/ac. The Arkansas Extension recommendation for the production region is 110 lb N/ac. In-season plant monitoring with COTMAN 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 there were significant treatment effects on lint yield and fiber quality. There were differences in yield among soil texture classes and fertilizer-N rates. In 2021, a yield response to increased N was noted only in the coarse-sand textured soil (ca. 35% of the field); however, in the 2022 study, overall yield increased in both soil textural zones. A maturity delay of ca. two weeks was observed with plants in loamy sand areas receiving the highest N rates. With good fall growing conditions, bolls set in late season contributed to yield. Additional research is needed to increase the understanding of the cotton-peanut rotation benefits and how directed soil sampling for N fertilization could improve N fertilizer management efficiency for mid-South cotton producers.

Introduction

With expanding peanut (*Arachis hypogaea*) production across eastern Arkansas and the mid-South, cotton producers are exploring opportunities to reduce N fertilizer inputs in cotton crops grown in rotation with the N-fixing legume. Extension recommendations from the Southeastern U.S. peanut-producing region suggest that cotton producers can reduce their standard N fertilization rates or apply N credits ranging from 20 to 60 lb N/ac for crops planted after peanut (Crozier et al., 2010; Caddel et al., 2012). Fertilizer management guidelines, specific for cotton (*Gossypium hirsutum*) in rotation with peanut, are lacking in the mid-South.

There have been no recent plant nutrition field studies in Arkansas with modern cotton varieties to examine changes in N fertility requirements in a cotton–peanut rotation. We initiated a 2-year study in 2021 to evaluate N fertilizer response in cotton. This report summarizes year 2 of the study. This research was 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. Because heterogeneous soils are common in the production area in question, we included consideration of soil texture in our experiment to examine plant response to N management across different soil textures. In our 2021 trial, in the first year of cotton production following peanuts, there was a positive cotton yield response with increased N but only in the coarse-sand textured soil (ca. 35% of the field) (Teague et al., 2021). In loamy sand soil texture classes, there was no yield increase above the base rate of N. In this 2022 study, we repeated the same N rates in the same field locations. 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 continued in a 40-ac commercial field located at Wildy Family Farms near Leachville in Mississippi County, Arkansas (35.858944, -90.248056). The study field was in its 2nd cotton year and in the second year of the experiment (Teague et al., 2022). Treatments of four nitrogen (N) fertilizer rates were arranged in a randomized complete block with three replications. Treatments were repeated from the 2021 study and were not re-randomized. A base level of 80 lb N/ac fertilizer (urea) was broadcast across the experiment on 11 June, 34 days after planting (DAP) which was 8 May 2022. For the experimental treatments, N fertilizer (urea) was applied as a "topdress" application during the week of first flowers (6 July, 60 DAP). The N treatments were: 1) No topdress (base 80 lb/ac only), 2) base + topdress 25 N lb/ac; 2) base+ topdress 40 N lb/ac; 4) base+ topdress 55 N lb N/ac. Plot strips were 24 rows wide (raised beds spaced at 38 in.) and 1275 ft long (2.22 ac). Nitrogen treatments were applied using a commercial applicator spreader calibrated to deliver a 24-row swath. Yield assessments

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and plant and pest monitoring activities were conducted in the center 12 rows.

Soils were classified as Routon-Dundee-Crevasse complex (Typic Endoqualfs). Soil texture was included in the experimental design, sampling protocols, and analysis because of the heterogeneous soils in the study area. Located in the Mississippi Alluvial Plain, the field site also lies in the New Madrid seismic zone, where field areas with sandy deposits from sand blows are common.

Planting, fertilizer and pesticide application, and harvest 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, were made only in irrigated field areas (excluding field areas in the rainfed "pivot corners"). The timing of practices, inputs, and sampling are listed in Table 1.

Sampling activities and sample site locations in the spatially variable field were similar to those used in the first year of the study (Teague et al., 2021). The plot plan, including sample points for plant and pest monitoring, is shown in Fig. 1 and is overlaid on a soil EC_a map generated from indirect measurements of soil electrical conductivity using a Veris 3150 EC Surveyor instrument®. Sampling was stratified into two soil textural zones: 1) loamy-sand [soil EC_a values from shallow layer (0–24 in) with values <15 mS/m], and 2) coarse sands [soil EC_a values from shallow layer (0–24 in) with values <15 mS/m]. The coarse-sand areas, likely related to sand deposits associated with sand blows, category encompassed ca. 35% of the field.

Composite soil samples, consisting of 8, 0.75-in.-wide cores (AMS probe; 0.75-in. inner diameter, AMS, Inc., American Falls, Idaho), were collected from 0- to 6- (shallow) and 6- to 12-in. (deep) depths at designated sample sites within each soil texture category in each treatment strip plot. Samples were sent to the University of Arkansas System Division of Agriculture Soil Testing Laboratory in Fayetteville for soil pH and Mehlich-3 extraction.

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 markers to guide field scouts to specific field areas for weekly plant and pest monitoring activities. Scouts followed a strict sampling protocol that included rotating the position of their sample points in areas adjacent to the flag in order to avoid thigmonastic effects of re-sampling the same plants each week.

Plant monitoring was initiated at first square and included evaluations of plant main-stem nodal development, height, and first position square and boll retention using COTMAN SquareMap and nodes above white flower (NAWF) sampling protocols (Oosterhuis and Bourland, 2008). Plant maturity measurements included calculations of days from planting to physiological cutout (NAWF = 5). Arthropod pest numbers were monitored at weekly intervals using sweep net and drop cloth sampling procedures.

Fiber quality was evaluated using hand-picked 40 boll samples collected at the designated harvest sample points. Samples were ginned using a laboratory gin, and fiber was sent to the Texas Tech Fiber and Biopolymer Research Institute for HVI (high volume instrument) evaluations.

Yield assessments were based on geo-referenced yield monitor data collected from the cooperating producer's John Deere cotton picker and post-calibrated using final module weights retrieved from the commercial 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 the yield-monitor-measured yield with fertilizer treatment and block effect, and soil EC_a classifications were included as a covariate. Point sample data from the experiment were analyzed as a split-plot design with fertilizer-N treatments considered main plots and soil textural classes considered subplots. 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, Inc., Cary, N.C.).

Results and Discussion

Weather conditions in spring 2022 were favorable for good stand establishment; however, hot, dry conditions followed and prevailed through June and early July. There was no significant rainfall from 8 June through 17 July (31 to 70 DAP). The field was irrigated 5 times during this period. After mid-July, rainfall patterns resulted in above-average precipitation for the study site (Table 2). Late summer and fall weather was conducive for a high yielding 2022 crop at the study site.

Results from the routine soil sampling analysis indicated no differences in soil test results for NO_3-N or OM measurements associated with the 2021 N fertilizer treatments; however, there were significant ($P < 0.05$) differences associated with the depth of the soil sample collection and the soil textural category (Table 3). The highest NO_3-N levels were observed in loamy sand texture in shallow-depth samples. The OM levels were reduced ($P = 0.03$) in deep compared to shallow sample depths.

The 2021 N applications had no effect on other extractible nutrients in the 2022 soil sample analysis results. There were differences associated with the soil texture categories and sample depth on mean Mehlich-3 extractible nutrients (Table 4). Concentrations of P were increased in coarse compared to the loamy texture. Soil pH values were lower in coarse sand compared to loamy texture. There also were lower concentrations of Ca, Mg, Na, S, Mn, Cu, B, and NO_3-N ($P < 0.05$). For samples collected at the deep (6- to 12-in.) depth, there were increased Na concentrations and reduced K, Fe, and Zn concentrations compared to samples from the shallow (0- to 6-in.) depth.

COTMAN growth curves provide a gauge of crop fruiting dynamics through the season in response to growing conditions. For each growth curve, the mean number of squaring nodes [main-stem fruiting branches (sympodia) that have not developed to the flowering stage] are plotted by DAP. 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.

Growth curves from COTMAN plant monitoring (Fig. 2) showed reduced numbers of squaring nodes at 47, 50, and 60 DAP for plants growing in field areas with coarse sand compared to loamy sand soil texture ($P = 0.001$). Nodal development likely was slowed due to water deficit stress during squaring node development. Even with irrigation, there were indications of water deficits apparent in readings from soil moisture sensors located in the field (data not shown). First flowers were observed by 60 DAP, and on that sampling date, the overall mean number of squaring nodes for plants in the loamy sand was 8.2 compared to 6.7 nodes for plants in the coarse sand. The standard target development curve (TDC) value at first flower is 9.25 nodes.

After first flowers, growth curves deviated from the target development curve for all treatments with a flatter downward slope compared to the TDC. The combination of mid-July rains and more moderate temperatures, along with the topdress N application at 58 DAP, resulted in an increase in squaring node development during the effective flowering period. This was particularly apparent for plants growing in loamy sand that received the highest N treatment rates. The slope of the NAWF curves for those treatments was flattened, and there was a significant maturity delay ($P < 0.01$). The mean number of days from planting to physiological cutout (mean NAWF = 5) ranged from 79 to 93 DAP (Table 5), with earliest cutout observed for plants in the 80 lb N/ac treatment in coarse sand and the latest cutout observed for plants in the 135 lb N/ac in loamy sand. The maturity delay associated with high N rates extended the effective flowering period for plants in those loamy sand areas by ca. 2 weeks.

No confounding effects from insect pest feeding were noted in response to N fertilizer applications in the 2022 trial. The cooperating producers maintained low pest numbers with insecticide applications throughout the season. Pest and plant monitoring results from COTMAN showed pest numbers were below action thresholds and that square retention on 1st position, main-stem sympodia was maintained above 90% through the 3rd week of flowering (data not shown).

There were significant yield effects associated with N rate and soil texture ($P = 0.001$); however, there was a significant fertilizer and soil texture interaction ($P = 0.001$). Mean lint yield ranged from a low of 1433 lb/ac with 80 lb N/ac in coarse sand to a high of 1788 lb/ac with 135 lb N/ac in the loamy sand (Table 6). Overall, yields increased with increased N, and there was a yield penalty for reduced fertilizer-N rate in both the coarse sand and loamy sand field areas.

Results from fiber quality analysis of 40-boll hand-picked samples (Table 7) showed no significant differences in fiber quality parameters or boll size among N rate treatments. Mean boll size was reduced for samples collected from plants growing in coarse sand compared to loamy sand. Fiber elongation was higher for plants in coarse sand compared to loamy sand field areas. All other fiber properties were not significantly different.

Practical Applications

In our 2021 study with cotton grown the year following peanut, there was no significant yield advantage for increasing N rates above 80 lb N/ac for cotton in field areas comprised of soil with a loamy sand texture. We did measure a yield benefit to supplemental fertilizer-N in field areas with coarse sand (Teague et al., 2022). In the second year of cotton in the 3-year rotation (peanut-cotton-cotton), we measured a positive yield response to increased N in both soil textural zones.

There was a significant plant maturity delay associated with high N application rates in 2022. In the northeast Arkansas cotton production area, the growing season is often shortened by fall weather conditions, and there are production risks associated with delayed maturity. Because of unusually favorable fall weather conditions, late-season, upper canopy bolls contributed to economic yield in 2022.

Producers should consider within-field variability when reducing fertilizer-N rates for cotton to improve fertilizer efficiency and reduce costs. More research work is needed to increase our understanding of how directed soil sampling for N fertilization could improve N fertilizer management.

Acknowledgments

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Table 1. Dates of planting, irrigation, fertilizer application, and harvest for the 2022 peanut cotton rotation nitrogen research study in Manila, Arkansas.

Operation	Date	Days after planting
Date of cotton planting	8 May	
Soil sample collection	20 May	12
Base fertilizer application	11 June	34
Topdress urea application[†]	5 July	58
Irrigation (sprinkler)	19, 26 June, 3, 10, 14 July	42, 49, 56, 63, 67
Hand harvest	3 October	148
Machine harvest	4 October	149

[†] Only treatment-specific plots received the prescription urea application.

Table 2. Monthly precipitation (inches) measured at the study site for the 2022 season compared with the 2021 cotton season and the 30-year average for the county in 2022 at Manila, Arkansas.

Mean Month	30-Year Average	2021 Rainfall	2022 Rainfall
	---	(in.)	---
May	5.37	5.37	4.51
June	3.99	3.04	2.22
July	4.04	6.87	4.29
August	2.36	2.10	6.25
September	2.88	2.64	2.61
Total Season	15.76	17.38	19.88

Table 3. Mean results from soil test analysis for NO_3-N and organic matter (OM) from soil samples† collected in two soil texture zones established using soil EC_a measures (<15 mS/m or ≥15 mS/m) at two depths (0 to 6-in. (shallow) or 6 to 12-in. (deep)) from 2021 N-treatment plots in the second cotton crop year of 3-year cotton-peanut rotation in 202 at Manila, Arkansas.

			N Fertilizer applied in 2021 (lb N/acre)							
			80		105		120		135	
Variable	Sample depth	Soil textural class	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
NO_3-N (ppm)	Shallow	Coarse sand	4.3	0.7	4.7	0.9	5.7	2.2	3.0	0.0
		Loamy sand	6.7	0.9	9.3	1.9	6.7	0.9	8.0	1.0
	Deep	Coarse sand	4.7	0.9	3.7	0.3	5.0	0.6	3.7	0.3
		Loamy sand	5.3	0.7	5.3	0.3	7.3	0.9	5.0	1.0
OM (%)	Shallow	Coarse sand	1.4	0.1	1.6	0.3	1.5	0.3	1.3	0.2
		Loamy sand	1.6	0.1	1.6	0.1	1.9	0.2	1.9	0.3
	Deep	Coarse sand	1.5	0.4	1.2	0.7	1.1	0.4	0.9	0.2
		Loamy sand	1.2	0.2	1.3	0.2	1.6	0.2	1.1	0.4

† 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 Soil Test Laboratory, Fayetteville, Arkansas.

Table 4. Mean soil pH and Mehlich-3 extractable nutrients from soil samples† collected in two soil texture zones established using soil EC_a measures (<15 mS/m or ≥15 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, Arkansas.

	Soil textural category				Sampling depth			
	Coarse sand		Loamy sand		Shallow (0 to 6 in.)		Deep (6 to 12 in.)	
Soil property	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
Soil pH	6.6	0.0	6.7	0.0	6.6	0.1	7	0.0
P (ppm)	41	3.3	31	3.1	28	2	24	1.6
K (ppm)	112	9.7	107	8.2	71	4.3	73	3.1
Ca (ppm)	917	73.4	1201	57.2	892	133.2	1067	85.2
Mg (ppm)	117	9.8	171	11.2	113	17.7	150	14.8
Na (ppm)	10	0.5	16	1.2	10	0.8	15	1.3
S (ppm)	5	0.3	7	0.3	4	0.5	5	0.4
Fe (ppm)	203	5.4	207	6.8	191	8.6	196	6.7
Mn (ppm)	25	2.8	54	5.0	17	1.7	35	5.3
Cu (ppm)	1.2	0.1	1.6	0.1	1.2	0.1	1.4	0.1
Zn (ppm)	4.2	0.4	4.1	0.4	3.5	0.6	3.3	0.4
B (ppm)	0.4	0.03	0.6	0.4	0.5	0.0	0.5	0.0
NO_3-N (ppm)	4.3	0.3	6.7	0.4	6.0	0.5	5.0	0.3

† 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 Soil Test Laboratory, Fayetteville, Arkansas.

Table 5. Mean no. (±SEM, standard error of mean) days from planting to physiological cutout (nodes above white flower, NAWF) = 5 in 2022 for the four different fertilizer-N rates for plants in coarse sand and loamy sand soil texture categories in the 2nd year of cotton rotation in 2022 at Manila, Arkansas.

	Season Total Fertilizer-N rate (lb/ac)			
Soil texture	80	105	120	135
	--(days)--			
Coarse sand	79 ± 1.5	84 ± 1.8	86 ± 3.7	81 ± 2.8
Loamy sand	83 ± 1.2	86 ± 2.1	93 ± 2.0	93 ± 3.0

Table 6. Mean lint yields of fertilizer-N rate and soil texture effects on findings from calibrated yield monitor measured harvest results in second cotton crop year of 3-year cotton-peanut rotation in 2022 at Manila, Arkansas.

	Mean Lint yield†	
Season total N rate	Coarse sand	Loamy sand
(lb N/ac)	------------------------(lb/ac) ----------------------	
80	1433 f	1643 c
105	1496 e	1721 b
120	1433 f	1746 b
135	1586 d	1788 a

† Means with the same letter are not significantly different (Tukey-Kramer Grouping for Least Squares Means ($\alpha = 0.05$)).

Table 7. Mean boll weight and results from fiber quality assessments (HVI[†]) for 40-boll samples showing soil texture effects in 2022 cotton-peanut rotation nitrogen research study in Manila, Arkansas.

Soil texture	Boll weight	Micronaire	Length	Uniformity	Strength	Elongation
	(g)	(Mic)	(in.)	(UI)	(g/tx)	(%)
Coarse sand	4.97	4.78	1.24	83.83	31.48	6.84
Loamy sand	5.39	4.71	1.24	83.86	30.69	6.59
P-value	0.02	0.52	0.97	0.93	0.06	0.03

[†] HVI assessments made at the Fiber and Biopolymer Research Institute, Texas Tech University, Lubbock.

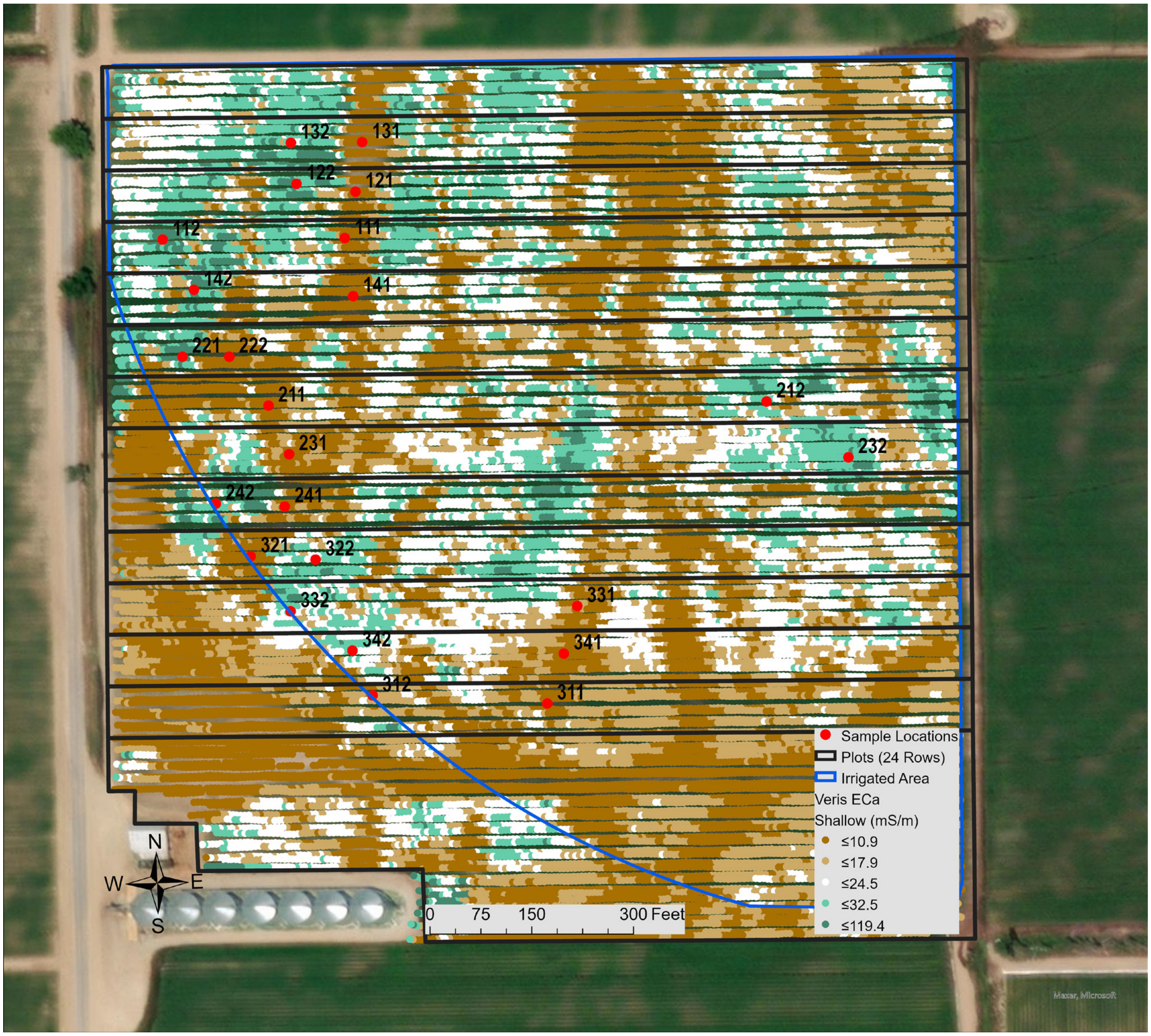

Fig. 1. Field plan overlaid on soil EC$_a$ (shallow) map of the N fertilization study field trial (year 2) at Wildy Family Farms showing spatial variation in soil texture. Sample points shown were designated for hand-harvest for fiber quality assessments and served as the field reference points for scouts in soil, plant, and pest monitoring activities. Plot strips were 24 rows wide (76 ft) and 1275-ft long. 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 for the 2022 peanut-cotton rotation nitrogen N research study in Manila, Arkansas.

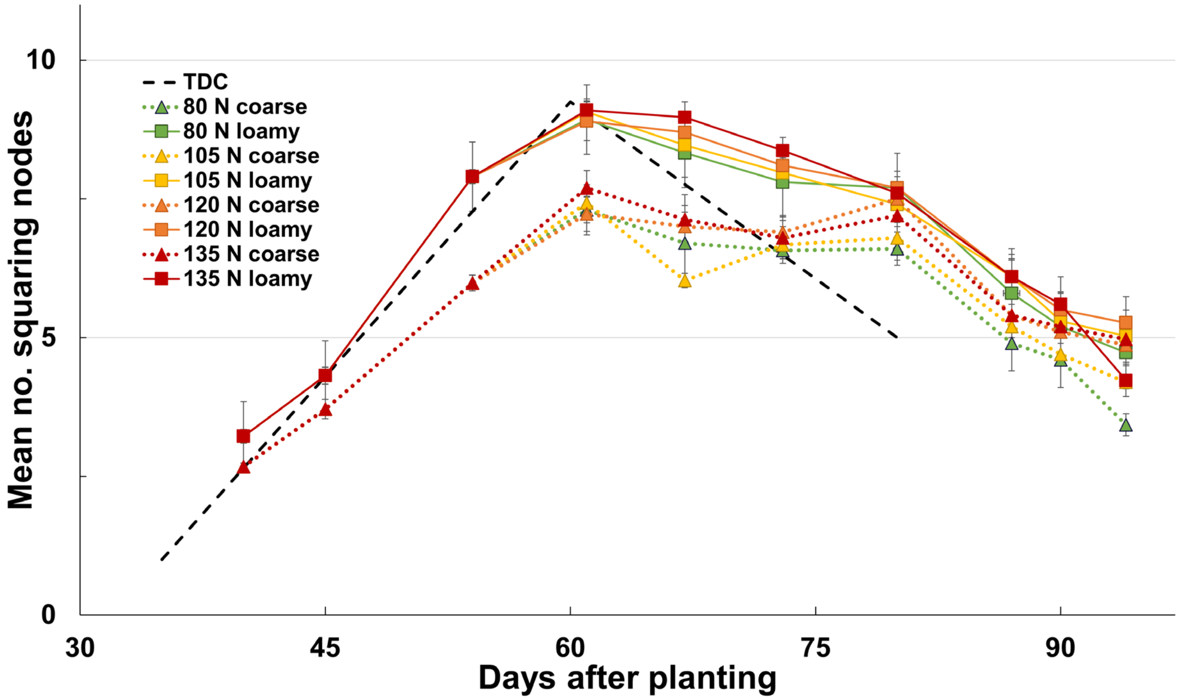

Fig. 2. COTMAN growth curves for the 2022 peanut-cotton rotation N fertilization trial (year 2) with plants in coarse sand and loamy sand areas of treatment plots which received the base rate of 80 lb N/ac at 34 days after planting (DAP) plus a topdress application of either 0, 25, 40, or 55 lb N/ac at first flower at 58 DAP.

Discovery Farms Program Research

A Comparison of Haney Soil Health Test and Mehlich-3 Soil Analysis Results in an Arkansas Pasture

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Abstract

Achieving agronomic production goals for pasture-raised beef requires knowledge of the soil fertility status (i.e., N, P, and K) for optimal forage growth. Recent interest has emphasized using soil health assessments as a way for land managers and conservation agencies to measure the functional capacity of managed soil resources to sustain crop production. The Haney Soil Health Test is one method that has garnered much attention since being developed in 2006. However, data comparing the H3A (Haney, Haney, Hossner, and Arnold) extractant used in the Haney Soil Health Test to conventional soil test methods is limited. The main objective of this study was to evaluate the correlation between soil test phosphorus (P) and potassium (K) extracted using the H3A and Mehlich-3 (M3) extractants. Biennial soil samples were collected from a rotational-grazing pasture from 2013 to 2021 and analyzed using both M3 and H3A extractants. Mehlich-3 and H3A extractable P ($r = 0.86$) and K ($r = 0.94$) were strongly and positively correlated. Mehlich 3 extracted 4.4 times more P and 3.7 times more K than H3A. The results indicate that more work is needed to determine how soil health indicators included in the Haney Soil Health Test, such as soil respiration and water-extractable N and P, might help inform management decisions while safeguarding Arkansas producers' profits and production goals.

Introduction

Phosphorus (P) and potassium (K) plant availability using conventional soil test methods have been used in soil test correlation trials to define their relationship with relative crop yield or plant nutrient uptake. In Arkansas, the Mehlich-3 (M3) method is used by the University of Arkansas System Division of Agriculture's Soil Testing Program to extract plant-available soil nutrients and develop fertilizer recommendations based on field trials that define crop yield response to P or K fertilization. Over the past decade, there has been growing interest among agricultural researchers, conservationists, and producers regarding the purported benefits that occur from assessing the soil health of agricultural lands. However, a consensus is lacking as to what soil health indicators are most meaningful to management decisions in terms of providing the necessary information for growers to achieve agroeconomic yield goals while improving soil biotic quality and ecosystem services.

Various soil health assessment methods used across the United States factor in labile pools of nutrients (e.g., water extractable nitrogen and carbon), an estimate of microbiology activity, and estimates of plant available nutrients based on extractants such as a Mehlich-3 or H3A (Haney, Haney, Hossner, and Arnold; a weak organic acid extractant) in a combined indexing approach to estimate the nutrient supply available to growing crops (Norris et al., 2020). One method developed by USDA-ARS and advocated by USDA-NRCS is the Haney Soil Health Test (HSHT), which relies on soil chemical and biological indicators, including soil respiration (Solvita CO_2 burst test), as well as water-soluble organic carbon and organic nitrogen (Haney et al., 2010). The objectives of this study were to: a) investigate the relationship between M3 and H3A soil test P and K in Arkansas soils and b) compare N, phosphate (P_2O_5), and potash (K_2O) recommendations derived from the Haney Soil Health Assessment Tool with those derived from M3-P and M3-K tests used by the Arkansas Soil Test Laboratory in Marianna, Arkansas.

Procedures

A field study was initiated on a 40-ac rotationally grazed pasture at the Morrow Discovery Farm in Washington County in 2013. Grid soil samples were collected to account for four different soil mapping units, dominated by variations of Pembroke silt loam (Fig. 1). Predetermined sample points were located using a handheld GPS unit (Garmin, 64st). From each location, 7, 1-in.-diameter cores were collected to a 4-in. depth, with 1 sample collected from the center point and 6 additional cores at 2-m, 60° radials. Once soil samples were collected, they were composited in plastic bags and placed in coolers on ice to protect soil microbes from high summer temperatures for the HSHT. At the lab, each composite sample was thoroughly mixed using a paddle hand mixer and then split into 2 subsamples. One subsample was sent on ice "as is" to USDA-ARS Grassland, Soil, and Water Research Laboratory (Temple, Texas). The other subsample was oven-dried, ground to pass a 2-mm screen, and then sent to the Agricultural Diagnostic Laboratory (Fayetteville, Arkansas) for routine soil sample analysis.

Mehlich-3 extractable nutrients were determined using inductively coupled plasma atomic emission spectroscopy (Soltanpour et al., 1996; Zhang et al., 2014). Both pH and electrical conductivity were performed using a 1:2 v/v soil/water ratio (Sikora and Moore, 2014; Wang et al., 2014). Extractable H3A nutrients were determined by weighing 4 g of sample and extracting with 40 mL of Haney extractant (three organic

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acids, i.e., 0.0024 mol/L citric acid, 0.004 mol/L oxalic acid, and 0.004 mol/L malic acid at pH 3.75) in plastic centrifuge tubes (Haney et al., 2017). Samples were shaken for 10 min, centrifuged for 5 min, then filtered through Whatman 2V filter paper (GE Healthcare UK Ltd), and concentrations of K, Ca, and Mn were determined bv ICAP-AES. The Hanev soil health

$$HSHS = \frac{1 - day - CO_2}{10} + \frac{WEOC}{100} + \frac{WEON}{10} \quad \text{Eq. 1}$$

where *WEOC* is water-extractable organic C, and *WEON* is the amount of the total water-extractable N minus the inorganic (NH_4-N + NO_3-N -N) H3A extracted pools (Haney et al., 2017)

Relationships between M3 and H3A extractable nutrients were evaluated using pairwise correlation and linear regression models. Data analysis was performed in JMP Pro v. 16 (SAS Institute, Inc., Cary, N.C.) and evaluated at the 95% confidence level. Since differences in nutrient recommendations (N, P_2O_5, and K_2O) between the HSHT and University of Arkansas System Division of Agriculture's fertility recommendations for mixed warm- and cool-season pastures were not normally distributed, the Wilcoxon Signed Rank test for matched pairs was used to evaluate differences between the two soil tests. A criterion of 95% confidence ($\alpha = 0.05$) was used to determine significance.

Results and Discussion

Mean M3 and H3A extractable P concentrations were 64 and 14.6 ppm, respectively, while extractable K was 119 and 31.8 ppm, respectively (Tables 1 and 2). Mehlich-3 and H3A extractable P and K were strongly correlated ($r = 0.86$ and 0.94, respectively) with a positive linear relationship (Tables 3 and Fig. 2). The Root Mean Square Error (RMSE) was 5.6 for soil extractable P and 7.7 for extractable K. On average, M3 extracted about 4.4 times more P and 3.7 times more K than H3A. There was a strong positive association between M3 and H3A extracted Ca ($r = 0.75$, $P < 0.001$), with M3 on average extracting 2.1 times more Ca than H3A on average (Table 3 and Fig. 2). The relationship between Fe extracted with H3A and M3 was moderately correlated ($r = 0.68$, $P < 0.001$), with M3 extracting 2 times more Fe than H3A (Table 3 and Fig. 2). For soil evaluated in this study, M3 resulted in a greater concentration of nutrients extracted, a finding that others have reported and has been attributed to M3 being a more powerful extractant than H3A (Leytem et al., 2020; Rutter and Diaz, 2020). This result was expected since H3A was developed to be a weaker extractant that may more closely mimic the plant roots (Haney et al., 2016).

Pairwise correlation between the standard parameters measured by HSHT and routine soil analysis by the Arkansas Soil Testing Program showed that soil pH was moderately correlated with HSHS ($r = 0.5$, P < 0.001), H3A-Ca ($r = 0.51$, $P < 0.001$), and H3A-Fe ($r = -0.51$, $P < 0.001$), and weakly correlated with H3A-N ($r = 0.27$, $P < 0.001$), H3A-P ($r = 0.27$, $P < 0.001$), and 1-day CO_2 ($r = 0.41$, $P < 0.001$, Table 3).

A summary table comparing mean fertilizer recommendations for the HSHT and the University of Arkansas System Division of Agriculture averaged across all sample locations and years is given in Table 4. For the HSHT, the end user is required to enter a crop yield goal. Annual hay production in Arkansas was estimated to be 1.8 and 2.2 tons/ac in 2018 and 2019, respectively (USDA-NASS, 2020). Based on this information, a forage yield goal of 2 tons/ac was used to generate HSHT fertility recommendations. For the Arkansas Soil Testing Lab, crop code 212 (mixed cool- and warm-season grasses for pastures) was used for fertilizer recommendations. According to the soil test results, the recommended amounts of N, P_2O_5, and K_2O were 3, 2.5, and 7 times higher, respectively, for the Arkansas fertility recommendations versus the HSHT recommendations (Table 4). Using the fertilizer rate recommendations built into the HSHT, this represented a difference ($P < 0.05$) of $60.90/ac between the two tests (Table 4). Note that this is not a perfect comparison considering the differences in underlying yield goal assumptions built into each test.

Practical Applications

The prices of fertilizer have risen dramatically over the last two decades, making it more important for producers to make fertilizer decisions that will help them achieve profitability. While extractable P and K from the H3A extractant correlated well to M3 results, the Haney Soil Health indicator has not been adequately correlated to plant nutrient uptake or yield through field trials, which limits its use for fertilizer recommendations in Arkansas. Routine soil testing using M3 conducted by the University of Arkansas System Division of Agriculture is still the recommended procedure for optimal fertilizer recommendations due to the extensive field correlation and calibration research base. More research is needed on the HSHT to 1) better correlate H3A results to plant uptake and crop yield through field trials, 2) improve the calibration of microbial respiration measurements to microbial populations and diversity to better understand the impacts on nutrient cycling, and 3) evaluate a variety of sites, cropping systems, and soils to evaluate variability and increase understanding.

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The authors would like to extend appreciation to Ron Morrow for his participation in the Arkansas Discovery Farms program, for allowing the sampling of pastures, and for sharing management information. The United States Department of Agriculture-Agriculture Research Service Grassland Soil and Water Research Laboratory in Temple, Texas, Walton Family Foundation, Arkansas Soil Test Lab, and the Soil Test Review Board.

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Table 1. Mean chemical properties from Arkansas Soil Test Lab routine sample analysis using Mehlich-3 (M3) extraction for each soil series by year with the coefficient of variation in parenthesis.

Year	Soil	pH[a]	EC	OM	TP	TN	M3-P	M3-K	M3-Ca	M3-Fe
			(dS/m)	(%)	---------------------------------------(ppm)---------------------------------------					
2013	Jo	5.1 (4.8)	133 (31)	3.3 (12)	292 (16)	1719 (18)	44 (23)	101 (29)	927 (27)	163 (16)
2013	PeB	5.3 (6.1)	157 (30)	3.1 (11)	386 (28)	1822 (12)	78 (55)	269 (54)	864 (29)	140 (15)
2013	PgC2	5.2 (7.2)	137 (6.0)	2.8 (8.9)	331 (21)	1494 (12)	59 (37)	86 (23)	912 (27)	189 (41)
2015	Jo	5.9 (2.5)	99 (11)	3.2 (5.0)	323 (23)	1786 (5.2)	52 (67)	82 (49)	974 (16)	190 (14)
2015	PeB	6.2 (4.6)	100 (26)	3.2 (24)	361 (34)	1868 (19)	68 (72)	75 (24)	1026 (27)	126 (27)
2015	PgC2	5.8 (2.5)	81 (23)	2.8 (18)	327 (16)	1701 (12)	47 (34)	78 (53)	824 (7.3)	158 (20)
2017	Jo	5.5 (4.3)	60 (19)	3.1 (8.8)	266 (13)	1484 (13)	15 (39)	123 (68)	814 (16)	150 (19)
2017	PeB	6.0 (3.7)	104 (31)	3.5 (10)	423 (23)	1985 (15)	71 (63)	208 (68)	1241 (26)	104 (15)
2017	PgC2	5.6 (4.8)	80 (21.3)	3.0 (15)	290 (19)	1455 (20)	21 (42)	115 (48)	905 (22)	135 (17)
2019	Jo	6.0 (2.0)	125 (26)	3.3 (9.3)	321 (10)	2195 (27)	48 (31)	80 (25)	919 (17)	153 (18)
2019	PeB	6.5 (1.2)	211 (8.5)	3.4 (15)	477 (45)	1707 (34)	89 (24)	150 (17)	1079 (9)	118 (8.0)
2019	PeC2	6.4 (0.9)	143 (26)	3.4 (13)	441 (14)	1482 (14)	85 (29)	116 (23)	1187 (16)	123 (26)
2019	PgC2	6.2 (4.4)	161 (14)	3.0 (9.1)	350 (14)	1366 (14)	61 (29)	111 (23)	1040 (25)	151 (22)
2021	Jo	5.4 (3.8)	372 (16)	3.6 (11)	363 (11)	1768 (13)	60 (27)	82 (13)	1050 (19)	163 (17)
2021	PeB	5.9 (3.4)	416 (28)	3.2 (9.0)	441 (17)	1745 (13)	104 (35)	154 (21)	1109 (12)	126 (10)
2021	PeC2	6.0 (3.5)	454 (15)	3.3 (33)	435 (30)	1496 (36)	105 (34)	119 (40)	1303 (23)	127 (21)
2021	PgC2	5.6 (5.0)	398 (15)	2.8 (25)	352 (28)	1341 (28)	69 (25)	107 (17)	1045 (18)	149 (19)
All		5.8 (7.7)	204 (68)	3.1 (17)	363 (28)	1626 (24)	64 (54)	119 (58)	1021 (24)	145 (25)

[a] Units and abbreviations are as follows: pH (–log[H+]), EC (electrical conductivity) in dS/m (deciSiemens per meter); OM (organic matter determined by loss on ignition); TP (total phosphorus), TN (total nitrogen); N (nitrogen), P (phosphorus), K (potassium), Ca (calcium), Fe (iron); Jo is Johnsburg silt loam, 0 to 2 percent slopes; PeB is Pembroke silt loam, 3 to 6 percent slopes, eroded; PgC2 is Pembroke gravelly silt loam, 3 to 8 percent slopes, eroded; PeC2 is Pembroke silt loam, 1 to 3 percent slopes.

Table 2. Mean soil health indicators from Haney Soil Health Test (H3A) for each soil series by year with the coefficient of variation in parenthesis.

Year	Soil	H3A-N[a]	H3A-P	H3A-K	H3A-Ca	H3A-Fe	1-d-CO_2	WEOC	WEON	HSHS
		--(ppm)--								
2013	Jo	66 (31)	8.6 (14)	27 (33)	-[b]	-	25 (24)	164 (16)	8.7 (28)	3.8 (7.4)
2013	PeB	93 (33)	17 (55)	89 (64)	-	-	34 (23)	175 (17)	6.6 (51)	3.7 (32.)
2013	PgC2	79 (20)	18 (61)	25 (27)	-	-	28 (20)	151 (21)	6.6 (43)	3.4 (27)
2015	Jo	63 (21)	11 (38)	18 (60)	354 (10)	100 (21)	74 (32)	293 (7.3)	24 (8.1)	12.7 (20)
2015	PeC2	82 (22)	18 (66)	16 (20)	453 (23)	49 (7)	92 (15)	281 (21)	22 (22)	14.2 (17)
2015	PgC2	60 (26)	10 (42)	15 (46)	302 (12)	84 (28)	65 (30)	269 (17)	23 (15)	11.4 (23)
2017	Jo	59 (8)	0.8 (81)	32 (41)	387 (12)	77 (26)	179 (23)	277 (8.9)	27 (9.5)	22.3 (14)
2017	PeB	80 (16)	19 (81)	51 (52)	595 (22)	49 (14)	301 (42)	278 (5.6)	31 (12)	28 (19)
2017	PgC2	64 (22)	1.9 (65)	30 (30)	433 (15)	67 (13)	246 (93)	267 (18)	27 (19)	24.2 (46)
2019	Jo	90 (15)	3.8 (126)	23 (19)	437 (17)	76 (28)	162 (25)	198 (8.8)	24 (11)	19.5 (17)
2019	PeB	113 (12)	20 (17)	40 (25)	576 (4)	42 (9)	200 (9.9)	189 (3.7)	28 (11)	21.6 (5.4)
2019	PeC2	82 (12)	18 (38)	33 (33)	612 (7)	46 (39)	222 (23)	192 (16)	22 (11)	22.5 (16)
2019	PgC2	88 (18)	9.6 (84)	30 (30)	487 (26)	64 (31)	181 (27)	186 (12)	24 (10)	20 (16)
2021	Jo	83 (8.2)	14 (38)	21 (14)	487 (11)	100 (38)	148 (50)	229 (6.7)	33 (3.2)	19.7 (23)
2021	PeB	84 (11)	29 (36)	45 (24)	591 (9)	60 (30)	124 (17)	220 (4.9)	32 (4.6)	17.9 (9.3)
2021	PeC2	97 (13)	32 (39)	30 (29)	614 (17)	73 (29)	155 (80)	241 (13)	37 (8.8)	20.2 (32)
2021	PgC2	87 (22)	18 (45)	27 (21)	471 (23)	90 (35)	103 (21)	224 (19)	34 (21)	17 (179)
All		82 (24)	15(75)	32 (68)	487 (25)	71 (39)	139 (72)	223 (23)	25 (38)	16.9 (46)

[a] Units and abbreviations are as follows: H3A (weak organic acid extractant); N (nitrogen), P (phosphorus), 1-day-CO_2 (carbon dioxide evolution determined using Solvita® Paddle), WEOC (water-extractable organic carbon), and WEON (water-extractable organic N); HSHS (Haney Soil Health Score); Jo is Johnsburg silt loam, 0 to 2 percent slopes; PeB is Pembroke silt loam, 3 to 6 percent slopes, eroded; PgC2 is Pembroke gravelly silt loam, 3 to 8 percent slopes, eroded; PeC2 is Pembroke silt loam, 1 to 3 percent slopes.

[b] The Haney Soil Health Test did not measure or report Ca or Fe in 2013; therefore, there is no data reported for 2013.

Table 3. Pearson's pairwise correlation (r) matrix of soil properties from Mehlich-3 (M3; University of Arkansas System Division of Agriculture Diagnostics Laboratory) and Haney Soil Health Tool (H3A) (U.S. Department of Agriculture-Agricultural Research Service, Grassland, Soil and Water Research Laboratory) soil samples (*n* =120) collected biennially from the Arkansas Discovery Morrow Farm in Arkansas, 2013 to 2021.

Soil Property	------------------Arkansas Soil Test Lab------------------									---------------------------------Soil Health-----------------------------------								
	pH[a]	EC	M3-P	M3-K	M3-Ca	M3-Fe	OM	TP	TN	H3A-N	H3A-P	H3A-K	1-d-CO_2	WEOC	WEON	HSHS	H3A-Fe	H3A-Ca
		(dS/m)	--------------(ppm)--------------				(%)	---(ppm)---										
pH	1	ns[b]	0.35	ns	0.53	-0.35	ns	0.36	Ns	0.27	0.27	ns	0.41	ns	0.35	0.50	-0.51	0.51
EC	ns	1	0.50	ns	0.33	ns	ns	0.30	Ns	0.43	0.54	ns	ns	ns	0.56	ns	ns	0.35
M3-P	***	***	1	0.38	0.54	ns	0.28	0.66	0.18	0.58	0.86	0.33	ns	ns	0.25	ns	-0.28	0.58
M3-K	ns	ns	***	1	ns	-0.24	0.20	0.39	0.21	0.34	0.25	0.94	ns	ns	ns	ns	-0.29	0.29
M3-Ca	***	***	***	ns	1	ns	0.28	0.46	Ns	0.26	0.56	ns	0.35	0.18	0.38	0.37	ns	0.75
M3-Fe	***	ns	ns	**	ns	1	ns	-0.20	Ns	-0.20	-0.20	-0.23	-0.30	ns	-0.26	-0.33	0.68	-0.47
OM	ns	ns	**	*	**	ns	1	0.55	0.78	0.24	ns	ns	0.34	0.26	ns	0.29	ns	0.26
TP	***	***	***	***	***	*	***	1	0.43	0.48	0.61	0.37	0.19	ns	0.24	0.22	-0.20	0.54
TN	ns	ns	*	*	ns	ns	***	***	1	ns	ns	ns	ns	0.23	ns	ns	ns	ns
H3A-N	**	***	***	***	**	*	**	***	Ns	1	0.53	0.41	0.25	ns	0.29	0.25	-0.31	0.58
H3A-P	**	***	***	**	***	*	Ns	***	Ns	***	1	0.25	ns	ns	0.31	ns	ns	0.70
H3A-K	ns	ns	***	***	ns	**	Ns	***	Ns	***	**	1	ns	ns	ns	ns	-0.33	0.42
1-d-CO_2	***	ns	ns	ns	***	***	***	*	Ns	**	ns	ns	1	0.34	0.48	0.92	-0.29	0.42
WEOC	ns	ns	ns	ns	*	ns	**	ns	*	ns	ns	ns	***	1	0.56	0.46	ns	ns
WEON	***	***	**	ns	***	**	Ns	**	Ns	**	***	ns	***	***	1	0.74	ns	0.43
HSHS	***	ns	ns	ns	***	***	**	*	Ns	**	ns	ns	***	***	***	1	-0.25	0.49
H3A-Fe	***	ns	**	**	ns	***	Ns	*	Ns	***	ns	***	**	ns	ns	**	1	-0.32
H3A-Ca	***	***	***	**	***	***	**	***	Ns	***	***	***	***	ns	***	***	***	1

[a] Units and abbreviations are as follows: pH (–log[H+]), EC (electrical conductivity); H3A (weak organic acid extractant); TN (total nitrogen), TP (total phosphorus), Fe (iron), Ca (calcium), N (nitrogen), P (phosphorus), K (potassium), WEOC (water-extractable organic carbon), and WEON (water-extractable organic nitrogen); OM (organic matter); HSHS (Haney Soil Health Score).

[b] The symbols *, **, and *** are used to show significance at the α = 0.05, 0.01, and 0.001 levels, respectively, ns is not significant.

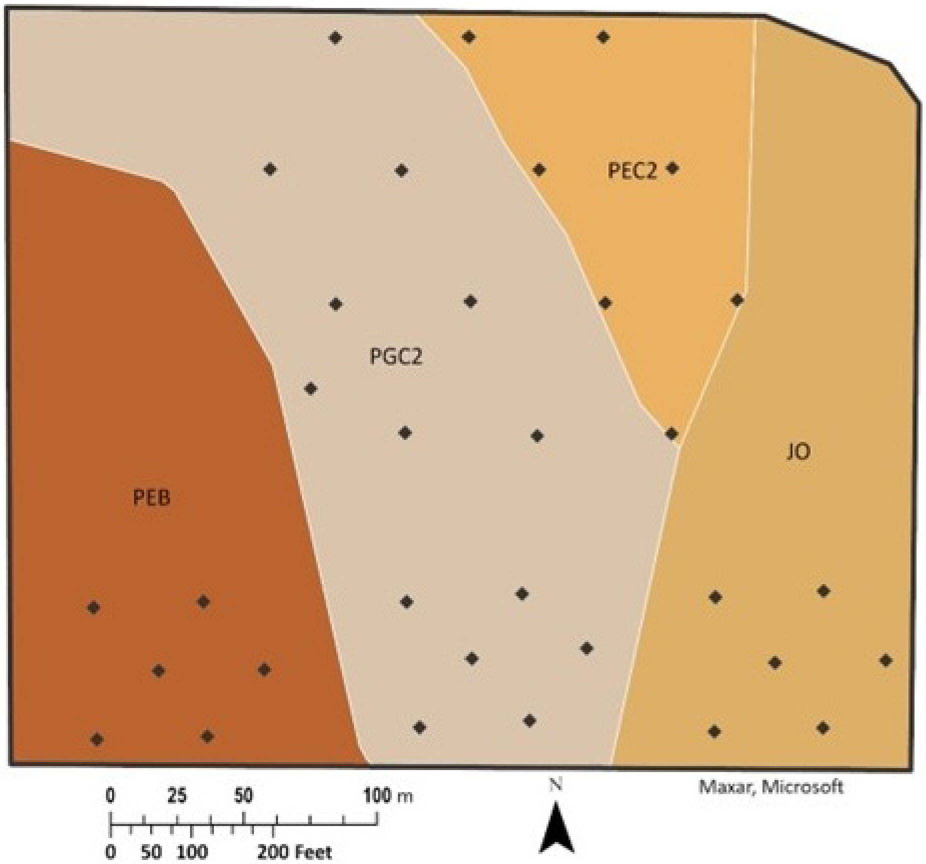
Table 4. Comparison of the fertility recommendations averaged across all years and sample points using a yield goal for the Haney Soil Health Test of 2 ton/ac of grass production and University of Arkansas Soil Test Recommendations for mixed cool- and warm season grasses pastures (Crop code 212).

	N[a]	P_2O_5	K_2O	Nutrient Value[b]
Soil Test	----------	(lb/ac)	----------	(USD/ac)
Arkansas Soil Test Lab	60.0	18.8	123.9	80.6
Haney Soil Health Test	20.3	7.6	17.6	19.6
Difference	39.7	11.2	106.3	60.9
P-value[c]	<0.0001	<0.0001	<0.0001	<0.0001
Standard Error	1.55	1.84	4.95	2.26

[a] Units and abbreviations are as follows: N (nitrogen), P_2O_5 (phosphate), K_2O (potash), lb/ac; USD (United States Dollar).

[b] Nutrient value estimate based on 2018 regional fertilizer prices used by Haney Soil Health Test as follows: N, \$0.40/lb; P_2O_5, \$0.70/lb; K_2O \$0.35/lb (pers. comm. Dr. Richard Haney, 2019, United States Department of Agriculture-Agricultural Research Services).

[c] Differences were determined using Wilcoxon Signed Rank test at the $\alpha \leq 0.05$ level.



Soil Series Name	Symbol
Johnsburg silt loam, 0 to 2 percent slopes	Jo
Pembroke silt loam, 3 to 6 percent slopes, eroded	PeC2
Pembroke gravelly silt loam, 3 to 8 percent slopes, eroded	PgC2
Pembroke silt loam, 1 to 3 percent slopes	PeB

Fig. 1. A map showing soil mapping units and descriptions for soils sampled biennially between 2013 and 2021 at the Morrow Discovery Farm in Washington County, Arkansas (United States Department of Agriculture, NRCS Soil Survey Staff, 2022).

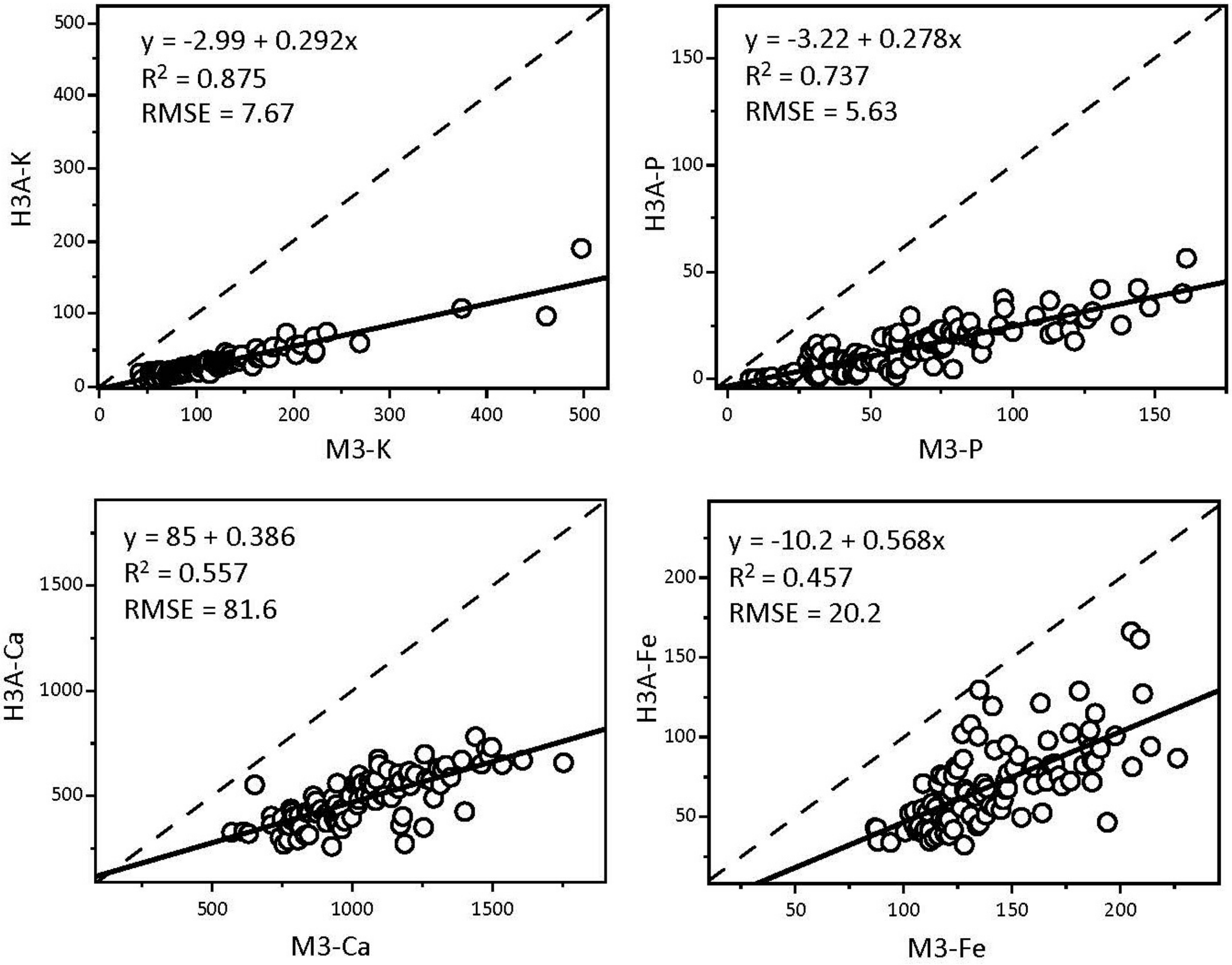


Fig. 2. Relationships between H3A (a weak organic acid extractant used in Haney Soil Health Test) and Mehlich-3 (M3) extractable potassium (K), phosphorus (P), calcium (Ca), and iron (Fe), fitted with linear regression equations, coefficient of determination (R^2), and root mean square error (RMSE) for soils sampled biennially between 2013 and 2021 at the Morrow Discovery Farm in Washington County, Ar.

Soil-Test Potassium Variability in Pastures Amended with Dry Manure on an Arkansas Discovery Dairy Farm

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Abstract

Environmental concerns regarding manure management in dairy production are typically confined to nutrients such as nitrogen (N) and phosphorus (P), while potassium (K) is a nutrient less likely to be considered. The Haak dairy farm employs a paddock arrangement with rotational grazing, seasonal crop production, and the milking of approximately 160 cows. Fields dedicated to grazing receive applications of dairy manure. This manure comes from the milking center, where it is then mixed with sawdust and deposited in an open-air containment area awaiting field application. The purpose of this study was to evaluate soil-test potassium (STK) levels from designated sites across the dairy's fields by grid-soil sampling in 2017, 2018, and 2020. A total of 100 soil samples were collected each year, 50 at the 0–4 in. depth and 50 at the 4–8 in. depth along 10 sampling transects. Grid-soil sampling techniques remained identical for all 3 years. Analysis of STK indicated that there was a significant rise in STK at the 0–4 in. sampling depth from 2017 to 2018 and 2020, while STK for 2018 and 2020 was not significantly different. Analysis of the 4–8 in. samples exhibited significant STK increases among the three experimental years. The significant increase in STK between 2018 and 2020 was recognized as the result of intensification in grazing and manure accumulation due to an expansion of dairy cattle from 2017 to 2018 (80 to 160 head).

Introduction

Dairy production often entails the land application of on-farm-generated cattle manure to be utilized as a fertilizer source (O'Brien and Hatfield, 2019). Typically, manure in Benton County is applied according to a nutrient management plan based on a P-Index tool that considers environmental concerns associated with phosphorus (P) (Sharpley et al., 2010). Manure applications based on the P-Index often reduce N (nitrogen) and potassium (K) to rates well below crop uptake and possibly result in STK deficiencies over time if additional synthetic K fertilizer is not applied. The N:K ratios for solid dairy manure have been reported as approximately 1.2:1 (Pennington et al., 2015; Boyd, 2018) to about 2:1 (Slaton et al., 2004), illustrating a narrow variability. If manure is applied to meet all N needs, then a narrow ratio increases the possibility of manure-applied K that is not assimilated by plants being lost through groundwater leaching and during surface runoff events, thereby contributing to the nutrient loading of adjacent streams and rivers (Aguirre-Villegas et al., 2018).

While field application of manure-derived K can reduce the need for synthetic K fertilization (O'Brien and Hatfield, 2019) and is not considered an environmental or water quality concern if over-applied, a better understanding of how manure management can affect STK is needed to improve K management and profitability to avoid issues ranging from K deficiencies in forages to reduced profitability if over applied.

Subsequent to the 2015 Haak Dairy NMP (USDA–NRCS, 2015), soil-test K (STK) fluctuated from 148–333 parts per million (ppm), which range from "optimum" to "above optimum" soil-test K levels according to agricultural soil testing guidelines.

The Haak dairy farm and the Natural Resources Conservation Service (NRCS), along with the Arkansas Discovery Farms Program (ADF), initiated investigations into evaluating STK levels and monitoring soil health throughout designated areas of the Haak dairy farm.

Procedures

Sampling was performed from 2017–2020 at the Haak dairy near Decatur (36°21'54.29", 94°26'30.4") located in Benton County, Ark. Fields at the farm receive treatments of manure produced in the dairy's milking center. The solid manure accumulated in the milking center is removed to blend with holding pen manure and sawdust bedding. This mixture is then placed in an open-air holding area prior to field application. Residual milking center manure is rinsed from the floors, where it is transported to an adjacent belowground storage tank.
Urea (46-0-0) and potash (0-0-60) fertilizers are applied twice per year at 150 lb/ac/application and potash twice a year at 50 lb/ac/application, respectively.

The sampling scheme for soil nutrients was developed by detecting surface-runoff routes at the Haak dairy using LIDAR (Light Detection and Ranging) GIS information and NRCS Total Station Elevation Surveys. These routes were utilized to construct 10 soil sampling transects traversing the milking center to a freshwater pond (Fig. 1). There were 5 sampling locations per transect for a total of 50 per sampling year. The soil underlying the experimental area was mapped as a Peridge silt loam with slopes of 3–8%, subsurface soil depth of 74 in., well-drained, low runoff class rating and hydrologic soil classification of B Transects and sample points were created in ArcMap Version 10.1 (ESRI, 2014) and coordinates were

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entered into a GPS device (GPSMap 64st, Garmin International) so soil sampling could be achieved at preset positions (Fig. 1). Samples entailed 6 cores taken at depths of 0–4 in. and 4–8 in. within a 5-ft radius of each GPS position. Each 8-in. soil core was separated into two depths, and the 6 soil cores were mixed into one combined sample for each depth. Samples were submitted to the University of Arkansas System Division of Agriculture's Marianna Soil Testing Laboratory for analysis by Mehlich-3 extraction, and the resulting nutrient concentrations were analyzed with an inductively coupled plasma-atomic emissions spectrometer (ICAP-AES; Zhang et al., 2014).

Statistical analysis was operated by paired t-tests evaluating yearly STK means from 2017, 2018, and 2020 in JMP Pro 16 with no blocking. Graphical analysis was implemented by contrasting STK from 2017, 2018, and 2020 in Microsoft Excel by computing and comparing the mean STK value from each transect per sampling year. Analyses were produced comparing annual STK paired t-test and transect means at soil sampling depths of 0–4 in. and 4–8 in.

Results and Discussion

Statistical analysis of STK for the 0–4 in. depth showed a significant STK increase from 152 ppm in 2017 to 244 ppm in 2018, and STK was not significantly different from 262 ppm in 2020 (Table 1). Analysis of the 4–8 in. depth revealed STK of 93 ppm in 2017 was significantly lower than 127 ppm in 2018, which was then shown to be significantly lower than 170 ppm observed in 2020 (Table 1). These results are presented by graphs of STK soil transect means at 0–4 in. and 4–8 in. (Figs. 2 and 3).

Soil-test K significantly increased at transect 6 over all other transects for both sampling depths from 2017 to 2018. Soil-test K also significantly increased on transect 6 over all other transects for both sampling depths from 2017 to 2020. Soil-test K for 2018 and 2020 was not significantly different for the majority of transects at both sampling depths but was significantly different at transect 6 at 4-8 in. from 2018 to 2020. Significant increases in STK on transect 6 from 2017 to 2018 and 2020 could be attributed to increases in cattle number from 80 to 160 head along with transect 6 containing a path for cattle traveling to and from the milking center, which would lead to an intensification in manure deposition (Fig. 1). While runoff flow pathways were determined with elevation derived from LIDAR, runoff quality was not measured. But perhaps if runoff velocity slowed through temporary ponding, soluble K in the runoff might have been deposited along this transect. Similar trends in STK were observed for both depths in all years, peaking at transect 6 and then descending towards transect 10.

Practical Applications

Understanding the dynamics of STK associated with manure application is an important consideration for proper K fertilization and profitability. Manure applications significantly increased STK in the top 4 in. of soil. As this is a grazing dairy with rotational grazing, STK increased most in a walkway between grazing paddocks where cattle congregated and traveled to and from the pastures and milking parlor. Soil sampling schemes should recognize locations of heightened cattle congregation and, based on STK in these areas, may not need additional fertilizer or manure applications. In addition, the use of soil transect analysis can identify localized areas of elevated STK within fields and paddocks that would result in STK levels in the "above optimum" range.

Acknowledgments

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Table 1. Haak dairy Mehlich-3 soil test potassium (STK) means for soil sampling events in 2017, 2018, and 2020. Means were analyzed and separated by using paired t-tests ($P \leq 0.05$).

Year	STK (0–4 in.)[†]	STK (4–8 in.)
	(ppm)	(ppm)
2017	152 b	93 c
2018	244 a	127 b
2020	262 a	170 a

[†] Values within a column (soil depth) not sharing the same lowercase letter are significantly different ($P \leq 0.05$).

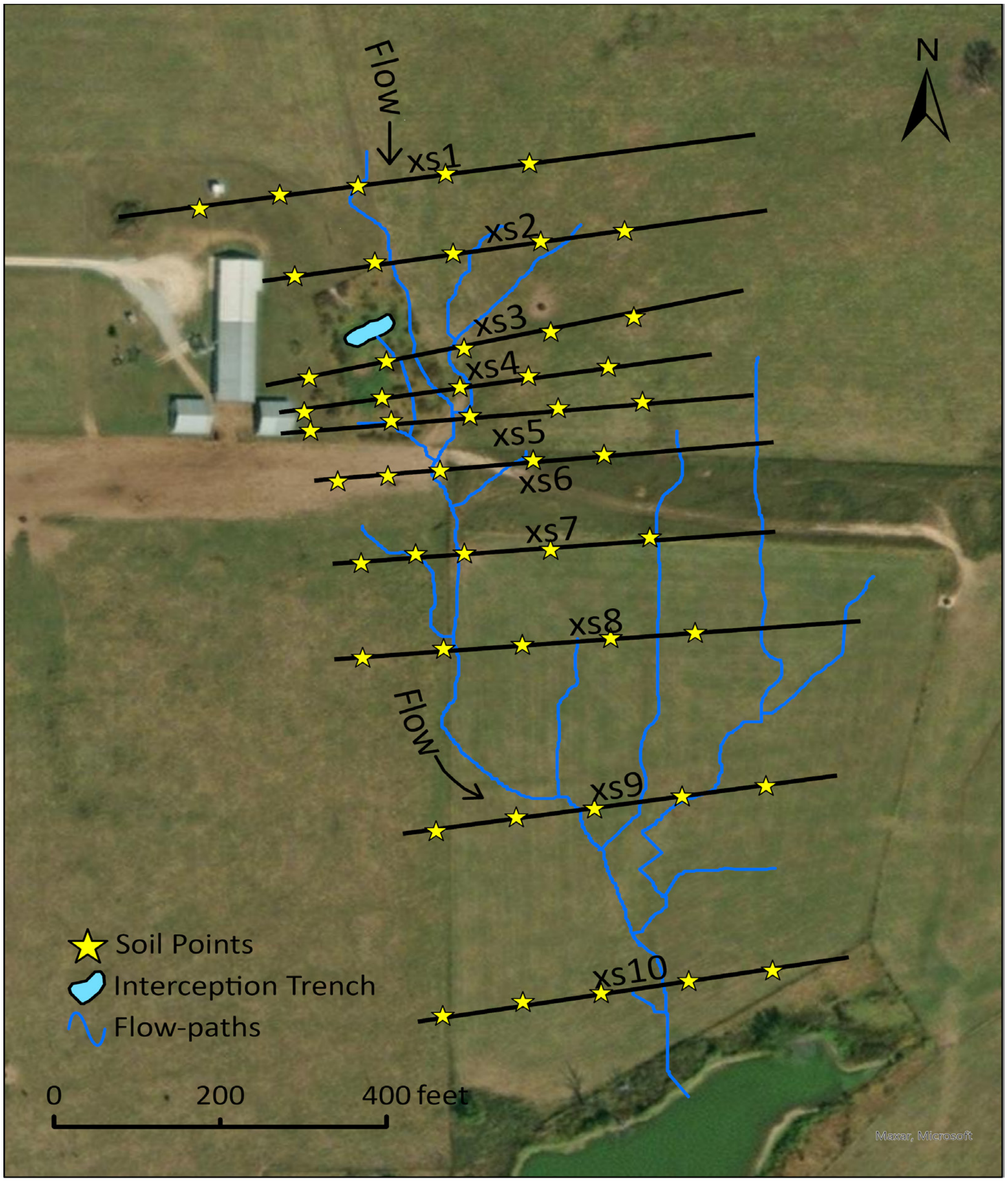

Fig. 1. Haak dairy soil sampling transects (1 through 10) used for sampling events in 2017, 2018, and 2020. Slopes of 3–8% from transect 1 downward to transect 10 were mapped and identified by ESRI (2014).

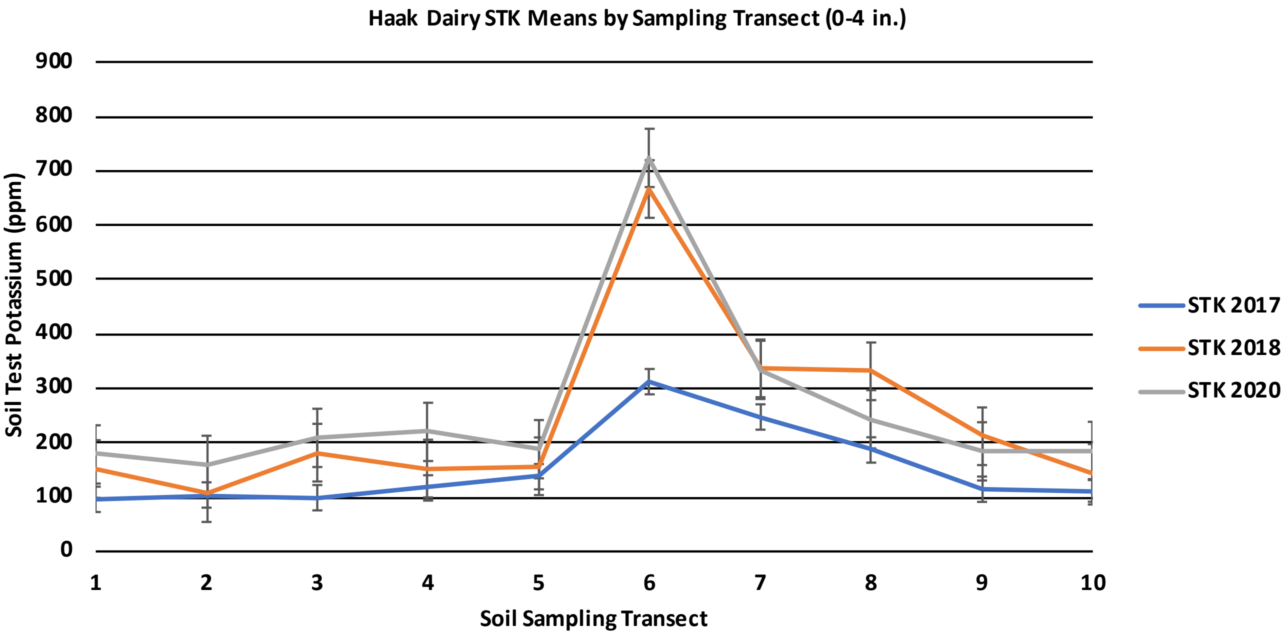

Fig. 2. Haak dairy soil test potassium (STK) means for 10 soil sampling transects at a sampling depth of 0–4 in. Error bars represent ± 1 standard error.

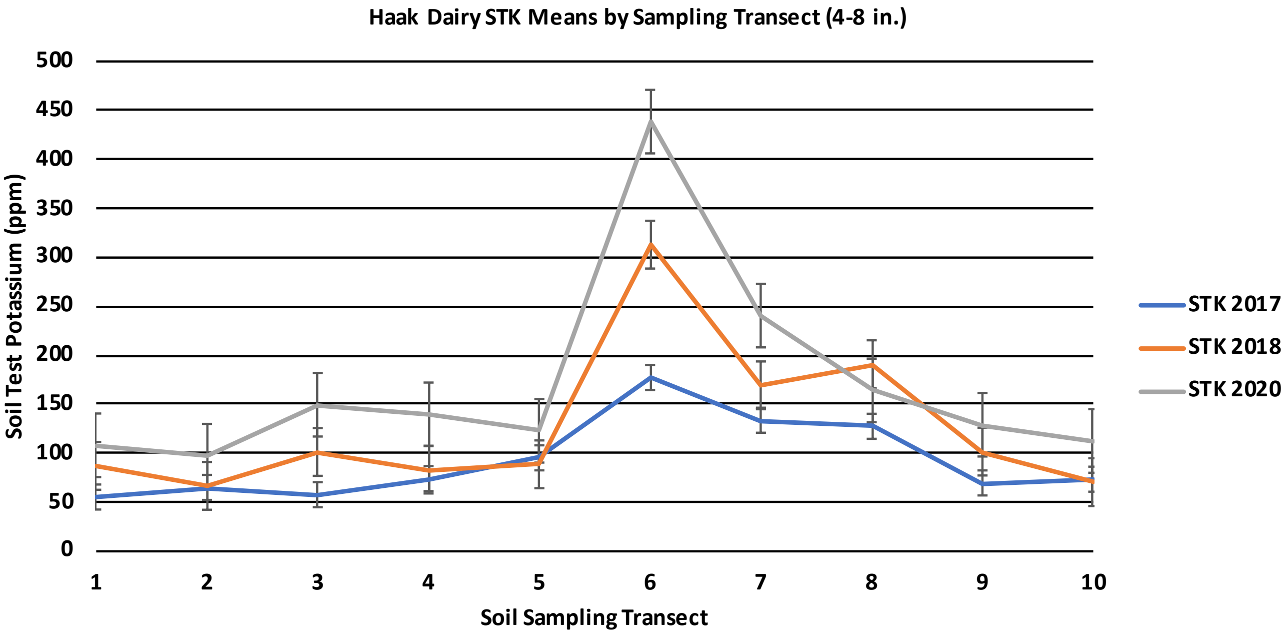

Fig. 3. Haak dairy soil test potassium (STK) means for 10 soil sampling transects at a sampling depth of 4–8 in. Error bars represent ± 1 standard error.

Okra Cover Crop Management and Poultry Litter Application Effect on Soil Chemical Properties in an Organic System

T.E. Holder,[1] M.C. Savin,[1] C.C. Nieman,[2] and J.G. Franco[3]

Abstract

This study investigated the effect of 1 year of cover crop termination strategy and poultry litter application method on soil chemical properties, including electrical conductivity (EC) and Mehlich-3 extractable nutrients in relation to soil chemical properties of perennial management systems. Soil samples were collected from three perennially managed locations and from an organic cropping system where an okra (*Abelmoschus esculentus* L.) cover crop was terminated by roller crimper, disk, or hay mower followed by poultry litter application treatments including top-dress unincorporated, top-dress incorporated, subsurface applied, or no poultry litter. A significant interaction between treatment and time was observed for EC, K, Mg, and S across treatments. Soil EC was greater under annual management treatments than perennial systems until the end of year 1, and Mehlich-3 extractable K and S averaged over all termination and poultry litter application treatments increased in the fall but were not different from the values observed under perennial management after 1 year. Mehlich-3 extractable Mg averaged over all termination and poultry litter application treatments were not different in the fall and were less than concentrations measured under perennial management in the first spring following the winter crop. These results are informative for understanding how nutrient availability may be affected by management in the first year after adding poultry litter and utilizing different termination methods following a cover crop in a summer rotation in the Mid-Southern U.S.

Introduction

Soil fertility is a foundational component of agricultural production that depends on complex biological, physical, and chemical processes within the soil. Conventional agriculture has relied on inorganic fertilizers to maintain soil fertility; however, as the cost of fertilizer increases and a greater emphasis is placed on soil and water quality for resilient production systems, producers are turning to management practices such as cover cropping and the use of organic amendments (Toor et al., 2021). These approaches affect soil fertility primarily through the addition of organic matter. Soil organic matter (SOM) influences plant-available nutrients by serving as a source of mineralizable N, P, and S, as well as a C and energy source for soil microorganisms (Gaskin et al., 2020). Soil organic matter also increases the cation exchange capacity of soil, which enhances the retention of macronutrients such as Ca, Mg, and K (Wright et al., 2007). Thus, management practices that increase SOM can have a profound effect on soil fertility.

Cover crops are a dynamic management option that can address several soil-related production needs, including increasing SOM over time, enhancing nutrient cycling, and redistributing existing nutrients in the soil profile (Wright et al., 2007; Roberts et al., 2018). The extent of a cover crop's influence on soil fertility is dependent on a number of factors, including species selection and residue management (Balkcom et al., 2020). In Arkansas, the majority of cover crops are winter annuals planted in the fall following a summer cash crop. However, within winter cash crop production systems, short-season, summer, annual cover crops can fill a production gap and provide soil quality benefits during an otherwise fallow summer period. There is an interest in using okra (*Abelmoschus esculentus* L.) as a summer cover crop because of its fast growth rate, high biomass production, and drought tolerance. Preliminary trials have shown okra to be well suited as a summer, annual cover crop in the Mid-South (Johnson, 2017; Wang et al., 2010); however, more research is needed to optimize management.

Cover crop management influences SOM accumulation and plant-available nutrients. Several studies have reported that the termination method influences SOM through labile C and N pools (Adetunji, 2019; Adetunji et al., 2021; Dabney et al., 2010). Bloszies et al. (2022) showed that N mineralization from cover crops terminated by disking increased compared to mowing and roller-crimper termination methods, but C mineralization was not significantly impacted by the termination method. Most termination method studies have focused on C build-up and N mineralization, resulting in limited information on the effect of the termination method on the availability of macronutrients such as P, K, Ca, Mg, and S.

Cover crops alone often do not release enough macronutrients to meet the demands of the subsequent crop and are, therefore, often coupled with commercial fertilizer or animal manure application. In Arkansas, poultry litter is a readily available fertilizer source that is used primarily to meet N and P demands, but has also been shown to increase K, Ca, and Mg concentrations in the soil, as well as increase SOM over time (Espinoza et al., 2007; Wood et al., 1996). Similar to cover crops, poultry litter management can influence nutrient fate and availability.

The goal of this research was to evaluate combinations of various okra cover crop termination and poultry litter ap-

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plication methods on short-term soil chemical responses in an organic system. This report summarizes changes in soil chemical properties, including Mehlich-3 extractable nutrients, pH, and electrical conductivity (EC) following a single season.

Procedures

This trial was conducted in 2020 at the USDA-ARS Dale Bumpers Small Farm Research Center in Booneville, Arkansas (35°05'52"N, 93°56'42"W). A study site was established in a 4-ac organic crop field composed of Enders silt loam (fine, mixed, active, thermic Typic Hapludult) and Leadvale silt loam soils (fine-silty, siliceous, semiactive, thermic Typic Fragiudult) (USDA-NRCS, 2019). Three undisturbed perennial control sites were identified, including two perennial pasture sites and one unmanaged location bordering a loblolly pine (*Pinus taeda* L.) plantation, all of which are also composed of Enders silt loam and Leadvale silt loam soils.

An okra cover crop was planted in the organic crop field in July 2020, following the termination of a winter cereal rye (*Secale cereale* L.) cover crop. The site was tilled prior to planting, and Clemson Spineless 80 okra from Green Cover Seed (Bladen, Nebraska) was planted at a rate of 18 lbs/ac using a John Deere 1530 no-till drill (Deere & Co., Moline, Ill.). Plots were established in September 2020 using a randomized complete block, 2-factor, split-plot design with three replications where cover crop termination and poultry litter application method were the main plot factors and cereal grain planted following cover crop termination (wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.)) was the split-plot factor. Replications were oriented East to West along a 4% slope and plots measured 40 ft by 60 ft. A total of eight treatments were implemented with varying combinations of cover crop termination and poultry litter application methods (Table 1). The okra cover crop was terminated on 8 October 2020, followed by an application of poultry litter at a rate of 4,000 lb/ac on 14 October, and cereal grain planting on 21 October.

Soil sampling activities began in July 2020, one week prior to the establishment of the okra cover crop, to create a baseline of the top 4 in. (10 cm) of soil in each plot area. The second sampling date occurred in November 2020, following okra cover crop termination, poultry litter application, and cereal grain planting. The third and final sampling date occurred in June 2021, at cereal crop maturity. Samples from undisturbed perennial control sites were collected on the same day as okra cover crop soil samples. Samples were collected using an Ames hand trowel for the first two sampling dates and a 1-in. diameter sampling probe for the third sampling date. All soil samples were collected from the top 4 in. and consisted of 10 composited subsamples. Each composited sample was processed through a 4.75-mm sieve, air-dried, and stored at room temperature for future analysis.

Samples from all three collection dates were analyzed for soil pH and EC using a 1:2 soil-to-water (wt:vol) ratio. Mehlich-3 extractable nutrients (i.e., P, K, Ca, Mg, and S) were measured by inductively coupled plasma (ICP) atomic emission spectroscopy (SPECTRO CIROS ICP, Mahwah, N.J). Soil extractions were prepared using a 1:10 (wt:vol) ratio of dry soil to Mehlich-3 extracting solution filtered through Whatman #42 filter paper.

The effects of cover crop management and poultry litter application on Mehlich-3 extractable primary and secondary macronutrients (P, K, Ca, Mg, and S) and soil pH and EC were evaluated for each split-plot at the first, second, and third sampling dates. Results were analyzed using 3-way analysis of variance to determine if cover crop termination and poultry litter application treatment, cereal grain type, and sampling time significantly impacted soil chemical properties. No significant difference was found among cereal grain types within each split-plot; wheat and barley results were therefore averaged within plots at each sampling time. When significant, treatments were differentiated using Tukey's honestly significant difference ($P < 0.05$).

Results and Discussion

Significant differences were observed from treatment type alone for pH, EC, and all Mehlich-3 extractable macronutrients. However, the interaction between treatment type and sampling time was significant for EC and Mehlich-3 K, Mg, and S. In non-saline soils, greater EC values reflect increased nutrient availability. In this study, EC did not show significant change among sampling periods within any annual or perennial treatment (Table 2). Samples collected in November 2020 following PL application and cover crop termination showed that disk, top-dress unincorporated (DTU) was significantly greater than all treatments that did not include PL (DN, Control D, Control P, Control R). Similarly, Control P was significantly lower than all annual treatments that included PL on the November 2020 sampling date. By the third sampling date, however, there was no difference among any treatments, annual or perennial. Other studies have reported increased EC under high soil disturbance and residue incorporation; for instance, Brye and Pirani (2005) reported significantly greater EC in conventionally tilled soils compared to undisturbed prairie.

Mehlich-3 extractable soil K concentrations did not change from the beginning to the end of the sampling period across all annual management treatment types, although numerically, the means increased immediately following poultry litter application in November 2020 except in the roller-crimper, top-dress poultry litter treatment (RCT, Table 2). Changes in Mehlich-3 extractable soil K concentrations were not different among annual treatments, whether poultry litter was applied or not. Others have observed that the incorporation of plant residues resulted in a short-term increase in soil extractable K (Franzleubbers and Hons, 1996). The perennial ecosystem controls (Table 1) showed great variability in extractable K among the three control sites, with the lowest K concentrations across all treatments occurring under unmanaged pasture (Control D) and the greatest K concentrations occurring under the unmanaged forest border (Control P; Table 2).

Mehlich-3 extractable Mg increased numerically but not significantly immediately following PL application across all annual treatments that included PL. Despite the apparent increase, all annual treatments exhibited relatively stable extractable

Mehlich-3 Mg concentration measurements (Table 3). In contrast, the greatest range in extractable Mg concentrations occurred among the three perennial control sites in November and June. The unmanaged pasture site (Control D) did not differ in Mg concentrations from the values observed under the annual treatments except for hay mower, subsurface poultry litter application (HMSS) in November. In addition, extractable Mg concentration was significantly greater in the agroforestry border site (Control P) than in all annual and perennial sites in June.

Sulfur availability in soil is primarily dependent on organic matter mineralization and movement of sulfate in runoff and leaching. Extractable S did not change immediately following PL application and cover-crop termination in November 2020 across all annual treatment types (Table 3). This lack of change may be a result of sampling timing in relation to cover-crop termination date. Cover crops that have greater amounts of cellulose decompose slowly, resulting in the immobilization of macronutrients such as N and S (Carciochi et al., 2021). Okra biomass is highly cellulosic, and, therefore, S may not have mineralized within the 25-day period between cover-crop termination and soil sampling. Perennial site Control R showed a decrease in extractable S in November 2020, indicating reduced S availability in the fall may occur without organic amendment application.

Practical Applications

The results of this study showed that annual cropping systems that utilize organic matter-building practices such as cover cropping and poultry litter application exhibited K, Mg, and S availability that was not often different from perennial management in the first year of treatment application. While nutrient availability varied among the perennial locations, soil nutrient concentrations during 1 year of summer cover crop followed by poultry litter application ranged between the control site with the lowest nutrient values and the control site with the largest concentrations. There were very few significant differences in Mg, K, and S between the first sampling date and the final sampling date across annual treatments, indicating the importance of long-term monitoring (>1 year) to understand the impacts of management practices on soil nutrient availability and to make comparisons of annual cropping practices compared to perennial management.

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Table 1. List of treatment by termination method and corresponding poultry litter application method in the annual row crop treatments and the perennial systems serving as control soils.

Treatment	Termination Method	Poultry Litter Application
RCT	Roller Crimper	Top-dress
RCSS	Roller Crimper	Sub-surface
DTU	Disk	Top-dress - Unincorporated
DTI	Disk	Top-dress - Incorporated
DSS	Disk	Sub-surface
HMT	Hay Mower	Top-dress
HMSS	Hay Mower	Sub-surface
DN	Disk	None
	Perennial Ecosystem Type	
Control D	Unmanaged Pasture	
Control P	Unmanaged, Edge of Forest	
Control R	Organic Managed Pasture	

Table 2. Mean electrical conductivity (EC) and Mehlich-3 extractable potassium (K) for three sampling dates. Annual treatments include RCT (roller crimper, top dress), RCSS (Roller crimper, subsurface), DTU (disk, top-dress unincorporated), DTI (disk, top-dress incorporated), DSS (disk, subsurface), HMT (hay mower, top-dress), HMSS (hay mower, subsurface), and DN (disk, no poultry litter). Perennial treatments include Control D (unmanaged pasture), Control P (unmanaged agroforestry border), and Control R (managed pasture).

	Electrical Conductivity			Potassium		
Treatment	July 20	Nov. 20	June 21	July 20	Nov. 20	June 21
	------------------------(µS/cm)	------------------------		-------------------------- (ppm)	--------------------------	
RCT	305 ab[†]	259 abcde	288 abcde	145 abcdefghi	88 abcdef	88 bcdefghi
RCSS	291 abc	316 ab	237 abcdef	119 abcdefghi	227 abc	111 abcdefghi
DTU	235 abcdef	404 a	251 abcdef	126 abcdefghi	237 ab	122 abcdefghi
DTI	186 bcdef	291 abc	251 abcdef	131 abcdefghi	209 abcde	64 fghi
DSS	321 ab	267 abcde	310 ab	176 abcdefg	192 abcdef	124 abcdefghi
HMT	304 ab	310 ab	285 abc	141 abcdefghi	198 abcdef	96 cdefghi
HMSS	321 ab	327 ab	260 abcdef	123 abcdefghi	207 abcde	68 fghi
DN	268 abcde	206 bcdef	235 abcdef	154 abcdefghi	186 abcdef	77 efghi
Control D	89 ef	113 cdef	173 bcdef	71 fghi	45 ghi	29 i
Control P	101 def	80 f	179 bcdef	245 a	221 abcd	170 abcdefghi
Control R	276 abcd	153 bcdef	213 bcdef	131 abcdefghi	89 defghi	35 hi

[†] Means for each separate property (EC and K) followed by the same letter across the three sample dates do not differ significantly using Tukey's honestly significant difference; $P < 0.05$.

Table 3. Mean Mehlich-3 extractable magnesium (Mg) and sulfur (S) for three sampling dates. Annual treatments include RCT (roller crimper, top dress), RCSS (Roller crimper, subsurface), DTU (disk, top-dress unincorporated), DTI (disk, top-dress incorporated), DSS (disk, subsurface), HMT (hay mower, top-dress), HMSS (hay mower, subsurface), and DN (disk, no poultry litter). Perennial treatments include Control D (unmanaged pasture), Control P (unmanaged agroforestry border), and Control R (managed pasture).

	Magnesium			Sulfur		
Treatment	July 20	Nov. 20	June 21	July 20	Nov. 20	June 21
	------------------------------(ppm)----------------------------			------------------------(ppm)------------------------		
RCT	69.0 efg[†]	82.2 defg	58.8 efg	20.5 bcd	28.1 abcd	18.1 bcd
RCSS	63.4 efg	79.1 defg	55.2 fg	17.6 bcd	24.5 abcd	17.9 bcd
DTU	67.5 efg	84.3 defg	62.6 efg	15.7 bcd	30.1 abc	17.6 bcd
DTI	59.9 efg	90.3 defg	49.3 fg	15.5 bcd	27.9 abcd	12.8 bcd
DSS	66.0 efg	68.8 efg	61.9 efg	21.9 bcd	23.6 abcd	17.5 bcd
HMT	58.8 efg	95.1 cdef	76.9 defg	20.4 bcd	34.3 ab	18.5 bcd
HMSS	58.0 efg	107.1 bcde	73.0 defg	16.9 bcd	34.0 ab	16.3 bcd
DN	81.9 defg	60.2 efg	45.0 fg	19.8 bcd	13.8 bcd	12.9 bcd
Control D	67.0 efg	46.6 fg	41.6 g	15.7 bcd	6.4 d	15.6 bcd
Control P	131.0 abcdefghi	145.6 abc	186.0 a	18.0 bcd	10.4 cd	22.4 abcd
Control R	120.0 bcd	92.8 def	77.6 defg	44.1 a	12.8 bcd	23.8 abcd

[†] Means for each separate property (Mg and S) followed by the same letter across treatments and the three sample dates do not differ significantly using Tukey's honestly significant difference; $P < 0.05$.

The Usefulness of Glomalin-Related Soil Protein as a Functional Indicator for Soil Health When Establishing Forage in a Mid-Southern United States Forest

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Abstract

Silvopasture is an agroforestry practice in which forages are incorporated into the same system as woody perennials in order to create a sustainable grazing system. The main objective of this study was to investigate whether the establishment of agroforestry as a management system promotes soil health. Glomalin-related soil protein (GRSP), a glycoprotein often related to soil carbon and nitrogen, soil aggregation, and arbuscular mycorrhizae, has been suggested as a functional soil health indicator for the properties of promotion of soil structure and the sequestration of nutrients. Within a mixed hardwood forest in the Arkansas River Valley, an agroforestry system was established to evaluate three basal areas (30, 50, and 70 ft^2/ac) and two forages including tall fescue (*Lolium arundinaceum* [Schreb.] Darbysh) and orchardgrass (*Dactylis glomerata* L.). Soil properties assessed within this study include pH, electrical conductivity, particulate organic matter (POM), total organic matter (TOM), GRSP, Mehlich-3 extractable nutrients, and bulk density at soil depths separated at 0–4 (0–10 cm) and 4–12 in. (10–30 cm). It was observed within this study that GRSP is significantly correlated with TOM, potassium, and phosphorus. A significant difference in GRSP at the soil depth of 4–12 in. was observed between the 70 and 30 ft^2/ac basal treatments. The results of this study provided evidence that GRSP can be used as an early soil health indicator for nutrient cycling and availability of organic matter with the introduction of silvopastoral practices. Furthermore, results indicated that belowground properties might respond relatively rapidly to management techniques and thus highlight the importance of monitoring soil responses to change in tree basal area and forage establishment.

Introduction

Silvopasture is an agroforestry system that incorporates trees, forages, and grazing livestock into the same area. Silvopasture is intended to imitate the natural savanna ecosystem, which contains grasslands integrated with trees and shrubs (Jose and Dollinger, 2019). The objective of silvopasture is to create a sustainable grazing system that utilizes symbiotic relationships with management to optimize multiple ecosystem services—supporting (e.g., primary production, wildlife habitat, nutrient, and water cycling), regulating (e.g., erosion control, pest control), and in some cases cultural (e.g., aesthetic value) —for the ultimate benefit of enhanced provisioning services (e.g., food and lumber).

The effectiveness of a silvopastoral system is reliant upon interspecies relationships. Relationships between the forages and trees, and how grazing practices affect growth and both types of plant production, determine the ecosystem functions and services provided, which can create an efficient system in terms of productivity and sustainability (Jose and Dollinger, 2019). The selection of forage species and management of spatial density, such as tree basal area, have a direct influence on system outputs. The basal area can directly influence light inputs throughout the system, and depending on the forage species selected, light requirements will vary. Implementation of forage into a forest has the potential to increase soil health by introducing new primary productivity with a fibrous root system that contributes approximately half its carbon belowground and supplies resources to the base of a food chain that cycles nutrients and builds organic matter. With more resources and bioturbation, soil structure can be improved, water retention and filtration promoted, and disease resistance expanded. Selective harvest of tree biomass can add a revenue stream for animal producers.

Through the implementation of a sustainable silvopasture system, benefits such as the promotion of soil health can be achieved. Soil aggregation is crucial in determining how resources such as water, gases, nutrients, and vegetative roots move and function throughout the soil profile (Fokom et al., 2012). Glomalin-related soil proteins (GRSP), commonly referred to as glomalin, in the soil can act as a "glue" to promote soil aggregation, and these proteins may represent about 5% of carbon and nitrogen within the soil nutrient pool (Treseder and Turner, 2007). Arbuscular mycorrhizal fungi (AMF) are the typical organism associated with GRSP production, and GRSPs are being championed as a soil health indicator (Rillig et al., 2002). Multiple studies have observed increased soil aggregate stability in the presence of GRSP (Liu et al., 2020; Wright et al., 1999; Wu et al., 2014). With an increase in the effective movement of resources throughout the soil profile, the promotion of soil health supports a resistant and resilient system.

The purpose of this research is to evaluate the introduction of two forage species into a mixed hardwood forest thinned to one of three target tree basal areas for the potential to rapidly increase GRSP, particulate organic matter, and soil nutrients. It is hypothesized that GRSP concentrations will vary with forage species, with an increased concentration observed within the forage plots in comparison to areas of the forested site where forage

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was not established. Furthermore, relationships will be identified between GRSP concentrations and soil properties to utilize GRSP as a functional indicator. For this objective, it is hypothesized that GRSP will have identifiable relationships with soil properties to serve as an early indicator of the effects of management.

Procedures

Site Description

The experimental site is a previously undisturbed 22-acre mixed hardwood forest that was converted into an agroforestry site located within the Arkansas River Valley ecoregion (N35°05.56 W93°57.880) at the USDA-ARS Research Center in Booneville, Ark. The soil within the site is mapped as 44.6% Leadvale silt loam (fine-silty, siliceous, semiactive, thermic Typic Fragiudult), and 55.4% Taft silt loam (fine-silty, siliceous, semiactive, thermic Glossaquic Fragiudult, Soil Survey Staff, NRCS, 2020). The mean annual precipitation is 45–58 in., and the mean annual air temperature is 55 to 63 °F (12.8 to 17.2 °C; Soil Survey Staff, NRCS, 2020). Thinning of trees was accomplished by prescribed herbicide injection of trees with Imazapyr in May 2020 and subsequent mulching utilizing a mulcher attached to a skid steer to achieve targeted basal areas throughout the experimental site.

The experimental site contains 9 total basal area sections with dimensions of 328 × 1312 ft. (100 × 400 m) designated by basal area with values of 30, 50, and 70 ft^2/ac, with each basal area replicated three times. Within each basal area, four forage plots were established with dimensions of 8 × 30 ft (240 ft^2). Of the four plots, two are tall fescue (*Lolium arundinaceum* [Schreb.] Darbysh), and two are orchardgrass (*Dactylis glomerata* L.), which were planted on 8 December 2020, at seeding rates of 20 lb/ac. Each individual forage subplot was placed on a relatively high elevation point (mound) and relatively low elevation point (intermound) and replicated. The total number of utilized forage subplots across the site was 36. A mulch control laying in the high and low elevation areas outside of the forage subplots in which vegetation consisted of the natural forest undergrowth in each tree basal area treatment section was demarcated to assess areas with no forage establishment.

Soil Analysis

Soil samples were collected in November 2021. Three 1-in. diameter core soil samples collected to a depth of 12 in. were composited using a sterile soil probe that was changed between each basal area by forage treatment by site-specific topographic position. Soil samples were separated to depths of 0–4 and 4–12 in. Sampling was conducted using an aseptic technique, and soil was immediately placed within designated sterile bags, sealed, and stored on ice for transport. After collection, soil samples were stored in a -80 °C freezer until sieved at 0.08-in. (2 mm), removing debris.

Soil phosphorus (P), potassium (K), magnesium (Mg), sulfur (S), and calcium (Ca) were determined by Mehlich-3 extraction in a 1:10 soil-to-extract (wt:vol) ratio followed by analysis by inductively coupled plasma - optical emission spectroscopy (Mehlich, 1984). Glomalin-related soil proteins were measured using the easily extractable GRSP method (Wright and Upadhyaya, 1998), followed by the Bio-Rad Bradford total protein assay (Bradford, 1976). Extraction requires 60 min of autoclaving 0.026 oz (0.75-g) of soil in 0.21 oz (6 mL) of 20 mM sodium citrate after vortexing. After autoclaving, the mixture is centrifuged at 5000 × g for 10 min. The Bradford total protein assay, or Bradford-reactive soil protein (BRSP), acts as an indicator of GRSP concentration. The assay depends on a shift in the absorbance of light of Coomassie Brilliant Blue G-250 when the dye binds to protein within an acidic solution. Absorbance at 595 nm was measured using an infinite M200 microplate reader (Tecan, San Mannedorf, CH). Soil pH and electrical conductivity (EC) were measured at a 1:2 soil:water (wt:vol) ratio by electrode. Particulate organic matter (POM) was assessed on dried and ground soil (25 g) filtered through a 53-μm sieve following 16 h of shaking in 3.5 oz (100 mL) sodium hexametaphosphate $(NaPO_3)_6$ solution. Both particulate organic matter (POM) and total organic matter (TOM) were determined by combustion with the loss-on-ignition method (6 hr at 450 °C).

Data Analysis

Data analysis was conducted within R studio (RStudio Team, Boston, Mass.) with the use of analysis of variance with Holm-Sidak means separation or Tukey's honestly significant difference where appropriate ($P < 0.05$). Pearson product-moment correlations were run ($P < 0.05$) to assess correlation. The means reported are with ± standard error.

Results and Discussion

The GRSP concentrations observed within this study were 1510 ± 40 and 880 ± 40 ppm (mean ± standard error) at the 0–4 and 4–12 in. depths, respectively (Table 1), which is within values that are typical of a forested system (Wang and Wang, 2015). Decreased GRSP with depth was expected because root production and thus associated rhizosphere microorganisms decrease with depth, which in turn limits glomalin production. Total OM also decreased with depth, with an average of 3.37 and 1.38 % for the 0–4 and 4–12 in. depths, respectively.

The GRSP concentrations correlated significantly with soil TOM, K, and P concentrations at a depth of 0–4 in. ($P < 0.05$; Table 2). The relationships had moderate strength (r = 0.3–0.7) with a positive trend in each of the assessed properties. This positive relationship indicates that with an increase in GRSP within the soil, TOM, P, and K will also increase. The TOM, P, and K directly influence ecosystem functioning through nutrient cycling processes and plant productivity. Organic matter promotes soil aggregation (Boyle et al., 1989), while P (Shen et al., 2011) and K (Garcia and Zimmermann, 2014) are necessary elements for plant productivity that are readily influenced by mycorrhizae dynamics. It has been observed within low-P soils that mycorrhizal plants had an advantage over nonmycorrhizal plants due to the increase in uptake range (Shen et al., 2011). Not only do mycorrhizae promote spatial uptake of P, but mycorrhizae can also mineralize organic P for plant utilization (Jayachandran et al., 1992). Although studied less thoroughly than P dynamics, mycorrhizae interactions with K have been observed to improve plant health within K-limiting environments, such as forested ecosystems (Garcia and Zimmermann, 2014). With available nutrients for plant growth and healthy soil aggregation, ecosystem functioning can be strengthened. The significant relationship between these properties and GRSP within the soil provides evidence to support that GRSP may serve as an indicator for changes of forage establishment in soil with the introduction of silvopastoral management in mixed hardwood forests in the mid-southern U.S.

In terms of forage treatment, GRSP concentrations did not significantly differ among the forage treatments at the 0–4 in. depth ($P = 0.598$). The first growing season after grass establishment may not have been long enough to distinguish easily extractable GRSP concentrations in soil between grass species within the same hardwood ecosystem. The GRSP concentrations were significantly different between the 30 and 70 ft^2/ac basal treatments at a soil depth of 4–12 in. ($P = 0.032$; Fig. 1). The statistical difference in GRSP at the 4–12 in. depth may reflect that treatment effects are more likely to be detected below the initial surface layer in the forest where root and organic matter concentrations are smaller.

Practical Applications

A function of an indicator is to alert to a condition of property or process that is not easily measurable. Early treatment differences that were not previously observed throughout the site highlight how management techniques such as the selection of basal area could determine belowground soil properties. The results of this study can be utilized to assess soil health by using GRSP as an indicator of soil properties and functions. It can be expected that as the silvopastoral system develops, relationships among the soil health indicators will change or strengthen. While forage species have yet to show distinguishable effects through GRSP, there is evidence that the presence of forage is altering the soil functionality through inputs of organic matter and alterations in soil nutrient availability. Continued monitoring and utilization of proper indicators will assist in the implementation of silvopasture as a practice that may be promoted effectively as a sustainable management practice.

Acknowledgments

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Table 1. Mean soil properties and Mehlich-3 extractable nutrients in the 0–4 and 4–12 in. depths with all treatments combined (n = 54).

Soil Property[†]	Soil depth 0–4 in.	Soil depth 4–12 in.
Soil pH	4.93	4.94
Soil EC	88.31	37.55
GRSP (ppm)	1510.00 a	880.00 b
TOM (%)	3.37 a[‡]	1.38 b
POM (%)	6.98	ND
Bulk Density (g/cm^3)	1.42	ND
Ɵg (%)	0.22	ND
P (ppm)	1.14 a	0.53 b
K (ppm)	6.80 a	3.48 b
Ca (ppm)	37.24 a	20.53 b
Mg (ppm)	11.08	10.05
S (ppm)	0.80	0.74
Na (ppm)	2.93	2.45
Fe (ppm)	12.97	10.88
Mn (ppm)	9.60	9.76
Zn (ppm)	0.24 a	0.11 b
Cu (ppm)	0.06	0.06
B (ppm)	2.27 a	0.098 b

[†] Soil Electric Conductivity (EC), Glomalin Related Soil Protein (GRSP), Total Organic Matter (TOM), Particulate Organic Matter (POM), Gravimetric Water Content (Ɵg), and No Data (ND).

[‡] Different lowercase letters next to means for each property signify a difference between soil depths ($P < 0.05$). Property means unaccompanied by any letters are not significantly different ($P > 0.05$).

Table 2. Pearson correlation coefficient (r) matrix of soil properties and Mehlich-3 extractable nutrients at 0–4 in. soil depth (n = 54).

	GRSP[b]	pH	EC	TOM[b]	POM[b]	Ɵg[b]	BD[b]	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu	B
GRSP	1.00																	
pH	0.34	1.00																
EC	-0.23	-0.48	1.00															
TOM	**0.52**[a]	**0.52**[a]	-0.34	1.00														
POM	0.19	0.31	-0.15	0.32	1.00													
Ɵg	0.24	0.47	-0.34	0.58	0.52	1.00												
BD	-0.22	-0.08	0.31	-0.25	**-0.48**[a]	-0.38	1.00											
P	**0.56**[a]	-0.07	0.00	-0.06	-0.05	-0.32	-0.02	1.00										
K	**0.48**[a]	0.55	-0.11	0.41	0.22	0.27	0.14	0.31	1.00									
Ca	0.38	**0.71**[a]	-0.19	0.71	**0.48**[a]	0.69	-0.18	-0.28	**0.48**[a]	1.00								
Mg	0.14	0.53	-0.25	0.67	0.19	0.72	-0.13	-0.54	0.25	0.80	1.00							
S	0.27	-0.10	-0.11	0.19	0.56	0.31	-0.31	0.19	0.11	0.12	-0.09	1.00						
Na	-0.12	0.03	0.16	-0.06	-0.13	-0.16	0.01	-0.03	-0.19	-0.05	-0.05	-0.03	1.00					
Fe	-0.23	0.04	-0.21	0.06	0.16	0.37	0.04	-0.42	-0.03	0.09	0.20	0.20	-0.04	1.00				
Mn	0.16	0.38	-0.15	0.18	0.45	0.45	-0.03	-0.11	0.30	0.40	0.30	0.23	0.04	0.28	1.00			
Zn	0.24	-0.03	-0.27	0.25	0.24	0.35	-0.39	0.07	0.00	0.18	0.19	0.35	-0.11	0.08	0.23	1.00		
Cu	0.23	0.40	-0.23	0.54	0.27	0.61	0.02	-0.37	0.40	0.68	0.66	0.14	-0.25	0.23	0.33	0.29	1.00	
B	-0.16	-0.02	0.18	-0.16	-0.33	-0.38	0.10	0.08	-0.16	-0.18	-0.15	-0.29	0.89	-0.22	-0.09	-0.09	-0.35	1.00

[a] Correlations that are significant are shown in bold ($P < 0.05$).

[b] GRSP = Glomalin-Related Soil Protein; TOM = Total Organic Matter; POM = Particulate Organic Matter; Ɵg = Gravimetric Water Content; BD = Bulk Density.

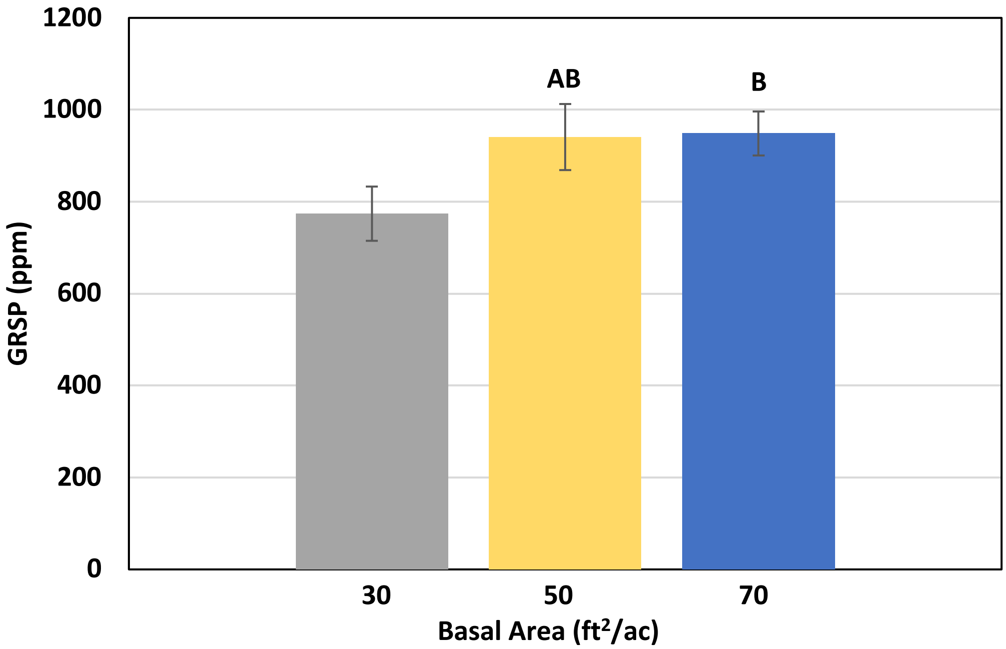

Fig. 1. Mean (± standard error) glomalin-related soil protein (GRSP) concentration at 4–12 in. soil depth for basal area treatments shown in ft^2/ac (n = 18). Basal areas with the same letter are not significantly different ($P < 0.05$).

Survey of Lower Mississippi River Valley Agricultural Sites: Cover Crop Effects on Near-Surface Soil Nutrients

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Abstract

Cover crops are widely considered to improve soil health in the form of erosion control and organic matter additions. Despite the well-documented benefits, cover crops remain under-studied in the Lower Mississippi River Valley (LMRV), an area historically dominated by intensive cultivated agriculture and with soils prone to erosion. The objective of this study was to evaluate the effects of cover crops [with cover crops (CC) and without cover crops (NCC)] on near-surface soil physical and chemical properties. Soil samples were collected between May 2018 and May 2019 across four locations within the LMRV portion of eastern Arkansas. Across all locations, extractable soil nutrient concentrations in the top 4 in. (10 cm) were unaffected ($P > 0.05$) by cover-crop treatment. However, extractable soil P, K, Fe, Mn, Zn, and Cu concentrations were numerically greater with CC compared to NCC, while extractable soil Ca, Mg, S, and Na concentrations were numerically greater with NCC compared to CC. Across all locations, total carbon (TC), total nitrogen (TN), and soil organic matter (SOM) concentrations in the top 4 in. (10 cm) were unaffected ($P > 0.05$) by cover-crop treatment. However, TC and SOM concentrations were numerically greater under CC compared to NCC, while TN was similar in both cover-crop treatments. Though many soil physical and chemical properties did not significantly differ between CC treatments due to the collective variations in background management practices, CC and cash crop species grown, and CC duration, which ranged from less than 1 year to greater than 19 years, results of this study clearly demonstrated that CC affect physical and chemical properties across a large area. With continued management using CC, soil properties that only numerically differed are expected to continue to deviate from one another into the future, at which time the fuller benefits of long-term CC use may be realized.

Introduction

Cover crops (CC) are a living, vegetative cover that protect and may improve soil functions for plant growth by promoting greater nutrient cycling, infiltration, water movement and storage, and increased biodiversity. Cover crops can be grasses, forbs, or legumes that are typically grown between cropping seasons when fields are left fallow in the summer and/or during the winter. Additionally, CC may grow in tandem with cash crops (Roberts et al., 2018). When soil is left bare, potential erosion and crusting may lead to soil and nutrient loss, decreased infiltration, diminished aggregate stability, and lower soil water content. The benefits CC impart on soil properties are well known and have been widely studied in certain areas of the United States (Dabney et al., 2001; NRCS-USDA, 2016; NRCS-USDA, 2018; Blanco-Canqui and Ruis, 2020). However, due to the dynamic nature of soil processes and the inherent variability of soil hydraulic processes, the magnitude of and length of time before soil enhancements are realized can be region-specific.

Cover crops benefit soil properties in many ways, including through nutrient retention and soil organic matter (SOM) additions. By utilizing excess nutrients not taken up by the preceding cash crop, CC keep nutrients in place (Dabney et al., 2001), while leguminous CC can provide additional nitrogen (N) into soil via fixation, lowering fertilizer demands (McVay et al., 1989; Roberts et al., 2018). Additionally, decomposing above- and belowground biomass act as natural organic soil amendments (Blanco and Lal, 2008). Aboveground plant biomass and residues provide soil cover that protects topsoil from the erosive forces of water and wind (Blanco and Lal, 2008; Blanco-Canqui et al., 2013; Marzen et al., 2016). Furthermore, belowground roots (i.e., living and decomposing roots) provide increased pathways for infiltrating water and access to the deeper soil profile to increase water storage capacity. Plant root additions from CC also promote greater soil microbial diversity and abundance and mycorrhizal fungi excretions (Locke et al., 2012). When SOM (Six et al., 2000) and fungi excretions in the soil increase, soil aggregation is enhanced. Soil aggregation promotes water infiltration and gas exchange by maintaining conductive pore space at the surface for water to enter rather than remaining at the surface to potentially run off. Aggregation is especially important for loessial and alluvial soils that are particularly prone to erosion due to the dominantly fine particle-size distributions.

Despite well-documented benefits, CC use in the Lower Mississippi River Valley (LMRV) region of eastern Arkansas remains low and under-studied (Kroger et al., 2012), with only approximately 5% of farmland under CC (USDA-NASS, 2017). The LMRV is an area historically dominated by intensive cultivated agriculture, with soils prone to erosion. Given that CC impacts can be site-specific (Blanco-Canqui and Ruis, 2020), it is important to document CC benefits to soil health and crop production within specific regions. Consequently, this study was conducted to fill a research gap within the LMRV region of eastern Arkansas. The objective of this study was to evaluate

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the effects of CC treatment [i.e., CC and non-cover crop (NCC)] on near-surface soil physical and chemical properties in loessial and alluvial soils under cultivated agriculture in the LMRV in eastern Arkansas. It was hypothesized that the extractable soil nutrient concentrations would be greater in the CC compared to the NCC treatment. However, salt concentrations (i.e., Ca, Mg, Na) were expected to be greater in the NCC compared to the CC treatment due to the lack of canopy cover in the NCC treatment that contributes to increased evaporation, which, in turn, causes near-surface salt accumulation. Total carbon (TC) and SOM concentrations were hypothesized to be greater in the CC compared to the NCC treatment due to CC above- and belowground biomass additions.

Procedures

Site Descriptions

Research was conducted between May 2018 and May 2019 across four LMRV locations that had varying crop-CC and crop-NCC combinations (Table 1). Sampling locations were in Cotton Plant, Marianna, Helena, and Dumas in eastern Arkansas (Fig. 1). Three locations were privately owned land (i.e., Cotton Plant, Dumas, and Helena), while one location had two separate research studies at an agricultural research station (i.e., Marianna).

Research was conducted at the Chappell location, near Cotton Plant, Ark., (35°0'52.61" N, 91°13'30.01" W) in late May 2018 on a Mississippi River terrace on a Teksob loam soil (Fine-loamy, mixed, active, thermic Typic Hapludalf; SSS-USDA-NRCS, 2019) in three adjacent fields. In two fields, the agroecosystems consisted of drill-seeded, dryland soybean (*Glycine max*) with 7.5-in. (19-cm) row spacing under no-tillage management, with one field in switchgrass (*Panicum virgatum*) as the CC and the second without a CC. Both fields were in corn (*Zea mays*) the previous year. The third field consisted of a cultivated, twin-row, furrow-irrigated soybean agroecosystem with 30-in. (76-cm) row-spaced, raised beds, where tillage occurred in Fall 2017, with cereal rye (*Secale cereale*) as the CC in year one.

Research was conducted at the Taylor location, near Helena, Ark., in late May 2018 in four fields in the Mississippi River floodplain. One area (34°29'52.40" N, 90°37'42.49" W) consisted of two adjacent fields on a Henry silt loam soil (Coarse-silty, mixed, active, thermic Typic Fragiaqualf; SSS-USDA-NRCS, 2013b). One field consisted of non-land-leveled, non-bedded, conventionally tilled, and irrigated soybean with 30-in. (76-cm) row spacing with NCC, while the adjacent field was non-land-leveled, bedded, conventionally tilled, furrow-irrigated soybean with 30-in. (76-cm) row spacing with cereal rye planted annually since the mid-1990s. Both fields had soybean grown the previous year. The third and fourth areas were on opposite ends of the same field (34°28'58.24" N, 90°37'58.78" W) on a Commerce silt loam soil (Fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquept; SSS-USDA-NRCS, 2013a) cropped to a furrow-irrigated, conventionally tilled, corn-soybean rotation, with corn planted on raised beds with 30-in. (76-cm) row spacing in 2018, with cereal rye and turnip (*Brassica rapa*) as the CC mix.

Research was conducted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS), near Marianna, Ark., in late November 2018 in two fields. One field (34°43'46.72" N, 90°44'39.58" W) on a Memphis silt loam soil (Fine-silty, mixed, active, thermic Typic Hapludalf; SSS-USDA-NRCS, 2018b), contained a multi-year, small-plot, furrow-irrigated soybean research study (LMCRS-1) with multiple CC treatments, including hairy vetch (*Vicia* sp.) and canola (*Brassica napus* cv. 'Coahoma') since 2015, cereal rye since Fall 2017, and a NCC fallow treatment, which was lightly disked each spring prior to soybean planting (Dr. John Rupe, pers. comm., 18 July 2020). The study area was conventionally tilled prior to raised bed and CC establishment in 2015, with soybean and CC drill-seeded without tillage annually thereafter with 38-in. (96.5-cm) bed spacing (Dr. John Rupe, pers. comm., 18 July 2020). The second field (34°43'37.43" N, 90°45'28.46" W), on a Calloway silt loam soil (Fine-silty, mixed, active, thermic Aquic Fraglossudalf; SSS-USDA-NRCS, 2018a), contained another research study (LMCRS-2), but with cotton (*Gossypium hirsutum*; Smartt et al., 2020) on raised beds with 38-in. (96.5-cm) row spacing, with and without cereal rye as a CC treatment (Slaton et al., 2018). Conventionally tilled, furrow-irrigated corn was cropped to the second field during the previous year (Slaton et al., 2018).

Research was conducted at the Stevens location, near Dumas, Ark., in late May 2019 in three fields on a Hebert silt loam soil (Fine-silty, mixed, active, thermic Aeric Epiaqualf; SSS-USDA-NRCS, 2002). One field (33°49'15.77" N, 91°20'28.16" W) was cropped to wide-row, furrow-irrigated cotton on raised beds, with 38-in. (97.3-cm) row spacing and 24-in. (60-cm) furrow widths, with one area with a cereal rye CC for the previous five years and cotton planted as no-tillage and an adjacent area without a CC treatment and cotton planted after minimum tillage. A second field (33°49'24.87" N, 91°19'56.08" W) was cropped with minimally tilled, furrow-irrigated cotton on narrow-spaced [38-in. (96.5-cm) row spacing with 24-in. (60-cm) furrow widths], raised beds with one area with two years of a cereal rye CC, and an adjacent area without a CC treatment. Additional details regarding management practices of these two fields are described in Daniels et al. (2019). The third field (33°48'56.89" N, 91°18'58.24" W) consisted of non-tilled, drill-seeded, twin-row, dryland soybean, with 30-in. (76.2-cm) furrow widths, with two years of cereal rye as the CC.

Across all locations where CC were present, the CC were chemically terminated prior to planting the summer cash crop, with one exception. The LMCRS multi-year soybean study with multiple CC treatments had the CC incorporated by disking several weeks prior to planting (Dr. John Rupe, pers. comm., 18 July 2020).

A total of 18 agroecosystems, 12 with CC and six without CC, were sampled from four locations. Among all agroecosystems, a total of 33 individual measurement and soil sample locations existed with a history of cover cropping with a variety of species and for various durations, while a total of 21 individual locations existed without CC.

Across the four locations included in this field study, the regional, 30-year mean monthly air temperature (1991 to 2020) ranged from 61 °F (16.1 °C) to 64 °F (17.8 °C; Table 2; NCEI-NOAA, 2021). The 30-year mean annual precipitation throughout the region ranged from 49.7 (126.3 cm) to 52.1 in (132.3 cm; Table 2; NCEI-NOAA, 2021).

Soil Sampling, Processing, and Analyses

Soil sampling was conducted at the four locations on five dates between late May 2018 and late May 2019 (Table 1). The same procedures were used at each location, with random sampling points chosen within each agroecosystem. A soil sample was collected from the top 4 in. (10 cm) and, if raised beds were present, from the top of the raised bed, using a slide hammer with a 1.9-in. (4.8-cm) diameter stainless-steel core. Soil samples were oven-dried at 158 °F (70 °C) for 48 hours, then pulverized and passed through a 0.08-in. (2-mm) sieve for modified, 12-hour-hydrometer-method particle-size (Gee and Or, 2002) and chemical analyses. Soil sampling and measurements were conducted in triplicate for each agroecosystem.

Total C and total N (TN) concentrations were determined by high-temperature combustion (Elementar VarioMAX Total C and N Analyzer, Elementar Americans Inc., Mt. Laurel, N.J.; Sikora and Moore, 2014). Soil organic matter concentrations were determined by weight-loss-on-ignition, combusting soil in a muffle furnace for 2 hours at 680 °F (360 °C; Sikora and Moore, 2014). All measured soil C was assumed to be organic C, as no soil effervesced when treated with dilute hydrochloric acid. Soil was extracted with Mehlich-3 extractant solution in a 1:10 (m/v) soil-to-solution ratio followed by analysis for extractable nutrient concentrations (i.e., P, K, Ca, Mg, S, Na, Fe, Mn, Zn, and Cu) using inductively coupled plasma-atomic emission spectrometry (ICP-AES; CIROS CCD model; Spectro Analytical Instruments, Mass.; Sikora and Moore, 2014).

Statistical Analyses

Based on a completely randomized experimental design and aggregating data across all sampled locations, a one-factor analysis of variance (ANOVA) was conducted using the GLIMMIX procedure in SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) to evaluate the effect of cover-crop treatment (CC and NCC) on near-surface soil physical and chemical properties. A gamma distribution was used for the Mehlich-3 extractable soil nutrient, TC, TN, and SOM concentrations. Significance was determined at $P \leq 0.05$. When appropriate, means were separated by the least significant difference at the 0.05 level.

Results and Discussion

Across the 18 agroecosystems (12 with CC and 6 with NCC treatments), sand, silt, and clay ranged from 10% to 62%, 32% to 84%, and 6% to 24%, respectively, and SOM concentrations ranged from 9.5 to 34.1 g/kg in the top 4 in. (10 cm; Lebeau, 2021). Additionally, soil pH and EC ranged from 5.3 to 7.8 and 81 to 284 µmhos/cm, respectively, while the soil BD ranged from 1.15 to 1.42 g/cm^3 in the top 4 in. (10 cm; Lebeau, 2021).

Across all agroecosystems in the LMRV, all measured near-surface soil physical and chemical properties in the top 4 in. (10 cm) were unaffected ($P > 0.05$) by cover-crop treatment (Table 3). Uptake and storage in CC biomass could have been responsible for the soil extractable nutrient concentrations in the CC treatment, where the nutrients are tied up in the CC residue and have yet to cycle back into the soil, while erosion from the bare soil surface could have contributed to the NCC treatment soil extractable nutrient concentrations. Table 3 summarizes the overall means for soil extractable nutrient concentrations (P, K, Ca, Mg, S, Na, Fe, Mn, Zn, and Cu) and TC, TN, and SOM concentrations.

Similarly, SOM and soil extractable nutrients (i.e., Ca, Mg, and Na) did not differ by CC treatment in a recent LMRV CC-aggregate stability study in loessial, silt-loam soils under various cotton-, corn-, and soybean-NCC and short-term (< 24 months) CC treatment combinations (i.e., cotton-rye, corn-rye, black oat (*Avena strigosa*), crimson clover (*Trifolium incarnatum*), and winter pea (*Pisum sativum*)/soybean-rye, oat, clover, and pea, soybean-rye, oat, and clover; Arel et al., 2022). Villamil et al. (2006) reported no difference in TN but greater SOM increases within the entire 12-in. (30-cm)-depth of corn-rye/soybean-vetch and corn-rye/soybean-vetch and rye CC rotations compared to corn-rye/soybean-rye and corn/soybean.

Conversely, a long-term cotton-CC study on a western Tennessee silt-loam soil reported 1.3 times greater SOM in the top 4 in. (10 cm) after 17 years in rye-vetch-CC treatment compared to NCC (Keisling et al., 1994). Additionally, TC concentration was 1.3 times greater in the top 0.8 in. (2 cm) in a west-central Mississippi silt-loam soil under 6 years of CC rotations (i.e., cotton-balansa clover (*Trifolium michelianum* Savi) and cotton-rye) compared to NCC (Locke et al., 2012). Sanchez et al. (2019) also reported SOM and TC concentration increases under three years of CC in a northeastern Louisiana silt-loam soil. In the conservation-tillage corn production study, SOM and TC concentration in the top 4 in. (10 cm) increased 1.2 and 1.4 times, respectively, under various CC (i.e., rye, radish (*Raphanus sativus*), berseem clover (*Trifolium alexandrinum*), crimson clover, winter pea, vetch, and rye-radish mix) compared to NCC (Sanchez et al., 2019).

The large number of soil properties that did not differ between CC treatments was likely due to the variation in background management practices, the variation in CC species and cash crop species, and the variation in CC duration, which ranged from less than one year to greater than 19 years. With continued management under CC, the soil properties in the top 4 in. (10 cm) measured in the current study may continue to deviate between CC treatments so that significant differences may be identified at some time in the future.

Practical Applications

Identifying the specific improvements that CC can impart on the near-surface soil properties in the LMRV will allow producers to make informed decisions about utilizing CC to contribute to overall soil health in the LMRV region of eastern Arkansas. While the parameters in this study were not significantly affected by CC treatment, the parameter numeric differences, given more time and based on previous CC study results (Keisling et al., 1994; Villamil et al., 2006; Locke et al., 2012; Sanchez et al. 2019), would be expected to continue to deviate over time to the point where differences would eventually become significant. Getting to the point of measurable significant differences will require more long-term, in-situ studies throughout the LMRV region that sample single agroecosystems multiple times throughout each year and over several years to decades. Comparing single agroecosystem results to itself and comparing long-term agroecosystem data to each other will allow for improved evaluations of differences and trends imparted on soil properties in the top 4 in. (10 cm) by CC treatment.

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Table 1. Summary of treatments (Trt), specific location names, sampling dates, agroecosystem descriptions for each sample location, duration (dur.) of the cover crop in years, soil parent material (PM), mapped soil series with taxonomic descriptions, location elevations (Elev.), and location slope.

Trt[†]	Location[‡]	Sample date	Agroecosystem description	CC dur. (year)	PM[§]	Soil series (Description)	Elev. (ft)	Slope
CC	Chappell	5-29-18	Soybean w/ switchgrass CC	3	A	Teksob loam (Typic Hapludalf)	192	<1%
		5-29-18	Soybean w/ cereal rye CC	1			192	<1%
	Taylor	5-28-18	Soybean w/ cereal rye CC	>19	L	Henry silt loam (Typic Fragiaqualf)	182	<1%
		5-28-18	Soybean-corn rotation w/ cereal rye and turnip CC	<1	A	Commerce silt loam (Fluvaquentic Endoaquept)	185	<1%
		5-28-18	Soybean-corn rotation w/ cereal rye and turnip CC	<1			185	<1%
	LMCRS-1	11-28-18	Soybean w/ cereal rye CC	1	L	Memphis silt loam (Typic Hapludalf)	212	<1%
		11-28-18	Soybean w/ hairy vetch CC	3			212	<1%
		11-28-18	Soybean w/ canola CC	3			212	<1%
	LMCRS-2	11-28-18	Cotton w/ cereal rye CC	1	L	Calloway silt loam (Aquic Fraglossudalf)	226	<1%
	Stevens	5-28-19	Cotton w/ cereal rye CC	5	A	Hebert silt loam (Aeric Epiaqualf)	157	<1%
		5-29-19	Cotton w/ cereal rye CC	2			156	<1%
		5-28-19	Soybean w/ cereal rye CC	2			154	<1%
NCC	Chappell	5-29-18	Soybean	-	A	Teksob loam (Typic Hapludalf)	187	<1%
	Taylor	5-28-18	Soybean	-	L	Henry silt loam (Typic Fragiaqualf)	182	<1%
	LMCRS-1	11-28-18	Soybean-fallow	-	L	Memphis silt loam (Typic Hapludalf)	212	<1%
	LMCRS-2	11-28-18	Cotton	-	L	Calloway silt loam (Aquic Fraglossudalf)	226	<1%
	Stevens	5-28-19	Cotton	-	A	Hebert silt loam (Aeric Epiaqualf)	157	<1%
		5-29-19	Cotton	-			156	<1%

[†] CC = Cover crop; NCC = No cover crop.

[‡] LMCRS = Lon Mann Cotton Research Station.

[§] A = Alluvium; L = Loess.

Table 2. Summary of the 30-year (1991–2020) mean annual precipitation, mean annual snow, mean monthly air temperature, and minimum and maximum air temperatures at each study location (NOAA-NCEI, 2021).

Location name[†]	Mean Annual precipitation	Mean Annual snow	Mean Monthly temperature	Minimum temperature	Maximum temperature
	------------in.--------------		-----------------------------°F-----------------------------		
Chappell	51.2	2.7	61	51.3	70.7
Taylor	49.7	0.3	62.2	52.5	71.8
LMCRS-1	52.1	1.3	62.1	52.3	72
LMCRS-2	52.1	1.3	62.1	52.3	72
Stevens	51.2	0.7	64	53.8	74.3

[†] LMCRS = Lon Mann Cotton Research Station.

Table 3. Summary of the effect of treatment (cover crop and no cover crop) on Mehlich-3 extractable soil nutrient (P, K, Ca, Mg, S, Na, Fe, Mn, Zn, and Cu) concentrations and mean soil physical properties in the top 4 in. (10 cm) across 18 agroecosystems in eastern Arkansas.

Soil property	*P*	Cover crop	No cover crop	Overall mean
P (ppm)	0.47	62.5 a[†]	50.9 a	56.7
K (ppm)	0.89	175.1 a	171.2 a	173.2
Ca (ppm)	0.19	1398.0 a	1552.0 a	1475
Mg (ppm)	0.87	295.9 a	303.4 a	299.6
S (ppm)	0.67	10.4 a	10.9 a	10.6
Na (ppm)	0.05	17.4 a	24.6 a	21.0
Fe (ppm)	0.85	244.1 a	239.3 a	241.7
Mn (ppm)	0.10	171.1 a	135.5 a	153.3
Zn (ppm)	0.15	5.5 a	2.2 a	3.9
Cu (ppm)	0.42	1.7 a	1.5 a	1.6
Total carbon (g/kg)	0.48	9.3 a	8.5 a	8.9
Total nitrogen (g/kg)	0.62	0.9 a	0.9 a	0.9
SOM[‡] (g/kg)	0.88	19.8 a	19.6 a	19.7

[†] Different letters following means within a row are different at $P \leq 0.05$.

[‡] SOM = Soil organic matter.

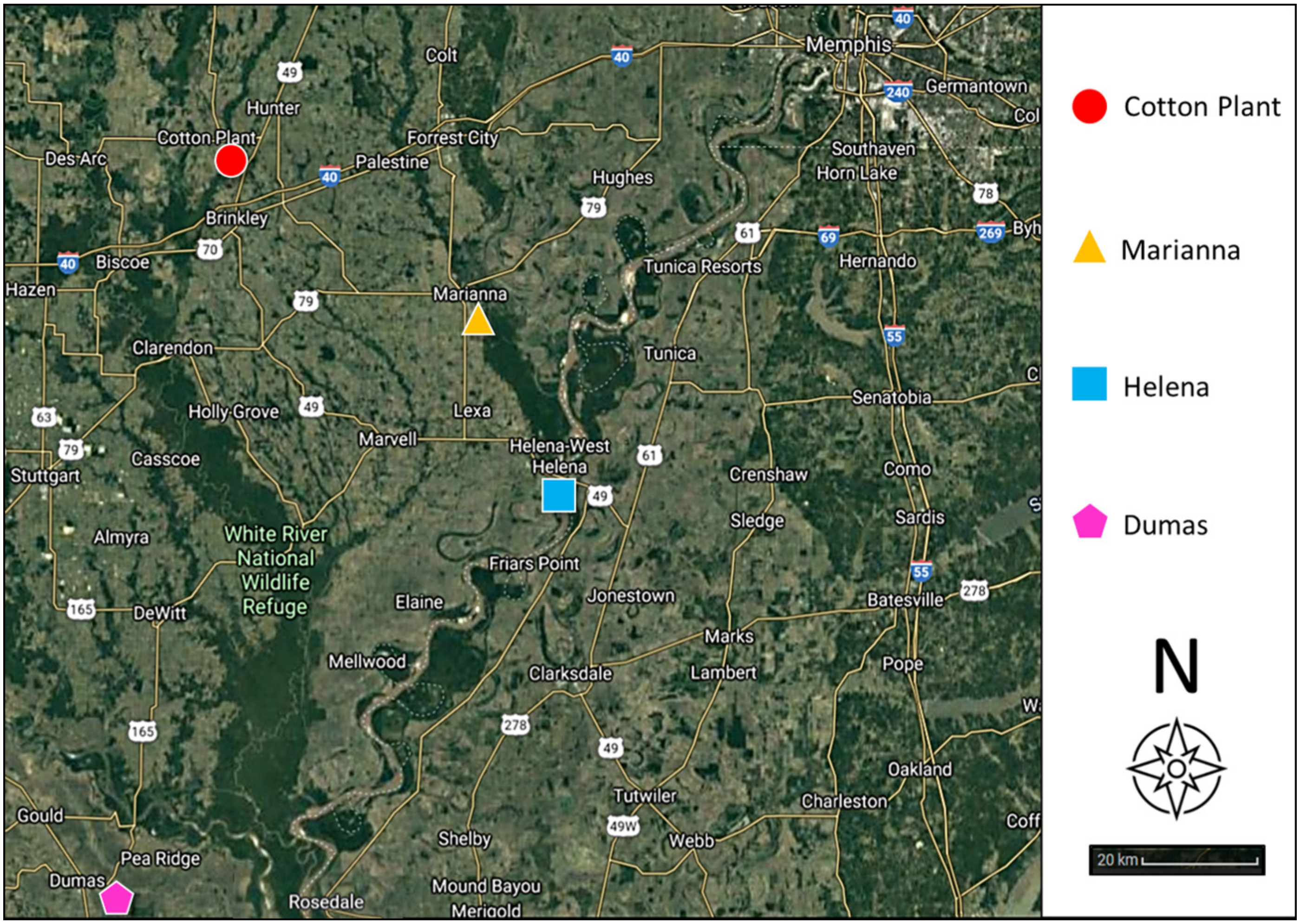

Fig. 1. Locations of sample areas west of the Mississippi River in the Lower Mississippi River Valley delta region of eastern Arkansas (Google Maps, 2020).

Microdialysis: An Emerging Method to Continuously Sample Soil Nitrogen

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Abstract

The application of microdialysis, a small-scale sampling technique that functions on a principle similar to the medical procedure of kidney dialysis, is an emerging approach to continuously sample nitrogen (N) movement within the soil profile. Current soil sampling methods rely on the destruction of soil structure during the physical removal of soil from the study site and can also introduce a considerable time lag between the multiple steps of laboratory analysis. Microdialysis probes can be implanted into the soil and left in place, giving this method the capability to provide information on a highly resolved temporal and spatial scale. The sample collected, called dialysate, can be analyzed directly in the lab and does not have to undergo any further processing, decreasing sample turnaround times, resources, and work hours needed to analyze soil samples for N. Past research has also revealed that nutrient data obtained by microdialysis also may be more representative of the forms and amounts of N that are plant- and microbe-available since the technique samples the region of the soil where bioavailable nutrients lie—the soil solution—rather than pulling nutrients bound to soil particles. In this study, the microdialysis technique was employed in a grassland established with two different types of plant communities to determine if the approach could successfully be used to monitor and differentiate N movement under field conditions. The results of this 5-day study demonstrate that microdialysis does generate distinct data from the two plant communities and also reveals the underlying heterogeneity in soil microsites.

Introduction

Microdialysis is a sampling technique based on diffusion that has been used in biomedical research for the past four decades (Duo et al., 2006; Kehr, 1993; Stenken, 2006). This method is similar to the well-known kidney dialysis procedure that relies on pumping fluids through tubing and a filter for delivery and collection of compounds. As the name suggests, microdialysis functions on a much smaller scale due to its miniature size, making it ideal for sampling soil in a minimally invasive manner at the scale relevant to where reactions occur.

The microdialysis apparatus consists of three components: the microdialysis probe, syringe pump, and pump controller (Fig. 1). The microdialysis probe is the component that interacts with the sampling site for diffusion-based sampling; the probe is implanted in the location of interest and can remain for the duration of experimentation time, making in situ (or in-place), real-time, continuous monitoring possible. Each probe contains an inlet tube, a semipermeable membrane, and an outlet tube (Fig. 2). Fluid, which resembles the chemical composition of the soil water in the sampling area, is delivered through the inlet tube. This fluid is termed perfusate. The perfusate travels from the inlet to the probe membrane, which consists of two cylinders nested in one another. As the perfusate flows from the inner cylinder into the outer cylinder, this flow generates a concentration gradient between the inside of the probe and the surface of the probe. Since the outside of the microdialysis probe is coated in a semipermeable membrane, the formation of this concentration gradient allows for the diffusion of compounds into the probe through the pores of the membrane. With the perfusate continuously flowing, the compounds that diffused into the probe are carried through the probe and out through the outlet tube. This fluid termed the dialysate, can then be collected and further analyzed. The pump, which houses syringes that are filled with the perfusate, dispenses the perfusate at a specified flow rate. The pump controller gives the user the ability to control the flow rate.

Recently, the microdialysis technique has shown utility in the field of soil science (Inselsbacher et al., 2011; Maddala et al., 2020; Maddala et al., 2021). More specifically, researchers have discovered that microdialysis has the ability to provide data on the movement of nutrients such as nitrogen (N) in soil microsites with high spatial and temporal resolutions (Brackin et al., 2015). In contrast to the current methods of soil sampling that physically remove soil, destroy the structure, and lose representativeness of innate processes, microdialysis provides in situ, real-time data on the movement of nutrient movement in soil solution while staying in the soil profile.

Due to the presence of the semipermeable membrane in the microdialysis probe, only compounds within a specified size range (as dictated by the molecular weight cut-off (MWCO) value of the probe) can diffuse into the probe, limiting the migration of soil into the dialysate samples collected. An advantage of sampling soil solution with this approach is that dialysates collected do not need to have soil particles removed, and analysis can occur immediately upon collection. The other advantage of sampling soil solution is that microdialysis provides information on the actual movement (fluxes) of N in the soil profile, distinguishing it from current extraction-based methods for determining plant-available N, which typically are expressed in terms of soil concentrations and can "blur" the heterogeneity present in microsites (Inselsbacher et al., 2014; Mulvaney, 1996; Oyewole et al., 2014). Mechanistically, microdialysis mimics a plant root and can provide data on mobility and turnover rates (Brackin et al., 2017).

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In this study, microdialysis probes were implanted in field plots established in two plant communities to determine if the emerging technique could successfully be used to monitor and differentiate N fluxes under field conditions.

Procedures

Site Description

Field experimentation was conducted at the University of Arkansas Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark., USA (36°05'30.6" N 94°11'19.0" W). The two locations included grassland plots growing, respectively, native, perennial, warm-season grasses {big bluestem [*Andropogon gerardii* Vitman], little bluestem [*Schizachyrium scoparium* (Michx.) Nash], and Indiangrass [*Sorghastrum nutans* (L.) Nash]} or an introduced species, perennial, cool-season grass [orchardgrass (*Dactylis glomerata* L.)]. The soil from both the orchardgrass and native grass sites is classified as a Captina silt loam (fine-silty, siliceous, active, mesic Typic Fragiudults) (Sauer et al., 2015; https://websoilsurvey.sc.egov.usda.gov).

Microdialysis Apparatus

The microdialysis system was set up according to Maddala et al. (2020, 2021) and adapted from Inselsbacher et al. (2011). Syringe pumps (MD-1001, BASi, Lafayette, IN) were equipped with a total of 24 gas-tight syringes (MDN-0250, 2.5 mL, BASi) that delivered MilliQ water at a flow rate of 2.0 µL/min. Each syringe was connected to a CMA 20 Elite probe (CMA8010436, membrane length of 10 mm, PAES membrane, and 20 kDa molecular weight cut-off, Harvard Apparatus, Holliston, MA). The equilibration time used at the beginning of every sampling was 15 min. All the probes were calibrated by placing them into a solution comprised of 10 µg/mL nitrate-N and 10 µg/mL ammonium-N with stirring (Maddala et al., 2020).

Field Study

Twelve plots were established in each of the two grass systems on 4 June 2021 with dimensions of 4.10 by 4.10 ft^2. One microdialysis probe was implanted in the center of each plot to a depth of 4.72 in. (distance of 5.18 ft between probes). Upon probe implantation, dialysates were collected in the morning around sunrise for 90 min daily on ice for 5 consecutive days. Hourly precipitation and air temperature data were obtained from the USDA weather station located approximately 66 ft away from the plots.

Chemical Analysis of Dialysates

Nitrate-N in microdialysis samples was analyzed using the Griess reaction based on the technique described by Miranda et al. (2001). Ammonium-N in the dialysate samples was analyzed using a microplate adaptation of the indophenol Berthelot reaction described by Baethgen and Alley (1989). Absorbance values were measured using a SpectraMax iD3 Multi-Mode Microplate Reader (Molecular Devices, LLC, San Jose, Calif.) at 540 nm and 650 nm for the Griess and indophenol Berthelot reactions, respectively.

Statistical Analyses

Statistical analyses on microdialysis fluxes were performed by a two-way repeated measures analysis of variance followed by a Bonferroni test as a post-hoc test. All statistical analyses were performed using a 95% confidence interval; differences were considered significant at $P \leq 0.05$.

Results and Discussion

Over the 5-day sampling period, nitrate-N flux increased significantly between June 5 and June 9 in both the native and orchardgrass soil (Fig. 3; $P \leq 0.05$). Furthermore, nitrate-N flux was greater in the native soil compared to the orchardgrass soil on June 6 ($P = 0.023$). Ammonium-N fluxes did not differ significantly over time or between the two soils (Fig. 4; $P > 0.05$).

The results of this study indicated that microdialysis is capable of yielding data on the movement of nitrate-N within the profile of soils growing differing plant communities. While most ammonium-N fluxes were below detection limits, decreased movement of ammonium-N in soil solution can be expected due to the affinity of positively charged ammonium ions to bind to clay particles. Microdialysis-generated fluxes for nitrate and ammonium revealed the underlying heterogeneity in soil microsites. This ability to produce spatially resolved data, along with its ability to stay implanted and provide in situ data, offering a temporal component, distinguishes microdialysis from current methods for determining bioavailable N (Inselsbacher et al., 2014). The mechanistic data from microdialysis can be used to augment current N data resulting from traditional soil nutrient sampling methods such as salt or water extractions.

Practical Applications

Though microdialysis is designed to function in a sterile laboratory setting for biomedical research purposes, it has shown potential to be applied to field studies to monitor N fluxes (movement) in situ. Prolonged and extensive utilization of the microdialysis technique can be employed to monitor changes in fluxes, providing a more mechanistic understanding of N cycling in soil that would otherwise not be provided by bulk concentration data from traditional, destructive sampling methods. However, further applications of the microdialysis technique to the field setting will require collaborations to engineer a more robust design to make the method better adapted for long-term field deployment. Furthermore, analysis of detection limits and changes in efficiency as soil wets and dries will require further evaluation to understand and quantify the advantages and limitations of using microdialysis in sampling N moving in soil solution as compared to the presence of different concentrations of nitrate and ammonium that are extracted from bulk soil samples.

Acknowledgments

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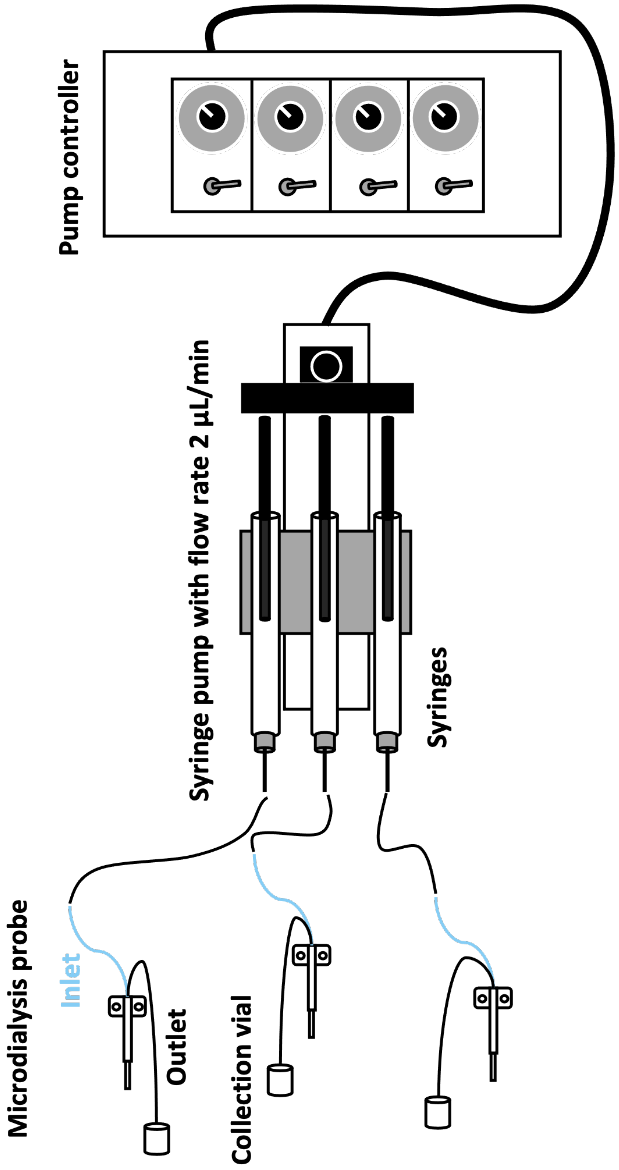

Fig. 1. The microdialysis apparatus consists of a pump controller that determines the flow rate of the perfusate, a syringe pump that houses three syringes and delivers the perfusate at the set flow rate, microdialysis probes that collect the targeted analyte, and collection vials.

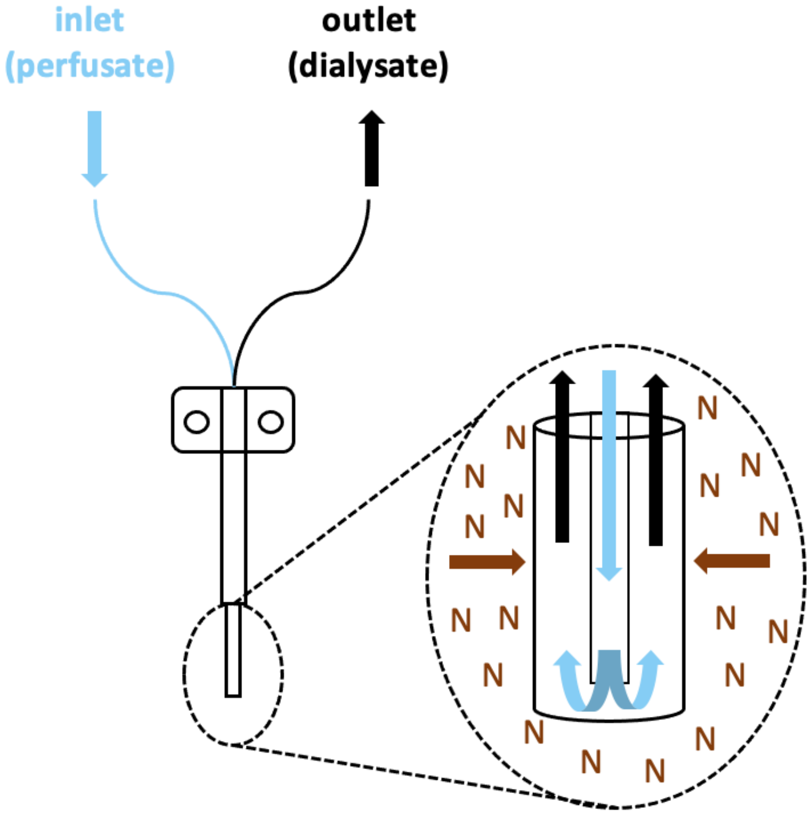

Fig. 2. An overview of the microdialysis probe. The perfusate travels through the inner cannula of the semipermeable membrane into the outer cannula. This flow of perfusate drives the diffusion of N in the surrounding soil water into the probe, which is then carried out through the outlet and is termed the dialysate.

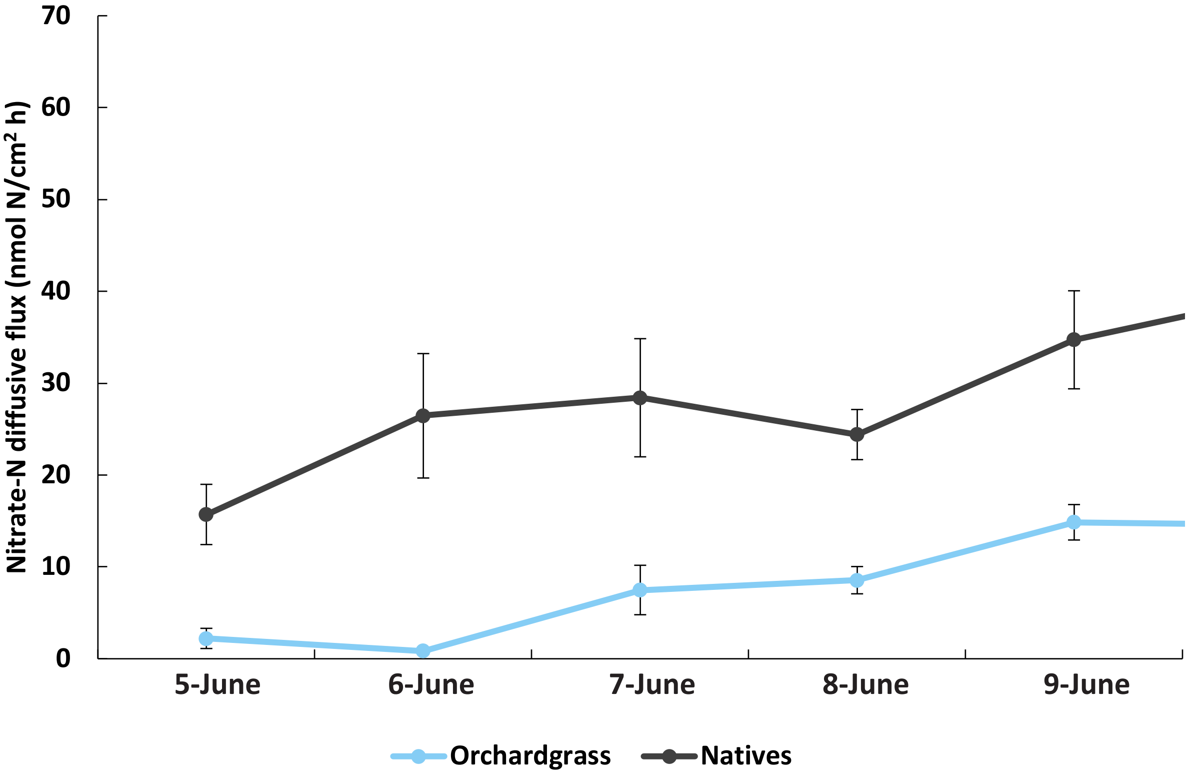

Fig. 3. Average nitrate-N fluxes (nmol N/cm^2 h) in the orchardgrass and native grasses over a 5-day span in the month of June (*n* = 12). Timepoints within a plant community labeled by a similar letter depict fluxes that are not significantly different ($P < 0.05$). Nitrate-N flux was also significantly different between the two plant communities on 6 June ($P = 0.023$).

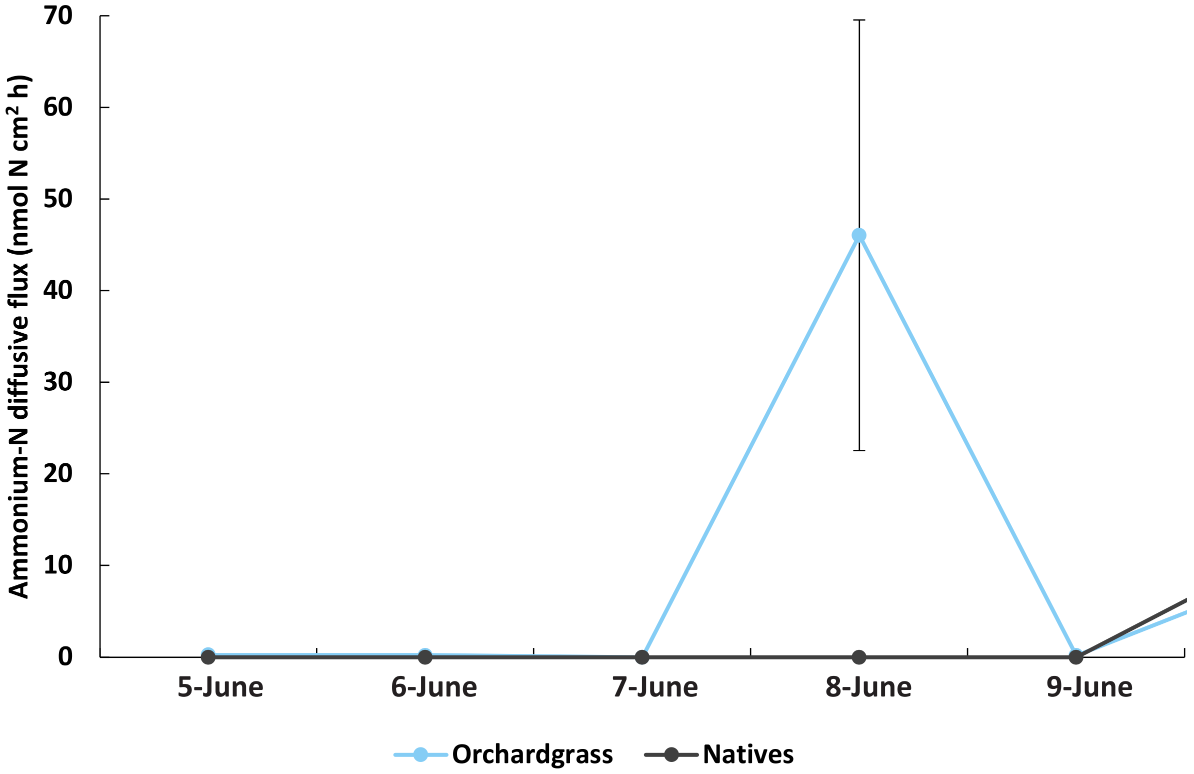

Fig. 4. Average ammonium-N fluxes (nmol N/cm^2 h) in the orchardgrass and native grasses (*n* = 12). Diffusive fluxes of ammonium were not different at any time point in either of the two plant communities (*P* = 0.286).

Soil Active Carbon as a Soil Health Indicator in Arkansas Discovery Farms

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Abstract

Agronomic practices such as cover cropping, conservation tillage, organic amendments, crop rotation, precision-grade land leveling, and forage diversity have an immense impact on soil's physical, chemical, and biological properties. The Arkansas Discovery Farms (ARDF) program evaluates conservation practice (CP) effectiveness by utilizing partnerships with the row crop and livestock producers across Arkansas. Some of the CPs implemented on ARDFs have the potential to improve soil biological properties. One of the useful tools to assess the degree of biological activities in the soil is measuring active carbon (C). It is a readily accessible C energy source for the soil microbial populations and generally responds quickly in response to changes in agronomic management. Therefore, the objective of this study was to measure active C, also known as permanganate-oxidizable C (POxC), of field soil collected from 3 pastures in northwestern and 3 row-crop fields in southeastern Arkansas. This report summarizes data through the first year of the 3-year project. The outcome of this research aims to identify site-specific and appropriate standard values of soil health biological indicators based on the agronomic practices adopted by Arkansas farmers.

Introduction

Soil health management is important to improve crop productivity, increase soil fertility, conserve biodiversity, mitigate environmental pollution, and reduce agronomic inputs (Doran, 2002; Lehmann et al., 2020). Several physical, chemical, and biological parameters are used to quantify on-farm soil health, and soil active carbon (C) is an important biological soil health parameter. Soil active C is a readily available portion of the total organic C pool that is easily accessible for microbial decomposition (Liptzin et al., 2022; Weil et al., 2003). Changes in soil active C have been linked to several soil biological processes, including microbial biomass growth and activity and soil nutrient cycling (Weil et al., 2003). Thus, measuring active C in soil could be a practical tool to assess soil health in agriculture.

One of the rapid methods to measure active C in soil is the permanganate-oxidizable C (POxC) method. Permanganate-oxidizable C is sensitive to changes in management practices; the method is rapid and inexpensive to conduct in the lab (Culman et al., 2012; Jagadamma et al., 2019). The Arkansas Discovery Farms (ARDF) program studies the efficacy of various conservation practices (CP) adopted by row crop farmers and livestock producers across Arkansas in improving soil health. The aim of this project is to assess soil active C or POxC on 3 livestock farms in northwest Arkansas, and 2 row-crop farms and 1 recently land-leveled rice (*Oryza sativa*) farm in the Arkansas Delta. Producers have adopted different CPs to improve environmental sustainability and farm profitability. Inferences made based on POxC data may help evaluate how a soil management practice affects soil C and, therefore, soil health.

Procedures

The ARDF program currently has 15 partnering farms across Arkansas, of which active C content data are reported from six farms. Soil was sampled with soil probes (0.982-in. diameter) between October 2021 and January 2022 to 0-to-4 and 4-to-8 in. depths for northwest Arkansas pastures and the 0–to-6 and 6-to-12 in. depths for the 2 row-crop farms, and 0-to-6 in. depth for the recently land-leveled rice farm. Fresh soil samples were ground and sieved (2-mm mesh), followed by air-drying and storage in airtight plastic bags prior to determining POxC as described by Weil et al. (2003).

The Marley farm (Marley 1, 2, and 3) is a poultry and cattle farm located in the Beaver Lake-Upper White River Watershed (Washington County). Soil samples for POxC were taken from 10 randomly selected points from each of the 3 pastures. Marley 3 pasture is primarily used for cattle grazing. Marley 1 and Marley 2 pastures act as grassed waterways or nutrient buffer strips behind 6 poultry houses. The grass waterways pastures have a mix of warm-season grasses, for instance, crabgrass (*Digitaria*), Johnson grass (*Sorghum halepense*), and bermudagrass (*Cynodon dactylon*), and cool-season grasses such as tall fescue (*Festuca arundinacea*) and annual ryegrass (*Lolium multiflorum*). Each year, poultry litter is removed from the poultry houses and applied to the pastures.

The Morrow farm is in Washington County in the Illinois River Watershed. This farm has cattle and sheep grazing pasture. On this farm, we have 12 plots (1 ac each) in a 40-ac pasture with 3 treatments, and treatments are arranged in a completely randomized block design with 4 replications. The treatments are cover crop mixtures (20 different cover crops) planted by broadcasting (BCC), by drilling (DCC), and a control with no cover crop planted (NCC). Soil samples for active C were collected from 5 randomly generated points from each 1-ac plot.

The final northwest Arkansas farm is the Haak Dairy in Benton County, which has a wastewater treatment system with underground pumping capabilities and a grassed walkway established between the grazing pastures and milking parlor. Soil

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samples were collected from 8 soil sampling transects (Transects 1 to 8), each containing 3 sampling points. On this farm, the cattle loafing/pre-milking parlor area is between Transect 3 and 4, and a nutrient retention pond is near the end of the farm area near Transect 8 (Burke et al., 2022).

The Long Lake Plantation (LLP) is in the Lower White watershed in Phillips County in eastern Arkansas. The major crops grown on this farm are corn (*Zea mays* L.), cotton (*Gossypium hirsutum*), soybean (*Glycine max*), and peanuts (*Arachis hypogaea*) with cover crops. On this farm, 4 fields were sampled: LLP1 acts as a control with no poultry litter application but does grow a cover crop, and LLP2 receives annual poultry litter and a cover crop mix consisting of cereal rye (*Secale cereale*) and radish (*Raphanus sativus*) as a treatment. Both LLP1 and LLP2 fields are cropped to a cotton-soybean rotation. The remaining 2 fields are soil health demonstration plots: LLP3 field is a control with no cover crop and receives no poultry litter, and LLP4 grows cover crops such as black oats (*Avena strigose*) and mustard (*Brassica juncea*) but does not receive poultry litter. Both LLP3 and LLP4 fields are managed with soybean-peanut rotation. We collected soil samples from 16 randomly selected points from each field. All fields have reduced tillage as a CP.

The second row-crop farm is in the Bayou Meto Watershed in Arkansas County, near Stuttgart, Arkansas, and is managed with rice, soybean, and corn rotations. Two soybean fields (STG 2 and 4) and 1 corn field (STG 3) were sampled for POxC after the crops were harvested. The CPs in this farm are variable rate fertilizer application and precision-grade land-leveling with a gradual slope.

The final row crop is a land-leveled rice farm (land-leveled in the Fall of 2021) in the White River watershed in Jackson County just west of Newport, Ark. Three fields were sampled from this farm: north field (furrow-irrigated rice), central and south fields (flooded rice) receiving 2, 3 and 4 ton/ac of poultry litter, respectively. The control plot is an area of 200 ft by 100 ft within the north field with no poultry litter application.

One-way analysis of variance with JMP PRO 16 software (SAS Institute, 2013) was used to determine differences between pastures (Marley farm), cover crop treatments (Morrow farm), transects (Haak Dairy farm), and fields (Long Lake Plantation, Stuttgart, and land-leveled rice farm) in soil POxC ($P < 0.05$), with each depth analyzed independently. Comparisons among multiple means of different POxC content were done with Tukey's honestly significant difference ($P < 0.05$).

Results and Discussion

Northwest Arkansas Discovery Farms

The POxC was significantly greater at both 0- to 4- and 4 to 8-in. depths for Marley 3 (1067 ppm and 565 ppm, respectively) compared to both Marley 1 (742 ppm and 390 ppm, respectively) and Marley 2 (720 ppm and 428 ppm, respectively; Fig. 1A and 1B). The significantly lower POxC content in Marley 1 and 2 pastures compared to Marley 3 for each depth may be attributed to two factors. Marley 1 and 2 are not grazed with cattle, and forage biomass is removed regularly for hay. Marley 3 is a grazing pasture that receives nutrients from cattle manure and poultry litter application. Moreover, Marley 3 and the rest of the pastures are separated by a pond that acts as a nutrient catchment area. The general direction of runoff from the pond is toward the Marley 3 field, which may have contributed to the increased POxC.

At the Morrow Farm, POxC in the 0 to 4-in. depth was significantly greater for BCC (1015 ppm) compared to DCC (836 ppm) but not compared to NCC (899 ppm; Fig. 2A). For the 4- to 8-in. soil depth, BCC (1065 ppm) had significantly greater POxC than both DCC (425 ppm) and NCC (499 ppm; Fig. 2B). The greater POxC in BCC might be explained by significantly more forage yield (fresh biomass weight was collected 3 days prior to soil sampling, $P < 0.10$, unpublished data) compared to the other two treatments. Another possible explanation for increased POxC could be the competition among forage species in the different treatments. In the BCC treatment, the dominant forage species was annual ryegrass (*Lolium multiflorum*), which may have contributed to the larger below-ground POxC concentration.

For the Haak dairy farm, from Transect 1 to Transect 8, POxC ranged from 603 ppm to 988 ppm at the 0- to 4-in. depth (Fig. 3). The numerically greatest POxC was measured at Transect 6 (988 ppm) at 0- to 4-in. which was 460 ft away from the manure separation system. Transect 4 had the numerically lowest POxC both compared to other Transects at 0- to 4-in. depth. This Transect is located under the cattle loafing/pre-milking parlor area and does not have vegetation. Frequent cattle movement may have led to compaction at the 0- to 4-in. depth leading to a numerically greater bulk density at this Transect (1.16 g/cm^3 average bulk density at Transect 4) compared to the remaining Transects at the 0- to 4-in. depth, and POxC is expected to have an inverse relationship with bulk density (Dahal et al., 2021). For 4- to 8-in. depth, the POxC ranged from 404 ppm to 685 ppm (data not shown). There was no statistically significant difference in POxC among the transects for the 4- to 8-in. depth.

Arkansas Delta Discovery Farms

For the Long Lake farm, LLP2 (737 ppm) had significantly greater POxC compared to LLP1 (644 ppm) for the 0- to 6-in. depth (Fig. 4A). In addition to cover crops, LLP2 field receives poultry litter application; thus, in LLP2 soil is expected to contain more active C. No significant differences were measured between LLP1 and LLP2 at the deeper depth (Fig. 4B). The POxC concentrations measured in LLP4 were not statistically significant from the LLP3 (data not shown).

For the Stuttgart farm, significantly greater POxC concentrations were detected at the 0- to 6-in. depth in STG2 and STG4 (604 and 593 ppm, respectively) compared to STG3 (464 ppm; Fig. 5A). For the 6- to 12-in. depth, all three fields were significantly different from each other in POxC concentrations, where STG3 (251 ppm) had the smallest POxC concentration compared to both STG2 (334 ppm) and STG4 (420 ppm; Fig. 5B). The lower POxC in both soil depths for STG3 compared to STG2 and STG4 may be attributed to the relatively recent land-levelling of STG3 compared to STG2 and STG4.

For the land-leveled farm, there was no significant difference in POxC in the 0- to 6-in. depth among the north, central, and control fields. Despite the south field (453 ppm) receiving the most poultry litter, it had lower POxC than the north (630 ppm) and central (583 ppm) fields (Fig. 6). Since this farm was recently land-leveled, and poultry litter recently applied, the first sampling may not have allowed enough time to observe the effects of poultry litter rates. Continued monitoring of its POxC in the future will be necessary to see changes or differences.

Practical Applications

Soil active C is an indicator of soil biological activity. Typically, greater active C suggests healthy soil with greater biological activities. The current research is a summary of data through the first year of the 3-year project. The first-year results suggest that practices such as broadcast planting of cover crops in pastures and adding poultry litter to fields in conjunction with growing cover crops in row crop production enhance POxC. Continued monitoring and assessment of POxC on these six ARDFs will help document how various CPs adopted by farmers might affect soil biological health.

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This research was conducted as part of the Arkansas Discovery Farms program and funded by the Natural Resources Conservation Service. The authors acknowledge the continuous support from the University of Arkansas System Division of Agriculture and thank the partnering farmers in the Arkansas Discovery Farms program for their time and land for this research.

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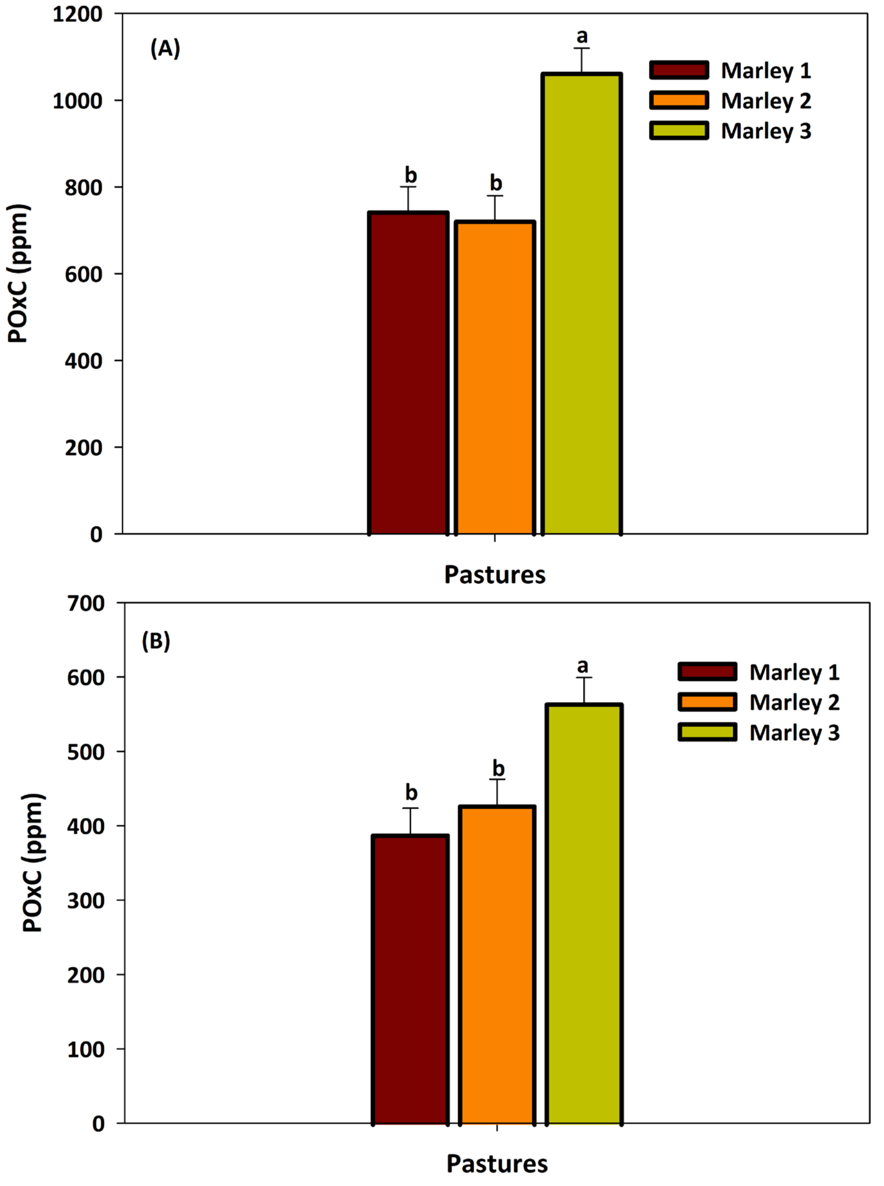

Fig. 1. Soil Active Carbon (POxC) in different pastures at Marley Farm at (A) 0- to 4-in. and (B) 4- to-8-in. depths. Statistical significance was determined at $\alpha = 0.05$. Different lowercase letters indicate differences in POxC between the pastures determined by Tukey's honestly significant difference test.

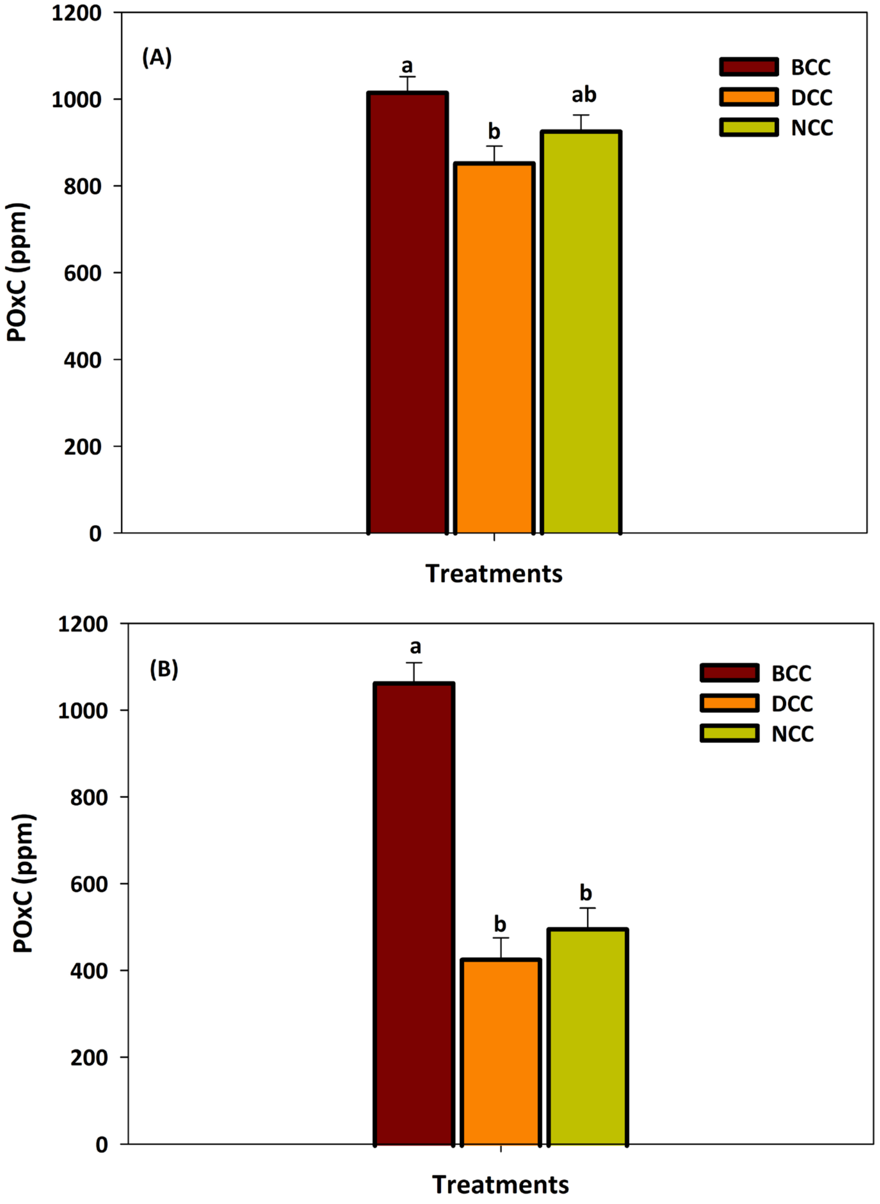

Fig. 2. Soil Active Carbon (POxC) in different cover crop treatments (BCC: Broadcast Cover Cropping, DCC: Drilled Cover Cropping, and NCC: No Cover Cropping) at Morrow Farm at (A) 0- to 4-in. and (B) 4- to 8-in. depths. Statistical significance was determined at α = 0.05. Different lowercase letters indicate differences in POxC between the treatments determined by Tukey's honestly significant difference test.

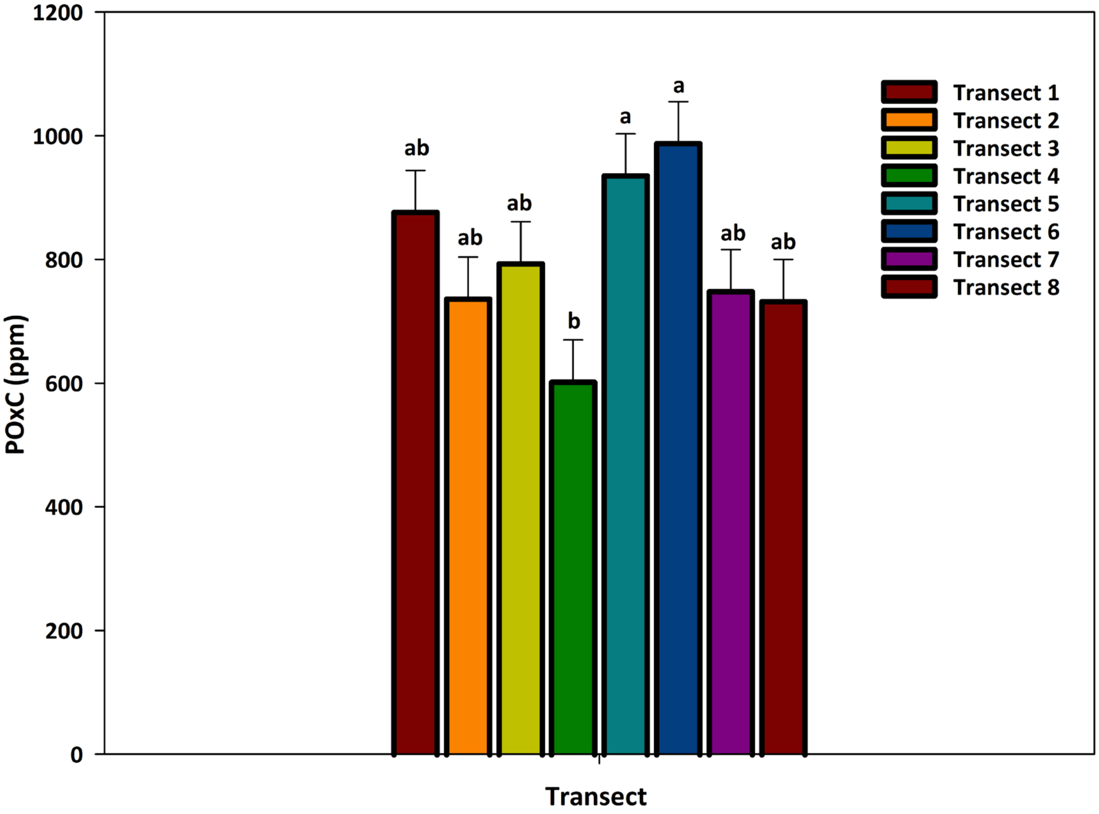

Fig. 3. Soil Active Carbon (POxC) in different Transects at Haak Dairy Farm at 0- to 4-in. depth. Statistical significance was determined at α = 0.05. Different lowercase letters indicate differences in POxC at each depth independently and was determined by Tukey's honestly significant difference test.

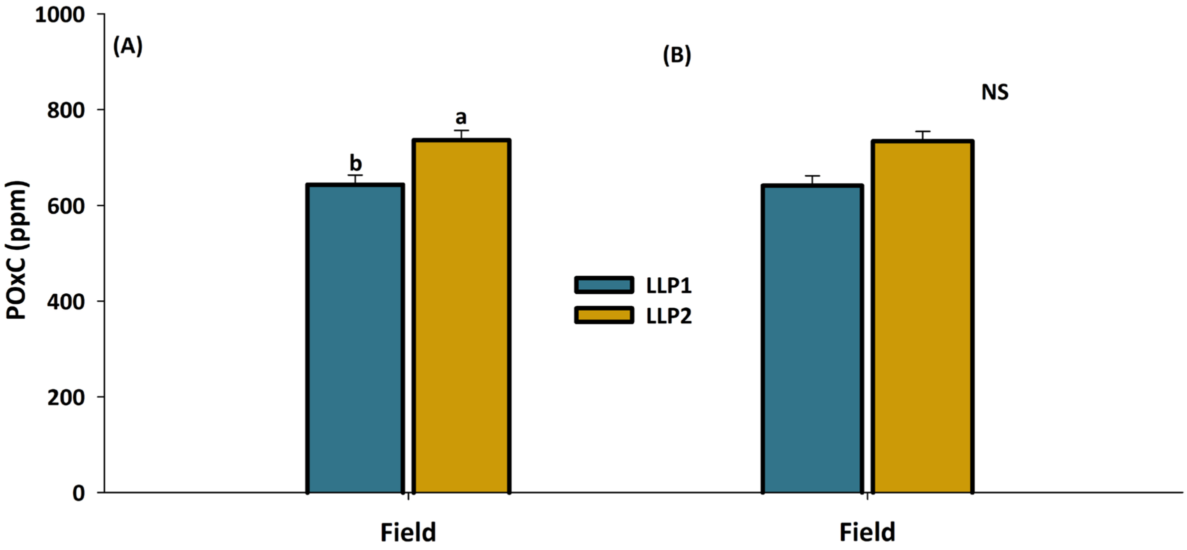

Fig. 4. Soil Active Carbon (POxC) at Long Lake Plantation 1 (LLP1) and Long Lake Plantation (LLP2) fields at (A) 0- to 6-in. and (B) 6- to 12-in. depths at Long Lake Plantation. Statistical significance was determined at α = 0.05. Different lowercase letters indicate differences in POxC at each depth independently and was determined by Tukey's honestly significant difference test.

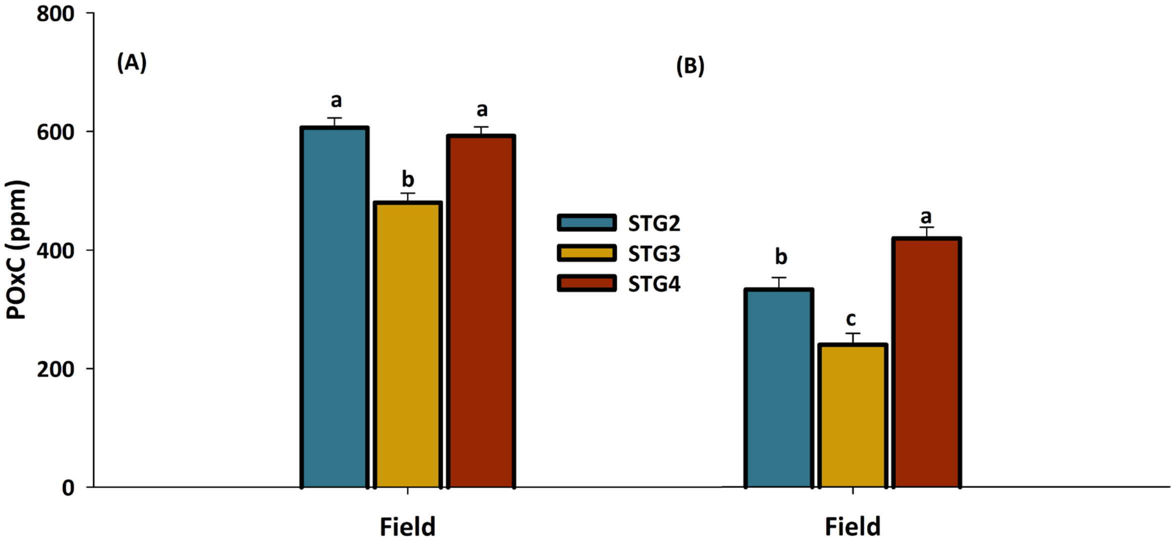

Fig. 5. Soil Active Carbon (POxC) at Stuttgart 2 (STG2), Stuttgart (STG3), and Stuttgart 4 (STG4) fields at (A) 0- to 6-in. and (B) 6- to 12-in. depths at Stuttgart farm. Statistical significance was determined at α = 0.05. Different lowercase letters indicate differences in POxC at each depth independently and was determined by Tukey's honestly significant difference test.

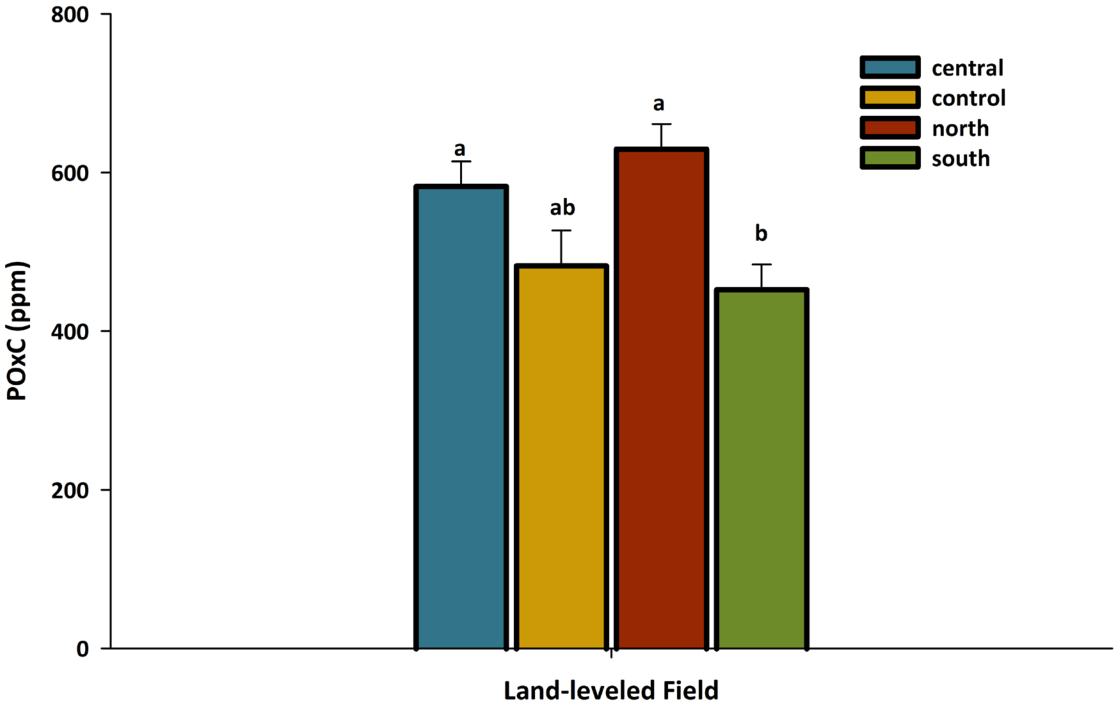

Fig. 6. Soil Active Carbon (POxC) in north, central, south, and control fields on a land-leveled rice farm in Arkansas Delta at 0- to 6-in. depth. Statistical significance was determined at α = 0.05. Different lowercase letters indicate differences in POxC at each depth independently and was determined by Tukey's honestly significant difference test.

Arkansas Cotton Discovery Farm Economic and Sustainability Summary: 2015–2020

B. Robertson,[1] *M.B. Daniels,*[2] *A. Free,*[1] *J. McAlee,*[1] *and B.J. Watkins*[3]

Abstract

Practices that lead to improved soil and water conservation, such as cover crops and reduced tillage, may improve profitability and sustainability as well as have a positive impact on the field's environmental footprint. The objectives of this study are 1) to compare the economics using partial budget analysis for cotton (*Gossypium hirsutum*) produced with tillage with no cover as opposed to cotton produced no-till with cover crops and 2) to examine the utility and differences in sustainability metrics as estimated by the Fieldprint Calculator. The University of Arkansas System Division of Agriculture's Cotton Research Verification Sustainability program, along with the Arkansas Discovery Farms in two fields in Southeast Arkansas from 2015–2020, collected field data and input parameters required by the Fieldprint Calculator for complete budget analysis. Each field was composed of two irrigation sets allowing for evaluation of farmer-standard practices, tillage with no cover to no-tillage with cover. All fields were monitored for input parameters needed for the Fieldprint Calculator and used to calculate expenses. The cotton yield on no-tillage with cover increased an average of 5.4% and was $0.02 per pound cheaper to produce than the farmer-standard tillage with no-cover during 2015–2020. Results from the Fieldprint Calculator did reflect differences in estimates of sustainability metrics between the two systems. The Fieldprint Calculator estimated that no-tillage with cover reduced greenhouse gas emissions and energy use by 8.3% and 10.7%, respectively. Using no-tillage with cover crops resulted in increased yield and increased profitability of cotton production, while the Fieldprint Calculator estimated a lower environmental footprint.

Introduction

As the cost of production continues to increase, producers are striving to increase profitability and sustainability. The key to remaining profitable is to continuously introduce technologies that will improve efficiency. Cotton (*Gossypium hirsutum*) producers utilize many different production practices to improve efficiency and profitability, as no single practice will benefit all producers. Producers are often hesitant to adopt new technology due in part to the associated costs. The University of Arkansas System Division of Agriculture has been conducting the Cotton Research Verification Program (CRVP) since 1980 with the objective of demonstrating the profitability of university production recommendations.

The cotton supply chain is placing an increasing value on demonstrating continuous improvement toward reducing the environmental footprint associated with cotton production. In fact, the U.S. Cotton Trust Protocol's vision is to set a new standard in sustainable cotton production where full transparency is a reality and continuous improvement to improve our environmental footprint is their main goal. Sustainability goals such as these that require documentation have prompted Field to Market, an alliance of hundreds of agricultural organizations, supply chain companies, and universities, including the University of Arkansas System Division of Agriculture, to develop sustainability metrics Fieldprint Calculator (https://fieldtomarket.org/).

The Fieldprint Calculator is a tool developed by Field to Market: The Alliance for Sustainable Agriculture, which employs multiple algorithms to capture direct and embedded properties of all inputs, including but not limited to seed, chemicals, fertilizer, irrigation, and tillage on sustainability metrics. The Fieldprint Analysis estimates field-level performance on the following sustainability metrics: biodiversity, energy use, greenhouse gas emissions, irrigated water use, land use, soil carbon, soil conservation, and water quality. Producers can assess the environmental performance of their management practices to their point of sale against local, state, and national benchmarks derived from United States Department of Agriculture data. It is designed to be an assessment tool to provide estimates of relative performance towards increased sustainability and not as a model to predict indicators. Calculated summaries give producers insight into the ability for improved management on their farms.

The objectives of this study are 1) to compare the economics using complete budget analysis for cotton produced with tillage with no cover as opposed to cotton produced no-till with cover crops, 2) to examine the utility and differences in sustainability metrics as estimated by the Fieldprint Calculator, and 3) to determine how well the Fieldprint Calculator estimates on irrigation water use and water quality with actual field measurements on irrigation water use and water quality as measured by the Arkansas Discovery Farms program. This paper describes the results from objectives 1 and 2.

Procedures

This study was comprised of two fields which allowed for the observation of two systems, including farmer-standard tillage compared to a modified production system involving no-tillage

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with cover to improve efficiency, profitability, sustainability, and soil health. Elbon cereal rye (*Secale cereale*) was the cover crop used in all no-tillage with cover fields, and it was broadcast at a rate of 56 lb/acre. Across all fields, no-tillage with cover had one tillage operation to push cover crop residue away from the furrow using a FurrowRunner vs. multiple tillage operations in the farmer-standard tillage. The fields used in this project averaged approximately 40 ac in size with each practice comprising one-half of the field. Throughout the study, all producers' inputs were recorded, providing the information needed to calculate both fixed and variable costs as well as input parameters for the Fieldprint calculator. A complete budget analysis and Fieldprint Calculator were utilized on both treatments on both sides. The fields were harvested with the producer's equipment. Grab samples were collected for lint fraction and fiber quality.

Results and Discussion

The six-year summary of this study indicates the no-tillage with cover crop produced 1381 lb lint/ac as compared to 1306 lb lint/ac for the tillage with no cover (Table 1). This yield difference resulted in the no-tillage with cover crop to be produced at $0.02/lb lint cheaper during the study period. There was concern initially that water flow rates down the row would be a problem in no-tillage with cover fields. The FurrowRunner allowed for a narrow trench in the furrow to help with water movement while leaving all cover crop residue on the sides of the furrow and top of the row, only having minimal soil disturbance. After the first irrigation, this was no longer a concern and resulted in a benefit. After large rain events, we visually observed that no-tillage with cover field areas had quicker water infiltration when compared to that of the producer standard of tillage with no cover.

The environmental footprint calculated by the Fieldprint Calculator estimated a smaller or more sustainable footprint in no-tillage with cover for metrics such as irrigation water use, greenhouse gas emissions, and energy use. The calculator estimated an increase in land use efficiency.

Practical Applications

In this six-year summary (2015–2020), no-tillage with cover crop practices resulted in a 5.38% increase in lint yield, and the Fieldprint Calculator estimated an increased water use efficiency requiring 12.7% less water to produce a pound of cotton. Irrigation water movement through the field is slower in the no-tillage with cover than the farmer-standard practices with tillage because increased water infiltration reduced flow velocity down the furrow. Additional research is needed to evaluate how lint yield and profitability are influenced by seasonal rainfall interactions with improved water infiltration, which appears to be yield-limiting in the mid-South in wet years. The adoption of practices to improve soil health will likely be limited until producers become more comfortable in eliminating non-yield limiting practices in a no-till cover crop system to have a more consistent positive impact on profitability.

The Fieldprint Calculator provided estimates that indicated a reduction in sustainability metrics such as greenhouse gas emissions, irrigation water use, and energy where no-tillage and cover crops were utilized. Although the Calculator provides estimates of environmental footprints, it is an assessment tool that can be used in planning as an indicator of directionally correct movement towards sustainability in a relative sense as compared to county, state, and national databases and should not be used as a tool that can predict strict and accurate changes in quantifying the effect of sustainability parameters. The next phase of this work will be to compare actual field measurements on water use and water quality to estimates provided by Fieldprint Calculator to further understand the applicability of this assessment tool.

Acknowledgments

The authors would like to acknowledge Cotton Incorporated for its support of this project. The authors would like to thank producers and County Extension agents for their interest and support of this study. Support was also provided by the University of Arkansas System Division of Agriculture.

Table 1. Harvested lint yield, operating expenses, and metrics used to evaluate sustainability as affected by tillage and cover crops.

Parameters	No-tillage with Cover (2015–2020)	Tillage with No-Cover (2015–2020)	% Change No-till vs. Till
Yield (lb lint/ac)	1381	1306	5.38%
Operating Expenses ($/ac)	558.22	542.43	2.83%
Operating Expenses ($/lb lint)	0.416	0.436	-5.01%
Land Use (ac/lb lint)	0.00067	0.00073	-7.92%
Irrigation Water Use (ac-in./lb lint above dryland yield)	0.0197	0.0222	-12.71%
Energy Use (BTU/lb lint)	4802	5316	-10.71%
Greenhouse Gas Emissions (lb CO_2 eq/lb lint)	1.32	1.43	-8.33%

Peak Discharge Versus Total Nitrogen and Total Phosphorus in Cover Crop and No Cover Crop Systems

P. Webb,[1] M.B. Daniels,[1] J. Burke,[2] and L. Riley[1]

Abstract

Edge of field monitoring (EOFM) was conducted as part of the Arkansas Discovery Farms Program (ARDF) in two cotton (*Gossypium hirsutum* L.) fields, one with and one without cover crops on a farm located in Desha County. Nutrients in runoff, runoff volume, and peak discharge were monitored for each runoff event over a 3-year period from 2017–2019. Total nitrogen (TN) and total phosphorus (TP) were compared to peak discharges from 198 runoff events to determine the relationship between nutrient losses and runoff intensity. There was a significant positive correlation for both TN load (lb/ac) and TP load with peak discharge (gpm). Results from all samples from each field within the 3-year period revealed a significantly greater rate of change (slope of linear regression model) in TP loads associated with greater peak discharge in the field with no cover crop (slope = 0.00024 lb P/ac/gpm) than the field with a cover crop (slope = 0.00011 lb P/ac/gpm). There was no significant relationship between TN or TP concentration (mg/L) with peak discharge. Results were also analyzed by cotton growing season (planting date to harvest date) and non-growing season. During the cotton growing season, there was no significant difference in either TP load or TN load with respect to peak discharge in either field. However, during the non-growing season, TP load regressed against peak discharge was significantly greater on the non-cover crop field than on the cover crop field. There was no significant difference in TN load versus peak discharge between field treatments on any time scale.

Introduction

The C.B. Stevens Farm, located in Desha County, Ark., is a part of the Middle Bayou Macon Watershed. In 2006, the Bayou Macon was listed on the State of Arkansas' 303d list as being impaired for aquatic habitat due to siltation/turbidity caused by agricultural activities (Integrated Water Quality Monitoring and Assessment Report, 2006). This watershed became an approved Mississippi River Basin Initiative (MRBI) project area in 2011 with the goal in part to reduce nitrogen (N) and phosphorus (P) loads within the watershed, which eventually drains to the Gulf of Mexico (Mississippi River Basin Healthy Watersheds Initiative, 2022). As part of the Arkansas Discovery Farms Program (ARDF), edge-of-field water quality monitoring implemented through Conservation Activity 201 and 202 was established on the Stevens farm to demonstrate the effectiveness of cover crops, NRCS conservation practice 340.

On a watershed scale, research has shown that the implementation of cover crops within row crop agriculture reduces runoff peak discharge and, thus, soil erosion and transport of excess nutrients (Harmel et al., 2006). On a small plot scale, research indicated that an actively growing crop has a significant impact on reducing runoff and its peak discharge (Yu et al., 2000). Korucu et al. (2018) simulated a 60-min rainfall of 6.5 cm to investigate runoff from plots with a cereal rye (*Secale cereale* L.) cover crop and with no cover crop on a somewhat poorly drained clay loam. The living rye cover crop significantly ($P \leq 0.05$) delayed surface runoff by 5.7 min and decreased total runoff by 65% compared to plots with no cover crop resulting in a 68% reduction in sediment loss.

The goal in part of this study on the Stevens farm and the objective of this paper is to determine if correlations between peak discharge and nutrient loss, specifically total N (TN) and total P (TP), are influenced by cover crops in cotton at the field scale.

Procedures

The study was conducted on two fields in Desha County, Ark., which were cropped to cotton (*Gossypium hirsutum*) grown on 38-in. beds with minimum tillage. The 24-ac field, Field 2, served as the treatment and had a cereal rye (*Secale cereale*) cover crop, which was established in the fall and chemically terminated in the spring. The 40-ac field, Field 4, served as the control with cotton grown in the summer but without a winter cover crop. Each field was furrow irrigated using groundwater with polypipe utilizing the Pipe Hole and Universal Crown Evaluation Tool (PHAUCET). At the outlet of each field, an automated edge-of-field monitoring station was established to measure runoff flow rate and volume, collect water quality samples of runoff for water quality analysis, and measure precipitation. A 60-degree, V-shaped, 8-in. trapezoidal flume that was pre-calibrated and gauged was installed in the flow channel. The ISCO 6712, an automated portable water sampler, was utilized to interface and integrate all the components of the flow station. An ISCO 720 flow module equipped with a submerged pressure transducer was used to measure the hydraulic head (H) at the flow-calibrated measurement point within the trapezoidal flume and was integrated with the automated sampler. Runoff discharge at any given time was estimated from the equation:

$$Q = 1.467\ H^{2.5} + 2.22\ H^{1.5} \qquad \text{Eq. 1}$$

where Q = discharge in cfs and H = head in ft.

Hydraulic head data and runoff discharge data were downloaded into the ISCO Flowlink software, where discharge curves

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integrated over time (hydrographs) were used to calculate total and peak discharge for each individual runoff event.

The ISCO automatic water sampler collected runoff samples at predetermined intervals during a discharge event. The sampler was programmed to collect 100, 100 mL samples integrated across various stages of the flow hydrograph, or up to a total of 10 L during each runoff event. Each sample was collected and analyzed following the protocol set forth by the USEPA for N and P. A sample was collected on a unit flow basis, such that a composite flow-weighted sample for the whole discharge event was obtained. This sample was collected from the auto-sampler within 24 h of collection for the determination of total Kjeldahl N (TN) and TP. Runoff water samples were placed in clean, acid-washed polyethylene bottles with caps and labeled with site number, date, time, and collector's name and immediately transferred for initial sample filtration within 24 h of collection to the Arkansas Water Resources Center Water Quality Laboratory, an EPA-certified lab.

Samples were collected from 198 runoff events between 2017 and 2019, including 102 samples from Field 2 (cover crop) and 96 samples from Field 4 (no cover crop). Regression analyses for each field and associated nutrient parameter versus peak discharge were conducted in JMP Pro 16 using the "Specialized Modeling" platform at a probability level of 0.05. Significant differences comparing fields were determined by analyzing the upper and lower 95% confidence intervals for each slope coefficient.

Results and Discussion

Analysis of all sample results from Field 2 (cover crop) and Field 4 (no cover crop) between 2017 and 2019 showed there was a significant positive correlation between both TN and TP load (lb/ac) and peak discharge (gpm). Linear regression models revealed that TP loads in the field without a winter cover crop increased twice as fast (cover crop slope = 0.00011 and no cover = 0.00024 lb P/ac/gpm) with peak discharge as the cover crop field for all samples within the 3-year period (Fig. 1). There was no significant difference in TN loads with peak discharge between cover crop treatments (Fig. 2). In terms of concentration, there was no significant relationship between TN or TP concentration with peak discharge.

Further analysis was done by comparing sample results from the two treatments during both the growing and non-growing seasons. The cotton growing season was defined as runoff samples collected from the date of planting (approx. mid-to-late April) to the date of harvest (approx. late Sept. to mid-Oct.), and the non-growing season was defined as any sample collected outside of the summer cash crop's growing season. For both seasons, there was no significant difference between treatments for TN loads versus peak discharge. There was no significant difference between treatments for TP loads versus peak discharge for cotton growing season samples. However, for non-growing season samples, the slope value for TP loss versus peak discharge was significantly greater for the non-cover crop field (slope = 0.00033 lb P/ac/gpm) than the cover crop field (slope = 0.00016; Fig. 3).

Practical Applications

With increases in fertilizer prices, reducing nutrient losses in runoff is of financial interest. Understanding the relationship between nutrient losses and runoff is important to find ways to better manage losses in runoff. This research indicates that TP losses at the edge of the field are positively and significantly correlated to peak discharge. The study further revealed that utilization of cover crops during the time in which a cash crop is not actively growing could reduce TP loads in runoff associated with peak discharge. Peak discharge provides better insight into storm and runoff intensity than does total discharge. This study indicates cover crops can reduce the effect of larger, more intense runoff on TP loss. Farmer use and adoption of cover crops during the winter months in the Arkansas Delta region can help reduce TP loads, especially with respect to events with greater peak discharges. Cover crops did not reduce TN loads associated with greater peak discharge events which may indicate that practices other than cover crops are needed for better N management.

Acknowledgments

The authors would like to thank the Arkansas Discovery Farmers, who welcome us to conduct research on their farms. This research was funded by the Arkansas Fertilizer Tonnage Fees and the University of Arkansas System Division of Agriculture.

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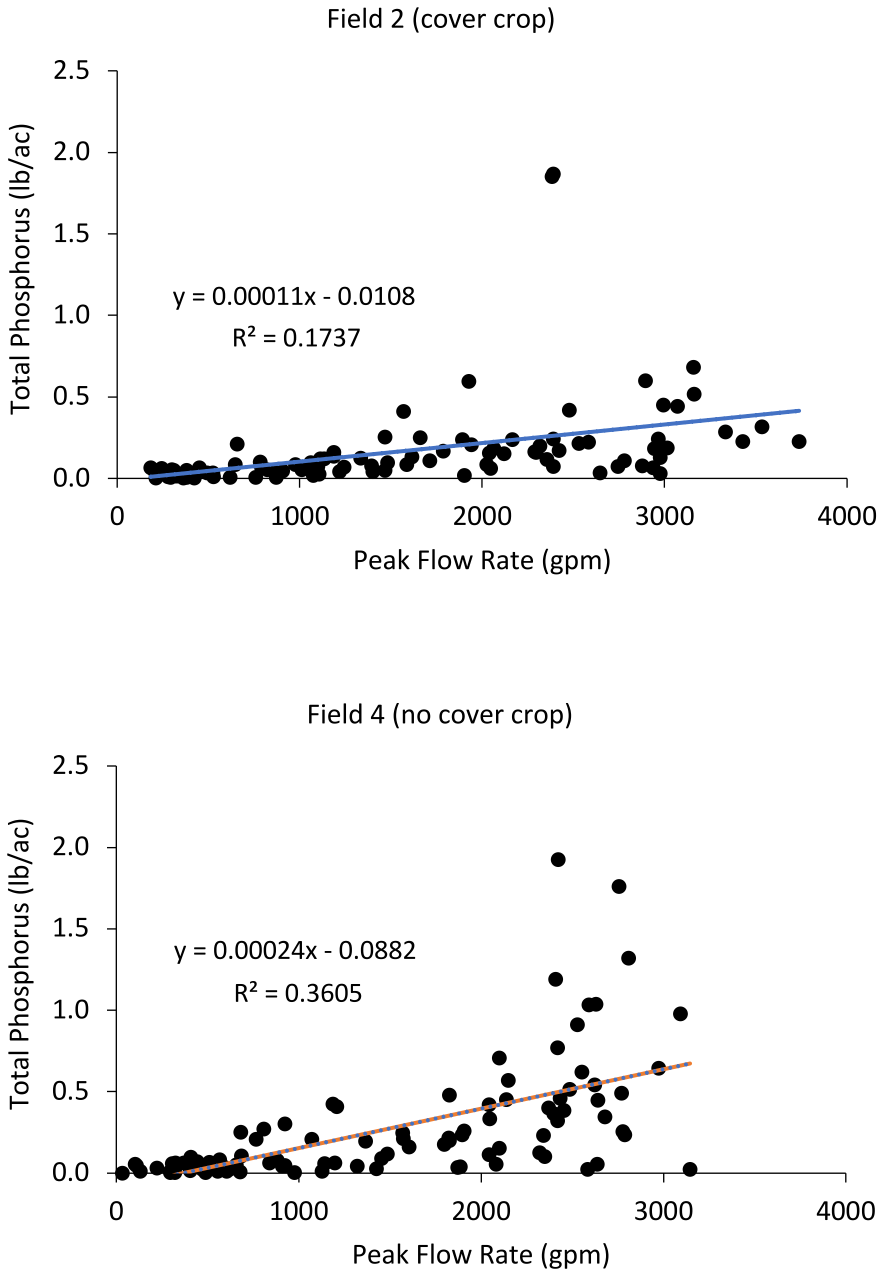
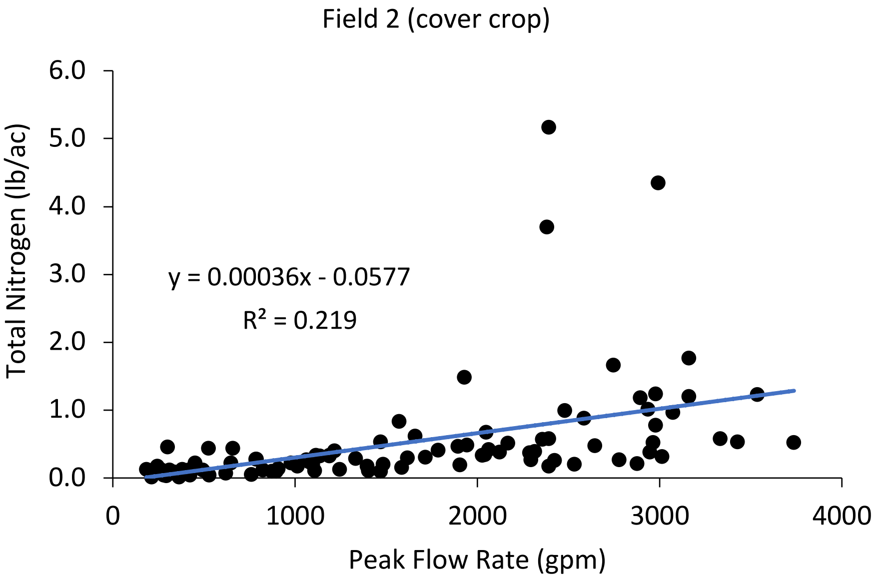


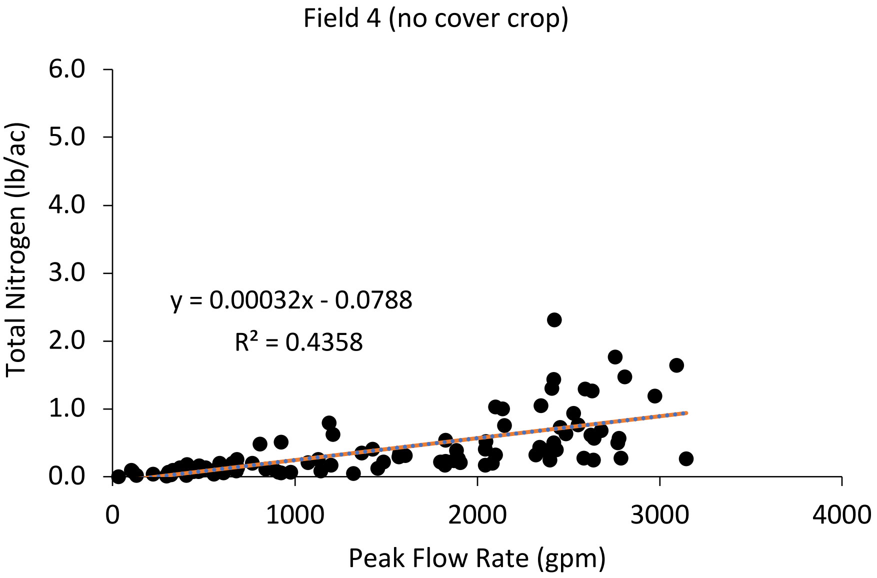
1A)

1B)

Fig. 1. The total phosphorus load (TP lb/ac) regressed against peak flow rate (gpm) for Field 2 (cover crop) (1A) and Field 4 (no cover crop) (1B) between 2017–2019.

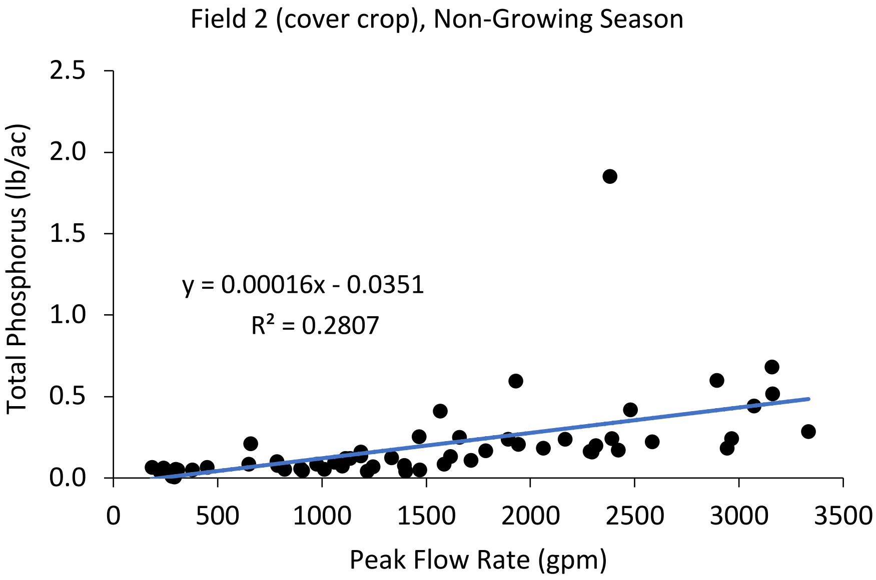


2A)

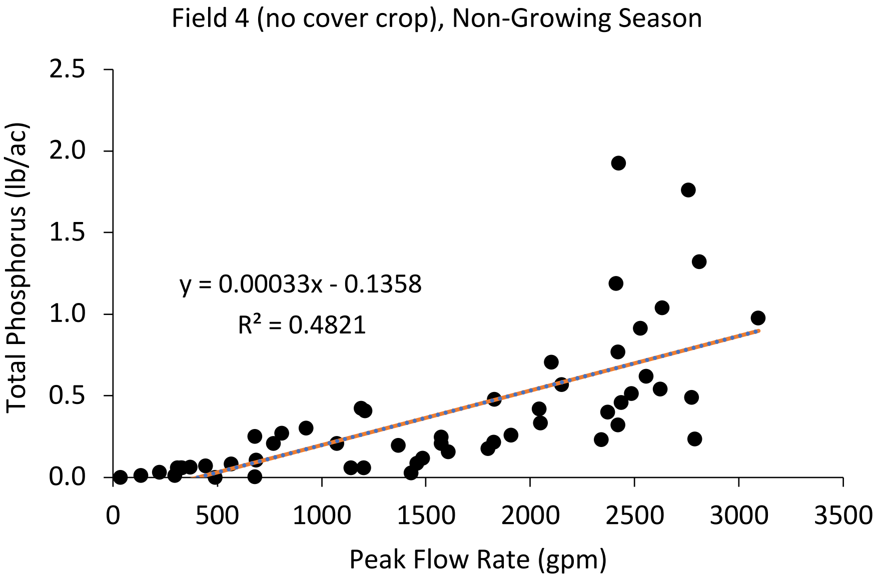


2B)

Fig. 2. The total nitrogen (TN lb/ac) regressed against peak flow rate (gpm) for Field 2 (cover crop) (2A) and Field 4 (no cover crop) (2B) between 2017–2019.



3A)



3B)

Fig. 3. The total phosphorus (TP lb/ac) regressed against peak flow rate (gpm) for Field 2 (cover crop) (3A) and Field 4 (no cover crop) (3B) for samples collected during the summer cash crop's non-growing season from 2017–2019.

Polyphenolic Concentrations and Algal Inhibition in the Presence of Rice Straw or Barley Straw Extract

H. Wren[1] *and M. Savin*[1]

Abstract

Harmful algal blooms are increasing in size, duration, and intensity around the globe. For several decades, cereal straws have been recognized as a viable algal control. The objective of this study was to explore the relationship between algal growth in aqueous cultures and total phenolics and flavonoids after the addition of barley (*Hordeum vulgare*) and rice (*Oryza sativa* L.) straw decomposition extracts. Results showed significant inhibition by 5.0 g/L rice straw extract on both *Microcystis aeruginosa*, a cyanobacteria responsible for freshwater harmful algal blooms, and *Raphidocelis subcapitata*, a green alga. Results also showed that the overall extract concentration of either barley or rice straw might be more important for the inhibition of green algae, whereas the particular compounds released during the decomposition of rice straw may be more important for cyanobacterial inhibition. However, more specific identification of flavonoids and phenolic compounds should be conducted to determine their inhibitory role(s).

Introduction

Harmful algal blooms promoted by cultural eutrophication are expanding in most regions throughout the world (Paerl et al., 2018). Though harmful algal blooms occur along the marine-to-freshwater continuum, the organisms responsible for freshwater blooms are primarily contained within a phylum known as cyanobacteria. Cyanobacteria (blue-green algae) are some of the earth's oldest photoautotrophic prokaryotes, with evidence of their presence as early as 2.5 to 2.7 million years ago. The long evolutionary history of these organisms has allowed the group to proliferate in a wide range of environmental conditions (Brocks et al., 1999; Summons et al., 1999; Paerl and Otten, 2013). More recently, cultural eutrophication resulting from agricultural, urban, and industrial nutrient depositions in conjunction with an altered global climate has further enabled cyanobacteria to dominate aquatic systems.

Where nutrient reduction or physical removal measures are not feasible, chemical or biological methods must be employed to reduce the formation of harmful algal blooms of cyanobacteria (or CyanoHAB) and sustain ecosystem health. Unlike physical methods that either remove, spatially limit, or kill algal cells mechanically, chemical control of algae works by interfering with cellular growth. The efficacy or dosage of chemical control methods is often dependent on variables such as pH, light, temperature, nutrient concentrations, and water chemistry.

For several decades, barley (*Hordeum vulgare*) straw has been gaining recognition as an economical and accessible algistat. Several studies have confirmed that the aerobic, microbial decomposition of lignin, the parent material of degradation products, is responsible for activating a cereal straw's algistatic effects (Pillinger et al., 1994; Murray et al., 2010; Iredale et al., 2012). Despite these findings, the primary compounds and pathways contributing to inhibition have not been determined definitively.

Multiple studies have concluded that polyphenolic compounds are the primary allelochemicals mediating inhibition, but the specific polyphenolic structures and mechanisms by which inhibition occurs have not yet been determined (Pillinger et al., 1994; Everall and Lees, 1996, 1997; Waybright et al., 2009; Murray et al., 2010; Ma et al., 2015). The objective of this study was to explore the relationship between total phenolics and flavonoids from barley and rice (*Oryza sativa* L.) straw extracts on algal growth.

Procedures

Objectives were achieved using laboratory incubations of cultures grown in pre-sterilized 1-L Erlenmeyer flasks with treatments added as shown in Table 1 ($n = 3$). Bioassays utilized cultures of 22 fl. oz (650 mL) sterile culture medium and 0.47 fl. oz (14 mL) of *Raphidocelis subcapitata* or *Microcystis aeruginosa* inoculated at an initial density approximating 1.7×10^7 cells/fl oz (5.8×10^5 cells/mL, similar to Hua et al., 2018). Following inoculation, flasks were placed in a growing chamber under full daylight spectrum (6400K), 24-watt (initial 2000 lumens) T5 high output fluorescent tubes on a 12 h:12 h light:dark cycle in a completely randomized pattern. Every 4 days, all flasks were swirled and randomly rearranged within the growing chamber to mitigate edge effects. Samples were collected (0.67 fl. oz; 20 mL total) at 0, 1, 4, 8, 15, and 28 days for measurement of chlorophyll-a, pH and dissolved organic carbon, total phenolics and flavonoids.

Maintenance of *Raphidocelis subcapitata* and *Microcystis aeruginosa* Algal Cultures

Sterilized Bristol medium (recipe found at https://utex.org/products/bristol-medium?variant=30991782838362) was inoculated with *Raphidocelis subcapitata* (https://www.atcc.org/products/all/22662.aspx#generalinformation) and placed on a shaking incubator at 40 rpm, 23 °C, and under full daylight spectrum (6400K), 24 watt (initial 2000 lumens) T5 high output fluorescent tubes on a 12 h:12 h light:dark cycle. *Microcystis aeruginosa* (https://utex.org/products/utex-lb-2385) was obtained and grown in blue-green (BG-11) medium (recipe found at https://utex.org/products/bg-11-medium?variant=30991786868826) with shaking

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at 40 rpm, 23 °C, and under full daylight spectrum (6400K), 24 watt (initial 2000 lumens) T5 high output fluorescent tubes on a 12 h:12 h light:dark cycle. Fresh media was inoculated with cultures at peak density every 14 to 21 days. Approximate cell counts were determined using a Bulldog-Bio 4-chip disposable hemocytometer.

Determination of Chlorophyll-a Content

First, each sample was filtered through a 0.00003-in. (0.7-µm) pore size Whatman GF/F filter, using enough volume to color the filter paper and rinsing the filter syringe with MilliQ water between each sample. Without disturbing the filter residue, the filter was folded and transferred to a plastic screw-top centrifuge tube. The tubes were wrapped in foil to preclude light and stored in the freezer until one day before analysis. One day before analysis, 0.24 fl oz (7 mL) of 90% acetone was added to each vial and returned to the freezer to steep for 23–25 h. The fluorescence was measured using a calibrated Turner fluorometer (Turner Designs, Sunnyvale, Calif.). In order to quantify pheophytin, fluorescence was measured a second time, 90 seconds after the addition of 0.003 fl oz (0.1 mL) of 0.1 N HCl.

Determination of Total Flavonoid Content

Total flavonoid content was measured using a method modified from Farasat et al. (2014). In order to determine total flavonoid content, 8.5×10^{-4} fl. oz (25 µL) of the sample was added to a clear, flat bottom 96-well microplate followed by 3.4×10^{-3} fl. oz (100 µL) of a 1:1 mixture of 10% $AlCl_3$ and 1 M sodium acetate. Then, 6.1×10^{-3} fl. oz (180 µL) of DI water was added to the wells and allowed to react for 30 min at room temperature. The absorbance was measured against a blank at 415 nm using a SpectraMax iD3 microplate reader (Molecular Devices, San Jose, Calif.). Calibration curves were created using quercetin as a standard at 0.5 to 25 µg/mL. Standards were measured throughout the analysis as indicators of quality control.

Determination of Total Phenolic Content

Total phenolic content was measured using Prussian Blue assays in clear, flat bottom 96-well microplates (Margraf et al., 2015; Pueyo and Calvo, 2009). Gallic acid standards were prepared by dissolving the gallic acid in the minimal volume of ethanol and brought to volume with MilliQ water in concentrations from 0.5 to 25 µg/mL. In order to determine the total phenolic content of samples, 3.4×10^{-3} fl oz (100 µL) of 0.50 mM $FeCl_3 \cdot 6H_2O$ in 0.01 N HCl was added to 3.4×10^{-3} fl. oz (100 µL) of the appropriately diluted sample (1:40 to 1:50 v/v in MilliQ water) and left to react for 2 min. Next, 3.4×10^{-3} fl oz (100 µL) of 0.50 mM potassium ferricyanide ($K_3Fe(CN)_6$) was added to each well and allowed to react for 15 min in the dark at 25 °C. Absorbance was measured at 725 nm using a SpectraMax iD3 microplate reader. Standards were measured throughout the analysis as indicators of quality control.

Data Analysis

The chlorophyll-a concentrations were used to calculate the growth inhibition for each algal population as a percentage of the control and to indicate inhibition in the presence of each straw concentration over time. Flasks representing different treatments ($n = 3$) were arranged and moved every 4 days in a completely randomized design. Treatment averages were analyzed by repeated measures analysis of variance (ANOVA, $P < 0.05$; SigmaPlot 11.0, San Jose, Calif.) with a Bonferroni post hoc test to separate the means where appropriate.

Results and Discussion

In *M. aeruginosa* cultures on day 0, flasks treated with 5.0 g/L rice straw extract contained the highest concentration of flavonoids, followed by 5.0 g/L barley straw extract (Fig. 1). Flasks treated with 2.5 g/L rice or barley straw extract contained the next highest concentrations of flavonoids. The control contained the lowest concentration of flavonoids. From day 0 to 28, there was no difference in flavonoid concentration in flasks treated with 5.0 g/L rice straw extract, but flavonoid concentration did increase in flasks treated with 2.5 g/L rice straw extract, 2.5 and 5.0 g/L barley straw extract, and in the control. During this time, total phenolic concentrations also increased in the control and with 2.5 g/L barley straw extract (Fig. 2).

In *M. aeruginosa* cultures on day 15, 2.5 and 5.0 g/L rice straw extract showed significant inhibition of 96% and 97% of biomass as measured by chlorophyll-a, respectively, when compared to the no-treatment control (Fig. 3). On day 28, 5.0 g/L rice straw extract was the only significantly inhibitory treatment, with growth inhibited by 98%. On day 28, cultures treated with 2.5 g/L barley straw extract showed increased growth in flasks when compared to the no-treatment control.

In *R. subcapitata* cultures, flavonoid concentration significantly increased from day 0 to 28 in all treatment groups and in the control (Fig. 4). Following treatment on day 0, flavonoid concentrations in *R. subcapitata* cultures were similar to those found in *M. aeruginosa* cultures. Flavonoid concentrations were significantly higher in flasks treated with 5.0 g/L rice or barley straw extract than in flasks treated with 2.5 g/L barley straw extract. Again, the no-treatment control contained the lowest flavonoid concentrations. Phenolic concentrations in R. subcapitata cultures showed no difference among treatments or over time (data not shown).

In *R. subcapitata* cultures on day 15, 5.0 g/L barley straw extract significantly inhibited growth by 58% and 5.0 g/L rice straw extract by 91% compared to the no-treatment control (Fig. 5). On day 28, 5.0 g/L barley straw extract significantly inhibited growth by 62% and 5.0 g/L rice straw extract by 94%. On day 28, these two treatments were significantly different from each other and the control. Growth in flasks treated with either 2.5 g/L rice or barley straw extract showed no difference from the untreated control.

Results show that 5.0 g/L rice straw extract is effective at controlling the growth of green algae, *R. subcapitata*, and cyanobacteria, *M. aeruginosa*. The growth of green algae treated with 5.0 g/L rice or barley straw extract versus 2.5 g/L rice or barley straw extract may indicate that the overall concentration of cereal straw decomposition extract is more important for inhibition than the compounds produced during the decomposition of either straw. Cyanobacterial growth treated with 2.5 or 5.0 g/L rice straw extracts versus 2.5 or 5.0 g/L barley straw extracts may indicate that compounds produced during the decomposition of rice straw are more critical than total extract concentration.

Greater flavonoid concentrations in flasks treated with 5.0 g/L rice straw on day 0, coupled with a significant reduction in algal biomass, support the hypothesis that flavonoids are an inhibitory component of cereal straws (Yu et al., 2019; Li et al., 2021). However, the increase in flavonoid and phenolic concentrations within experimental flasks indicates the net production of these compounds by *M. aeruginosa* and *R. subcapitata* (Ferdous and Yusof, 2021). To definitively determine inhibition by flavonoids or phenolics, more specific identification of phenolic compounds produced during the decomposition of rice and barley straw should be conducted.

Practical Applications

Arkansas is the leading rice-producing state, accounting for approximately 50% of the crop in the United States (USDA-NASS, 2022). Amongst the 40 rice-producing counties in Arkansas, farmers harvested nearly 240 million bushels of rice from over 1.4 million acres in 2020 (USDA-NASS, 2022). On average, rice straw comprises about 50% of the aboveground dry weight of the rice plant, and for every 1.1 tons of harvested rice grain, approximately 1.5 tons of rice straw is returned to the field (Bhattacharyya et al., 2021).

Rice straw waste is predominately managed through burning and soil incorporation. Though rice straw burning is still allowed in Arkansas, other rice-producing regions such as California, India, and China have implemented policies and subsidies to reduce residue burning as it contributes to serious respiratory conditions and air pollution, releases 6516 lb CO_2-e/ac, and contributes to soil and nutrient losses (Bhuvaneshwari et al., 2019; Skaug, 2017; Bhattacharyya et al., 2021; Sun et al., 2019). Harnessing the potential energy of rice straw for use as a biobased reuse product in biofuels, for fibers, or decomposition products such as algal inhibitors could incentivize less harmful agricultural waste management practices. Furthermore, many current algal control methods have been ineffective, expensive, or dangerous for non-target organisms. Cereal straws have been recognized as environmentally benign algal inhibitors, safe for non-target species, and can easily be applied with little to no additional management by land or homeowners (Zhu et al., 2021).

Acknowledgments

The authors would like to thank Nathaniel Elliot and members of the Soil Biology and Microbial Ecology lab for technical assistance. The authors would also like to thank the USGS 104B program in Arkansas for funding this work. This project was partially funded by USDA-NIFA Hatch project 1024383 and the University of Arkansas System Division of Agriculture.

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Table 1. Decomposing straw extract treatments and the control added to construct microcosms for bioassays for analysis of inhibition of the cyanobacteria *Microcystis aeruginosa* and the green algae *Raphidocelis subcapitata*.

Treatment[a]	Aqueous solution (fl oz solution added)
Control	11 (325 mL) Milli-Q water + 11 (325 mL) 2x media
2.5 g/L RSE[†]	11 RSE + 11 2x media
5.0 g/L RSE	11 RSE + 11 2x media
2.5 g/L BSE	11 BSE + 11 2x media
5.0 g/L BSE	11 BSE + 11 2x media

[a] RSE is rice straw extract, BSE is barley straw extract, media is BG-11 for *M. aeruginosa* and Bristol for *R. subcapitata.*

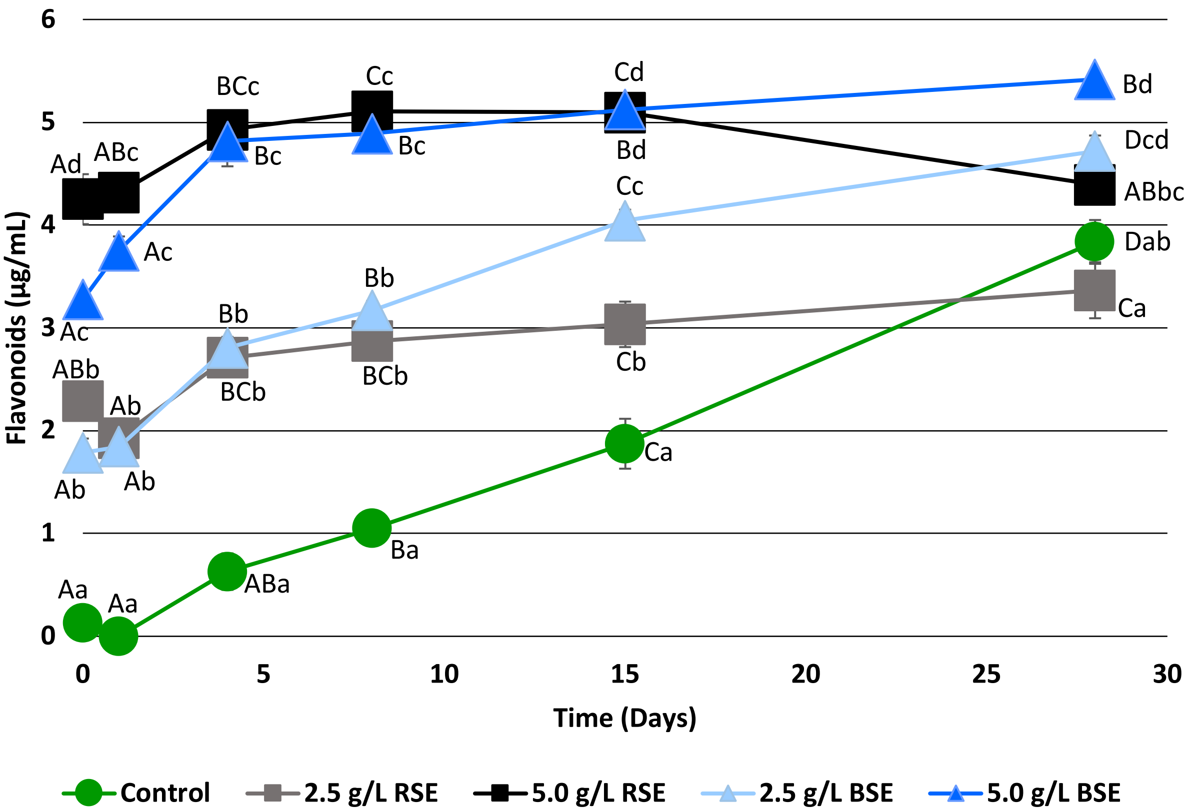

Fig. 1. Flavonoid concentrations (µg/mL) in quercetin equivalents in *Microcystis aeruginosa* cultures for 0 to 28 days following treatment with 2.5 or 5 g/L rice straw extract (2.5 g/L RSE or 5 g/L RSE), 2.5 or 5 g/L barley straw extract (2.5 g/L BSE or 5 g/L BSE), or no-treatment (control, C; *n* = 3). Sampling times followed by similar uppercase letters within a treatment represent a lack of significant differences within that treatment over time ($P > 0.05$). Similar lowercase letters represent a lack of significant differences among the treatments ($P < 0.05$).

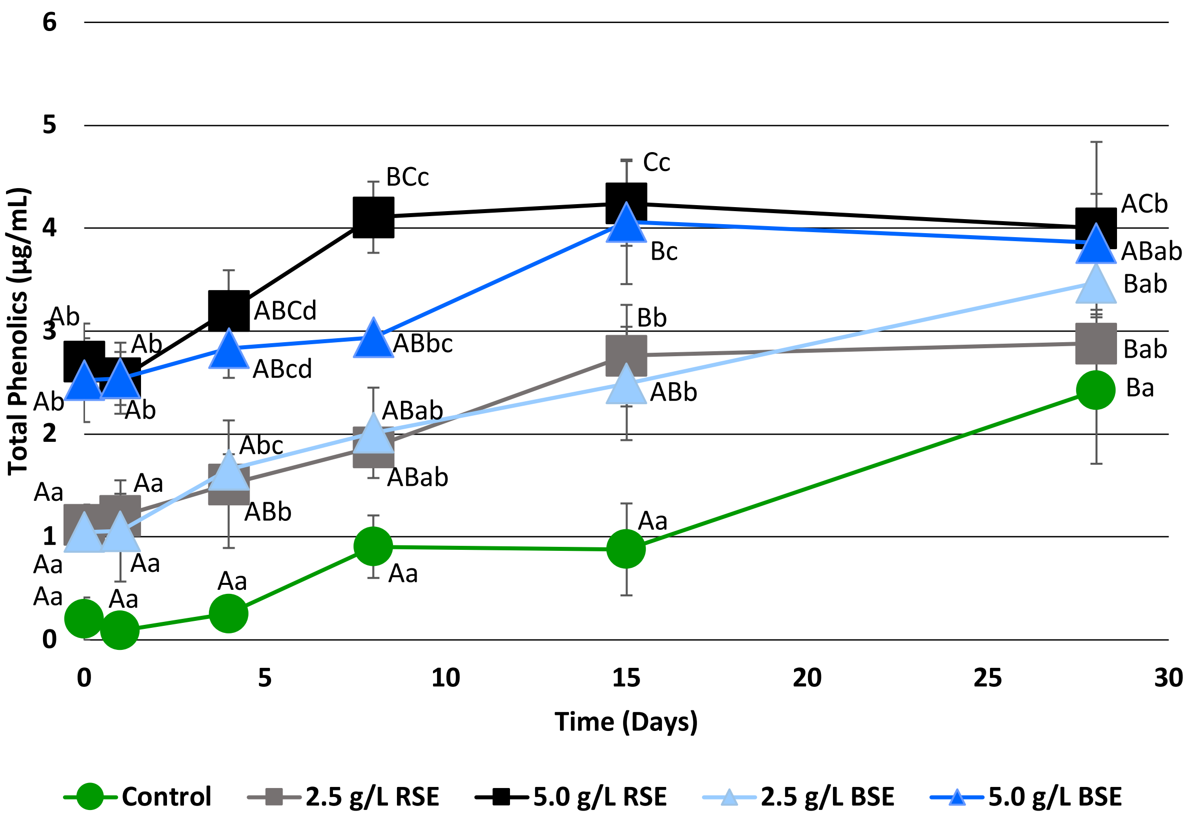

Fig. 2. Total phenolic concentrations (µg/mL) in gallic acid equivalents in *Microcystis aeruginosa* cultures for 0 to 28 days following treatment with 2.5 or 5 g/L rice straw extract (2.5 g/L RSE or 5 g/L RSE), 2.5 or 5 g/L barley straw extract (2.5 g/L BSE or 5 g/L BSE), or no-treatment (control, C; $n = 3$). Sampling times followed by similar uppercase letters within a treatment represent a lack of significant differences within that treatment over time ($P < 0.05$). Similar lowercase letters represent a lack of significant differences among the treatments ($P < 0.05$).

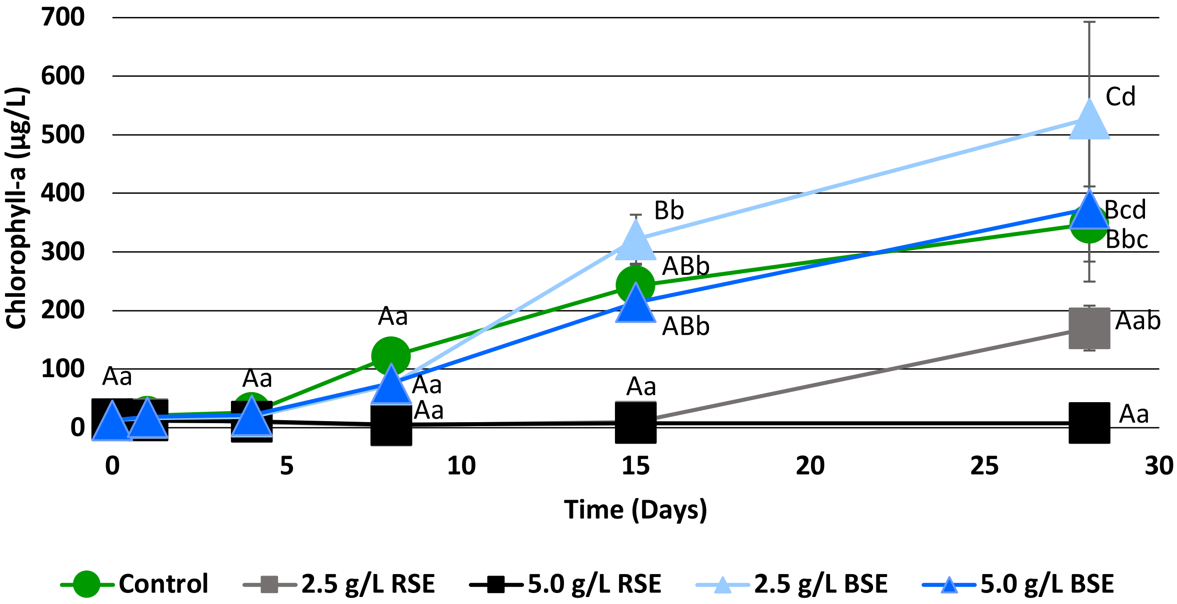

Fig. 3. Chlorophyll-a concentrations (µg/L) in media-based *Microcystis aeruginosa* cultures for 0 to 28 days following treatment with 2.5 or 5 g/L rice straw extract (2.5 g/L RSE or 5 g/L RSE), 2.5 or 5 g/L barley straw extract (2.5 g/L BSE or 5 g/L BSE), or no-treatment (control; *n* = 3). Sampling times followed by similar uppercase letters within a treatment represent a lack of significant differences within that treatment over time ($P < 0.05$). Similar lowercase letters represent a lack of significant differences among the treatments ($P < 0.05$).

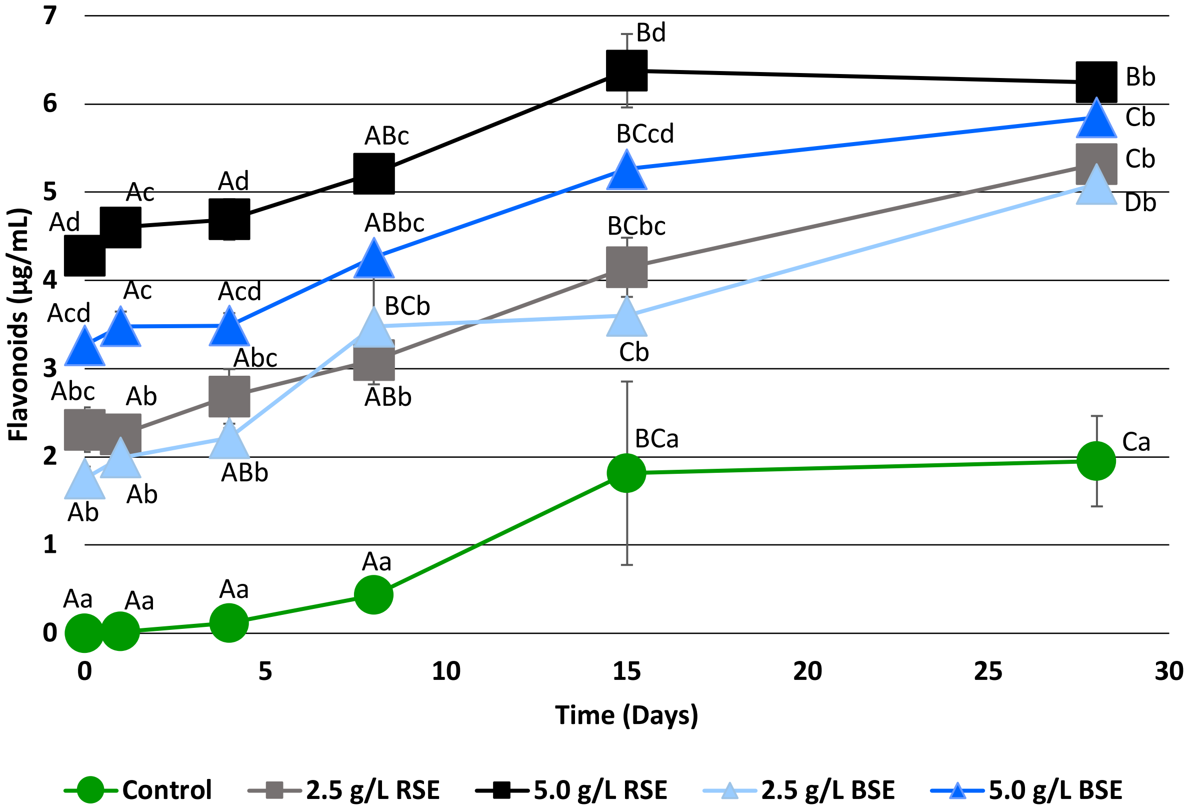

Fig. 4. Flavonoid concentrations (µg/mL) in quercetin equivalents in *Raphidocelis subcapitata* cultures for 0 to 28 days following treatment with 2.5 or 5 g/L rice straw extract (2.5 g/L RSE or 5 g/L RSE), 2.5 or 5 g/L barley straw extract (2.5 g/L BSE or 5 g/L BSE), or no-treatment (control, C; n = 3). Sampling times followed by similar uppercase letters within a treatment represent a lack of significant differences within that treatment over time ($P < 0.05$). Similar lowercase letters represent a lack of significant differences among the treatments ($P < 0.05$).

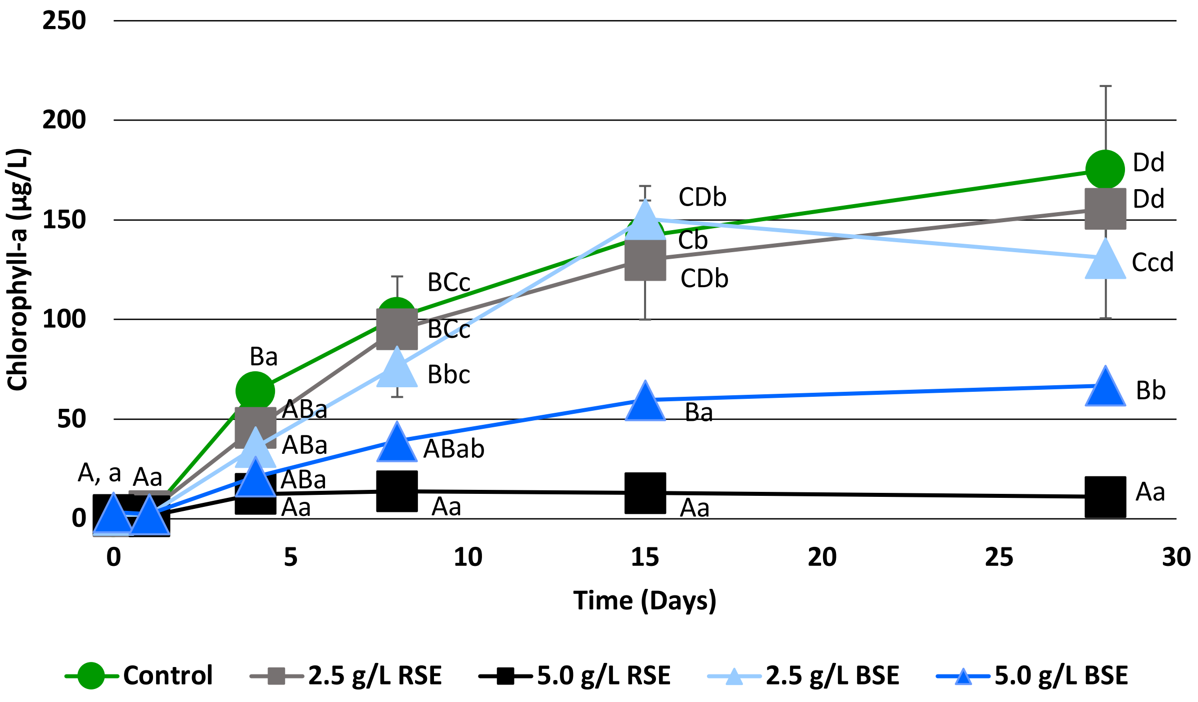

Fig. 5. Chlorophyll-a concentrations (µg/L) in media-based *Raphidocelis subcapitata* cultures for 0 to 28 days following treatment with 2.5 or 5 g/L rice straw extract (2.5 g/L RSE or 5 g/L RSE), 2.5 or 5 g/L barley straw extract (2.5 g/L BSE or 5 g/L BSE), or no-treatment (control, C; *n* = 3). Sampling time followed by similar uppercase letters within a treatment represent a lack of significant differences within that treatment over time ($P < 0.05$). Similar lowercase letters represent a lack of significant differences among the treatments ($P < 0.05$).

Appendix: Soil Testing Research Proposals

2022–2023 Soil Testing Research Proposals

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
Matt Bertucci	Dirk Philipp	Assessment of Bermudagrass Forage Yield and Nutrient Uptake in Response to Phosphorus and Potassium Fertilization	1 of 3	28,658
Mike Daniels	James Burke and Matt Fryer	Assessing Sulfate movement in Runoff using the Arkansas Discovery Farms	1 of 3	22,438
Amanda McWhirt	Trenton Roberts	Verifying Nitrogen Rate Recommendations and Plant Tissue Nutrient Sampling Ranges for Blackberry Grown in Arkansas	1 of 2	18,892
Aurelie Poncet	Leo Espinoza	Can We Use Remote and Proximal Sensing to Improve Soil Sampling in Arkansas	2 of 3	45,000
Aurelie Poncet	Leo Espinoza and Donald Johnson	A Survey to Evaluate Stakeholder Perceptions and Priorities Regarding Soil Sampling, Soil Testing, and Fertilizer Recommendations	1 of 3	10,000
Michael Popp	Aurelie Poncet and Nathan Slaton	Decision Tools for Potassium Fertilizer Recommendations	1 of 3	33,465
Trenton Roberts		Nutrient Uptake, Partitioning, and Remobilization in Modern Cotton Cultivars	2 of 3	47,760
Nathan Slaton	Gerson Drescher	Long-Term Phosphorus and Potassium Cover Crop Trials	3 of 3	49,500
Nathan Slaton	Trenton Roberts	Funding for Post-Doctoral Position and Graduate Assistantships	1 of 3	152,792
Tina Teague	N.R. Benson and John Nowlin	Optimizing Fertilizer Management in Arkansas Cotton in Rotation with Peanut	2 of 3	20,000
			Total:	**428,405**

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