Northern Missouri Research, Extension & Education Center

University of Missouri

Field Day Annual Report
August 6, 2026

Cornett Farm | Lee Greenley Jr. Memorial Farm | Thompson Farm

Grace Greenley Farm | Ross Jones Farm

NORTHERN MISSOURI RESEARCH, EXTENSION, AND EDUCATION CENTER

FIELD DAY ANNUAL REPORT 2026

(Volume 5)

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Acknowledgments: We would like to thank all authors, Jeff Case, and Northern Missouri Research, Extension, and Education Center staff for contributing to this field day annual report.

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New 8/2026

TABLE OF CONTENTS

WELCOME

Jeff Case
Director, NMREEC

Welcome to the Northern Missouri Research, Extension, and Education Center (NMREEC) annual field day. The NMREEC's focus is to conduct non-biased research that is beneficial to producers and the agricultural industry. In support of this mission, we evaluate new technologies in livestock, conservation, and crop management systems to ensure that they are cost-effective and applicable to the region. This field day combines the resources of three Agricultural Experiment Stations across Northern Missouri, demonstrating a sample of the practices we evaluate. The number of projects and researchers utilizing the center has increased and will continue to grow with collaborations gained across the NMREEC locations.

This year marks the 49th annual field day at the Lee Greenley Jr. Memorial Research Farm. The Lee Greenley Jr. Memorial Research Farm is comprised of three farms in Knox and Shelby counties for a total of 1390 acres. These farms are the Lee Greenley Jr. Memorial Research Farm near Novelty, the Ross Jones Farm near Bethel, and the Grace Greenley Farm near Leonard. The Lee Greenley Jr. Research Farm was established when Miss Hortense Greenley donated the 700-acre farm to the University of Missouri in memorium of her father Lee Greenley Jr. It became a part of the University of Missouri's comprehensive out-state research program in 1969 and was dedicated on October 6, 1974. The 240-acre Grace Greenley Farm was officially deeded to the University of Missouri in 2015 from Miss Hortense Greenley's estate upon her passing in memorium to her mother, Grace Greenley. Ross C. Jones left his farm to the University of Missouri in 1988 after his passing to be utilized as an Agricultural Experiment Station to "improve agriculture in this area". A key research focus has been the MU Drainage and Sub-irrigation (MUDS) project that was initiated at the Ross Jones farm in 2001. The system allows for the evaluation of a corn/soybean rotation with drainage and sub-irrigation on claypan soil that is prevalent across northern Missouri. Research is also conducted on the impact of various crop and soil management practices on crop production, soil, and water quality at different landscape positions. Our beef herd is used for research and demonstration. The herd continues to improve through estrous synchronization and artificial insemination with superior sires. We practice rotational grazing and continue to strive to reduce input costs and produce quality beef. The Greenley Farm has marketed heifers in the Show-Me-Select Replacement Heifer Program for more than 20 years.

The Cornett Research Farm (Forage Systems Research Center), located near Linneus, was established in 1965 when the University of Missouri began leasing land from the Cornett family to conduct grassland and grazing research. The farm was donated to the University of Missouri in 1981 upon the death of the last Cornett family member. The Cornett farm is comprised of three separate farms: Cornett, Allen, and Hatfield, formerly referred to as the Forage Systems Research Center, and consists of approximately 1,200 acres. The primary research goal of the Cornett Research Farm is the development and evaluation of forage/beef systems for all classes of beef cattle. For the past 59 years, we have conducted research and delivered the findings to our stakeholders. Field days, grazing schools, focused workshops, and technical training sessions are utilized throughout the year to deliver cutting-edge technologies to our communities. Research conducted at the Cornett Research Farm is integral to developing and implementing grazing management practices eligible for state cost share. Cornett Research Farm is the primary farm associated with CAFNR's Forage-Beef Program of Distinction. The Cornett Farm is an advocate for developing and implementing best management practices for protecting and promoting our environment and natural resources. Focusing on efficient and profitable beef production systems, research is designed to investigate the cause-and-effect relationships of cattle, plants, and soil (the systems approach) in forage/beef systems. These practices include the utilization of reproductive technologies, promoting live weight gains on pasture through season-long grazing and forage finishing beef, soil fertility management, and the development/adoption of smart farm technologies. Our goal at the Cornett Research Farm is to help farmers become more profitable by producing healthier, more nutritious products while improving the environment.

Thompson Research Farm was established in 1955 through the will of Dr. George Drury, a retired dentist. His will specified that 1,240 acres of land should be given to the University of Missouri. An additional 360 acres of the original tract were later added to the gift. The terms of the will prescribed that the farm should be "dedicated to public educational purposes in memory of Eulah Thompson Drury, Guy A. Thompson, Paschall W. Thompson, and Olive F. Thompson." Initial work at Thompson Farm involved research in crop production, soils, and insect control. A full-time agronomist directed crops and soil studies from 1956 until 1978. The research efforts at Thompson Farm historically centered on conducting yield tests with corn, soybean, alfalfa, wheat, and oats as well as herbicide studies in soybean and testing of Hessian fly resistance in wheat. The University of Missouri introduced beef cattle research on the farm in 1963. The first comprehensive cattle crossbreeding experiment was conducted at Thompson Research Farm under the direction of Dr. John F. Lasley. The farm was also the site of a bull progeny testing program from 1970-1990, where approximately 100 bulls were tested yearly. Current research at Thompson Farm focuses on beef cattle production systems and forest management. The Thompson Research Farm has been instrumental in the development and testing of estrous synchronization protocols in beef cattle and is a leader in the Show-Me-Select Replacement Heifer Program.

Visitors are always welcome to visit the NMREEC, whether you are attending a tour, meeting, wedding, or just passing through. This is your research center, and your suggestions often become the catalyst for projects that benefit the broader community. We encourage you to visit our social media pages on Facebook, Instagram, LinkedIn, X, and YouTube, where you can watch frequent center updates and see some of our day-to-day activities. You can find our direct social media links on the next page.

We are grateful to the many sponsors who make this event possible, and they are mentioned on the back cover of this book. I would also like to thank the members of our Advisory Boards for their continued support and guidance, and our staff who maintain the day-to-day operations of our farms. These partnerships and teams allow us to fulfill our Land Grant Mission of Teaching, Research, and Community Engagement.

We hope your time spent at the Lee Greenley Jr. Memorial Research Farm of the North Missouri Research, Extension, and Education Center was both educational and enjoyable. Thank you for joining us as we "Accelerate to Distinction".

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NMREEC FIELD DAY PRESENTATIONS

Agronomic Management

Flooding impact on Corn and Soybean Production

- Dr. Gurpreet Kaur & Manjot Kaur

Biological Stimulants in Corn: Hype or Reality?

- Dr. Gurbir Singh & Rose Paul

Soil Health and Soil Fertility Interpretation Update and Ongoing Research

- Dr. Md. Rasel Parvej

Blind Inlet Update & Demonstration

- Dr. Kelly A. Nelson & Gursewak Singh

Delayed Cover Crop Termination: Impacts on Corn Health and Yield

- Kaitlin Campbell

Beef and Forage Management

Reproductive Technologies in Beef Cattle

- Dr. Jordan Thomas

Virtual Fencing Systems

- Dr. Carson Roberts

Grazing Grain Sorghum

- William Lee

Right Mate Selection in Beef Cattle

- Dr. Jamie Courter

Integrated Pest Management

Managing Margin: Disease Updates and Fungicide Decisions

- Dr. Mandy Bish

Managing Insect Pests in Corn and Soybean: Current Issues and Outlook

- Dr. Ivair Valmorbida

Weed Management Considerations for 2026 & Beyond

- Dr. Kevin Bradley

Lunch Program

- Dr. Matthew Martens, MU Provost & Executive Vice Chancellor for Academic Affairs

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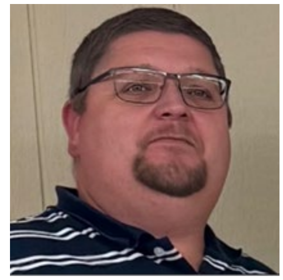
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Ag Associate II


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Ag Associate II


Myles Johnson
High School Student Worker

THOMPSON RESEARCH FARM


Stoney Coffman
Senior Farm Manager


Amanda Coffman
Ag Associate II


Justin Jones
Ag Associate II


Kyla Coffman
Temporary Technical

NMREEC GRADUATE STUDENTS

Emmanuel Barffour Oppong Adjei
Ph.D. in Plant, Insect, and Microbial Sciences (2025-2028)

Emmanuel is advised by Dr. Carson Roberts. His research focuses on improving the productivity, profitability, and sustainability of forage production systems through integrated nutrient management. His work examines nitrogen management in grazing and hay production systems, nutrient management in native warm-season grasses, and nitrogen carryover in tall fescue pastures to develop science-based recommendations that improve forage yield, quality, nitrogen use efficiency, and producer profitability. Through field-based research and collaboration with University of Missouri Extension, Emmanuel is committed to translating research into practical management strategies that help producers make informed, economically sound, and environmentally responsible decisions.

Kaitlin Campbell
M.S. in Plant, Insect, and Microbial Sciences (2025-2027)

Kaitlin received a B.S. in Agricultural Sciences from Truman State University in the spring of 2025. She worked at the Greenley Research Farm for two summers as an undergraduate student and started her M.S. degree in the fall of 2025. Her research focuses on nitrogen management strategies in corn including application rate and timing at different topographic positions, nitrogen stabilizers, and cover crops. She is grateful for the opportunity to work with Dr. Kelly Nelson and the knowledgeable staff at Greenley Farm.

Manjot Kaur
M.S. in Soil, Environmental, and Atmospheric Sciences (2024-2026)

Manjot received her B.S. from Punjab Agricultural University in Ludhiana, Punjab, India, and is now working towards her M.S. in Natural Resources at the University of Missouri. She is studying the impact of flooding stress on soybean production and potential management strategies for flooding recovery with Dr. Gurpreet Kaur. What Manjot loves about Greenley Farm is the cooperative work environment, and she believes the research conducted here is very novel.

Rajinder Kaur
M.S. in Plant, Insect, and Microbial Sciences (2024-2026)

Rajinder has been an M.S. student at the University of Missouri since the fall of 2024, under the advisement of Dr. Gurbir Singh. She graduated with her B.S. from Punjab Agricultural University, India. Rajinder is studying phosphorus and potassium trends in soil affected by landscape positions, cropping systems, and contributions to a decision support system for optimal application. She enjoys the work culture and support of fellow graduate students, staff, and her advisor at Greenley Center. Rajinder says that working at Greenley on real-world nutrient management has equipped her with knowledge and skills that will help her contribute to a better sustainable agriculture system.

Zarina Khurramova
M.S. in Soil, Environmental, and Atmospheric Sciences (2025-2026)

Zarina started her M.S. degree at the School of Natural Resources in spring 2025 under the advisement of Dr. Gurpreet Kaur. She is working on the effects of landscape position and nitrogen management on crop production and nutrient losses in Missouri. Her study aims to generate practical, science-based insight that can help farmers adopt more efficient and environmentally friendly nitrogen management strategies.

William Lee
M.S. in Plant, Insect, and Microbial Sciences (2024-2026)

William graduated from the University of Missouri-Columbia in the fall of 2023 with a B.S. degree in Plant Science. His thesis research relates to forage agronomy, looking at the production and grazing of grain sorghum as a feed alternative for livestock operations. His work has the potential to assist livestock producers in reducing feed costs and increasing profitability. He works under the advisement of Dr. Kelly Nelson.

Riley Merchen
M.S. in Plant, Insect, and Microbial Sciences (2026-2028)

Riley graduated from Brigham Young University-Idaho in Fall 2025 with a B.S. in Plant Science and Technology. She started her M.S. in Plant Sciences at the University of Missouri in Summer 2026. Her thesis research relates to forage quality and the effects that different biological fertilizers and management practices have on overall production. This research aims to keep farmers from all backgrounds in mind. She works under the advisement of Dr. Carson Roberts and appreciates working at the Cornett and Greenley research farms.

Rose Paul
Ph.D. Candidate in Plant, Insect, and Microbial Sciences (2024-2027)

This is Rose's seventh semester at the Lee Greenley Jr. Memorial Farm. She graduated with her M.S. in Agronomy from Punjab Agricultural University, India, in 2023. She is studying N responses in corn with different landscape positions, biological products, and cover crops. Her focus is on evaluating soil health in response to different nitrogen fertilizers in combination with nitrification inhibitors. She enjoys working with fellow graduate students and the friendly and resourceful staff at Greenley Farm.

Tucker Settles
M.S. in Plant, Insect, and Microbial Sciences (2026-2028)

Tucker graduated from Kansas State University in the spring of 2026, majoring in Agriculture Technology Management with a minor in Agronomy. He started his master's degree program through the University of Missouri in the summer of 2026 under the advisement of Dr. Carson Roberts. His research will be studying the effects of conventional vs. regenerative/sustainable/adaptive cow-calf grazing systems on surface runoff quality, sediment transport, soil health/infiltration, forage production, livestock performance, and the overall farm profitability. He is grateful and excited for the opportunity to be working with the students and staff at the Cornett Research Farm.

Gursewak Singh
Ph.D. in Plant, Insect, and Microbial Sciences (2026-2030)

Gursewak received a B.S. in Agriculture and an M.B.A. in Agribusiness from Punjab Agricultural University, India. He earned an M.S. in Sustainable Agriculture from Lincoln University, Missouri, in 2025. He started his Ph.D. at the University of Missouri under Dr. Kelly Nelson. His expertise includes data science, machine learning, and agricultural data analysis, complemented by industry experience in agribusiness. His Ph.D. research will focus on conservation practices to enhance sustainability and productivity in Missouri. His work also includes conservation practices, sustainable agriculture, soil and water quality management, and the evaluation of conservation practices to improve long-term agricultural resilience.

DELAYED COVER CROP TERMINATION AFFECTS CORN HEALTH AND YIELD

Kaitlin Campbell
Graduate Research Assistant

Kelly A. Nelson
Professor

Gurbir Singh
Assistant Professor

Gurpreet Kaur
Assistant Research Professor

INTRODUCTION

Cover crops provide a wide range of benefits to the soil and environment. They can be used to improve physical, chemical, and biological properties of soil, depending on the type of cover crop (Koudahe et al., 2022). Legume cover crops, such as clovers and vetches, fix nitrogen and add it to the soil. Their residues decompose quickly compared to other cover crops, releasing nutrients that are readily available for the subsequent crop. Legume cover crops seeded before corn can reduce the amount of synthetic nitrogen inputs needed and increase yield (Kocira et al., 2020). Legumes can be established by frost-seeding in late February or early March. Frost-seeding is a technique that relies on freezing and thawing cycles to incorporate seeds into the soil (Hall et al., 2020). Cover crop termination timing is a critical management decision. It is important to determine the optimal timing to maximize the nutrient contribution from the legume cover crop and avoid interference with the cash crop. Cover crops terminated too late can compete with corn for light and water which impacts yield. Research has found that delaying cover crop termination past planting can reduce corn yield in dry conditions (Moriles-Miller et al., 2025). In addition to competition for resources, emerging corn can detect changes in light quality from established weeds or cover crops which leads to altered seedling growth (Rajcan et al., 2004). Plant health can be evaluated in-season using satellites or drones to capture imagery which is used to calculate vegetation indices such as normalized difference vegetation index (NDVI), normalized difference red edge index (NDRE), or modified soil-adjusted vegetation index (MSAVI) (Voitik et al., 2023). These indices can also be used to predict corn yield. There is an ongoing need to explore effective cover crop management systems to maximize their benefits under varying environmental conditions.

OBJECTIVE

The objective of this study was to evaluate the impact of delayed termination of frost-seeded legume cover crops on corn health and yield.

PROCEDURES

Field research was conducted in 2023 and 2024 at the Lee Greenley Jr. Memorial Research Farm near Novelty, MO. The experiment was a factorial design with 6 replications of 48 treatments. Factors included cover crop species (red clover, crimson clover, hairy vetch, or non-seeded), termination timing (V2, V4, or V8), cover crop seed placement (broadcast or between-row), and nitrogen rate (0 or 120 lbs N acre^{-1}). Plots were 10 by 30 ft and each contained 4 rows of corn. Prior to cover crop seeding, a burndown herbicide application was made to remove winter annual weeds. Red clover, crimson clover, and hairy vetch were frost-seeded in the late winter/early spring, approximately six weeks prior to corn planting. Cover crops were either broadcast seeded with a hand spreader or seeded between corn rows using a two-row custom built garden seeder with 7.5 inch spacing between the two rows (EarthWay, Bristol, IN). Corn, DKC 67-44, was no-till planted at 35,000 seeds acre^{-1} into a field that was previously soybean. Field, cover crop, and corn management information is listed in Table 1.

At the V2 growth stage of corn development, nitrogen (SuperU®) was applied to the plots at 0 or 120 lb N acre^{-1}. Cover crops were terminated at either the V2, V4, or V8 corn growth stage. Before termination, aboveground cover crop biomass was collected from a 1 ft^2 quadrat randomly placed in the middle of the plot. Biomass was cut using handheld electric shearers and placed in a paper bag. The biomass was dried in an oven at 60°C for 48 hrs and weighed to determine dry matter production. Cover crops were terminated with an herbicide tank mixture applied with a pressurized CO_2 backpack sprayer, and were maintained weed-free with a herbicide application. The middle two corn rows of each plot were harvested with a Wintersteiger Quantum plot combine. Grain yield, test weight, and moisture were quantified using a HarvestMaster GrainGage for each plot. Grain yield was adjusted to 15% prior to analysis.

In 2024, a DJI Mavic 3M drone (Nanshan, Shenzhen, China) was used to capture aerial images of the field throughout the cropping season at V2, V4, V8, and VT. The drone was equipped with one 20MP RGB camera and four 5.5MP multispectral cameras capturing green (550 ± 16 nm), red (650 ± 16 nm), red edge (730 ± 16 nm), and near infrared (860 ± 26 nm) wavelengths. AgiSoft Metashape software was used to create orthomosaic images and ArcGIS Pro was used to calculate and extract vegetation indices (NDVI, NDRE, and MSAVI) from each plot. The vegetation indices were correlated to yield and nitrogen rate using a quadratic curve. The GLIMMIX procedure was used for data analysis at the 0.05 significance level (SAS statistical software). Least square means were separated using T-groupings.

RESULTS

Overall, yield was higher in 2024 compared to 2023 due to higher rainfall and more favorable growing conditions which affected interference of cover crops and removal timings differently (Figure 1). Corn yield was affected by an interaction between year, cover crop species, and termination timing. In both years and all cover crop species, yield was reduced when cover crops were removed at the V8 growth stage compared to V2 growth stage. Crimson clover did not affect yield when removed at V2 and V4 growth stages, but yield decreased by 12 bu acre^{-1} in 2023 and 18 bu acre^{-1} in 2024 when removed at V8 growth stage compared to V2 growth stage. Red clover had a greater effect on yield in 2023 than in 2024. In 2023, yield decreased 24 bu acre^{-1} with red clover from the V2 to V4 termination timing and 11 bu acre^{-1} from the V4 to V8 termination timing. In 2024, there was no difference between V2 and V4 termination timings, but yield decreased by 18 bu acre^{-1} when termination was delayed to V8 growth stage. Hairy vetch had the greatest effect on yield. Hairy vetch removed at V8 growth stage reduced yield 50 and 46 bu acre^{-1} in 2023 and 2024, respectively, compared to V2 growth stage.

An interaction between year, nitrogen rate, and termination timing also affected corn yield (Figure 2). In both years, yield was higher at 120 lbs N acre^{-1}compared to 0 lbs N acre^{-1}. In 2023 with 0 lbs N acre^{-1}, yield decreased by 12 bu acre^{-1}with each termination timing. At 120 lbs N acre^{-1}, yield decreased 19 and 11 bu acre^{-1}from V2 to V4 and V4 to V8, respectively, in 2023. In 2024, yield did not differ between V2 and V4 termination timings. From V2 to V8 termination, yield was reduced 15 bu acre^{-1}at 0 lbs N acre^{-1}and 39 bu acre^{-1}at 120 lbs N acre^{-1}.

Cover crop biomass at the time of termination was affected by year, cover crop species, seed placement, and termination timing (p=0.0258). Cover crop biomass was greater in 2023 than in 2024 which contributed to a yield response difference between years (data not presented).

NDVI, NDRE, and MSAVI were not strongly correlated to nitrogen rate or yield at V2 or V4 growth stage (data not presented). NDRE was strongly correlated to nitrogen rate at V8 (R^2=0.6072) and VT (R^2=0.8476). At V8, NDRE had the strongest correlation to yield (R^2=0.4903). At VT, NDVI (R^2= 0.7932) and NDRE (R^2=0.7558) was strongly correlated to yield (Figure 3). NDRE and NDVI at VT were both affected by an interaction between nitrogen rate, seed placement, and termination timing (Table 2). NDRE and NDVI were both greater when nitrogen was applied at 120 lbs N acre^{-1} compared to 0. NDVI was higher when cover crops were terminated at V2 compared to V8 when no nitrogen was applied and cover crops were seeded between corn rows. NDRE and NDVI was significantly greater when cover crops were terminated at V2 and V4 compared to V8 when cover crops were broadcasted and 120 lbs N acre^{-1} was applied. At 120 lbs N acre^{-1}, a higher NDRE and NDVI was observed for between-row seeded compared to broadcasted cover crops when cover crops were terminated at V8.

RECOMMENDATIONS

Delaying spring cover crop termination when planting corn should be avoided especially when large amounts of cover crop biomass is present. Cover crops should be terminated at or before corn growth stage V2 to reduce competition with corn and avoid yield loss later in the season. The effects on yield can be exacerbated when growing conditions are less favorable.

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Table 1. Field management of cover crops and corn in 2023 and 2024.

Field Operations	2023	2024
Fertilizer Application	Dec 7 2022	Mar 5
Source	MES10 + Potash	MAP + Potash + Elemental S
N-P_2O_5-K_2O-S (lb acre^{-1})	18-60-80-15	13-60-80-15
Cover Crops		
Frost-Seeding	Mar 13	Feb 27
Seeding Rate (lb acre^{-1})		
Red Clover	26	26
Crimson Clover	26	26
Hairy Vetch	96	96
Corn		
Planting	Apr 21	Apr 8
N Fertilizer Application	May 26	May 15
Cover Crop Termination		
V2 Growth Stage	May 26	May 15
V4 Growth Stage	June 5	May 20
V8 Growth Stage	June 29	June 10
Corn Harvest	Sept 27	Sept 20

Abbreviations: MES10, MicroEssentials® S10; Potash, muriate of potash; MAP, monoammonium phosphate

Table 2. Effect of nitrogen rate, seed placement, and cover crop termination timing on NDRE and NDVI values at VT growth stage. Means followed by similar letters within a column indicate no statistical difference at the 0.05 significance level.

Nitrogen Rate (lbs acre^{-1})	Seed Placement	Termination Timing	NDRE		NDVI	
0	Broadcast	V2	0.3969	c	0.8798	cd
		V4	0.3975	c	0.8764	d
		V8	0.4006	c	0.8791	cd
	Between Row	V2	0.4049	c	0.8813	c
		V4	0.4006	c	0.8777	cd
		V8	0.3952	c	0.8762	d
120	Broadcast	V2	0.4982	a	0.9063	a
		V4	0.499	a	0.9057	a
		V8	0.4861	b	0.9007	b
	Between Row	V2	0.4978	a	0.9052	ab
		V4	0.4961	ab	0.905	ab
		V8	0.4988	a	0.9071	a

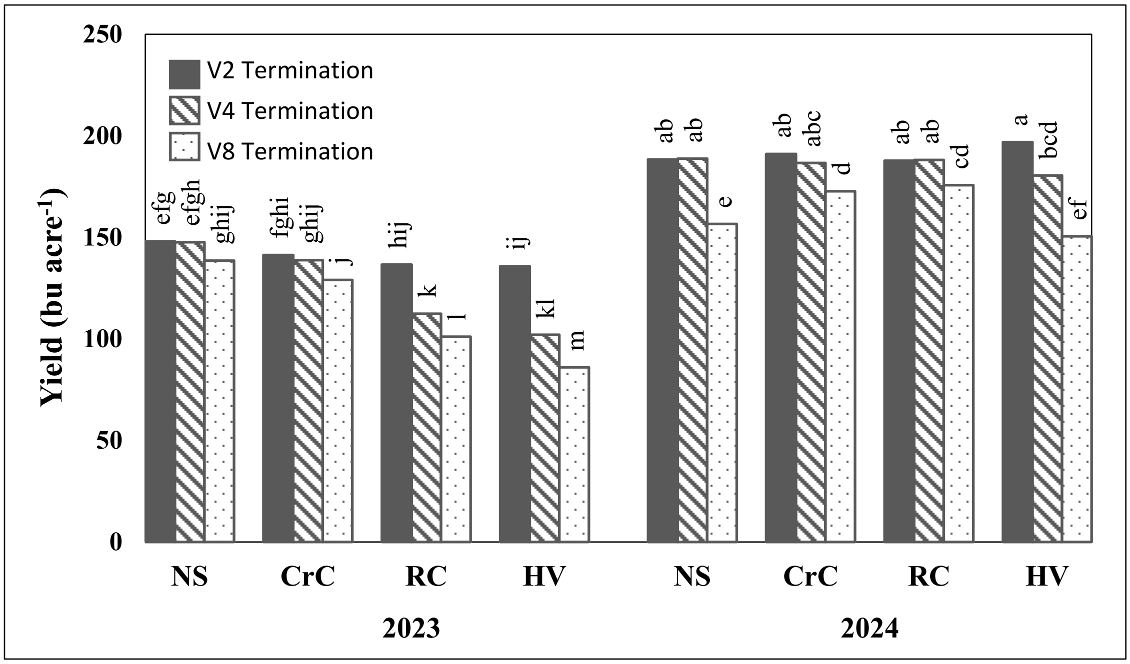

Figure 1. Effect of cover crop termination timing on corn yield for each cover crop species in 2023 and 2024. Similar letters on top of bars indicate no statistical difference between means at α = 0.05. NS is non-seeded control, CrC is crimson clover, RC is red clover, and HV is hairy vetch.

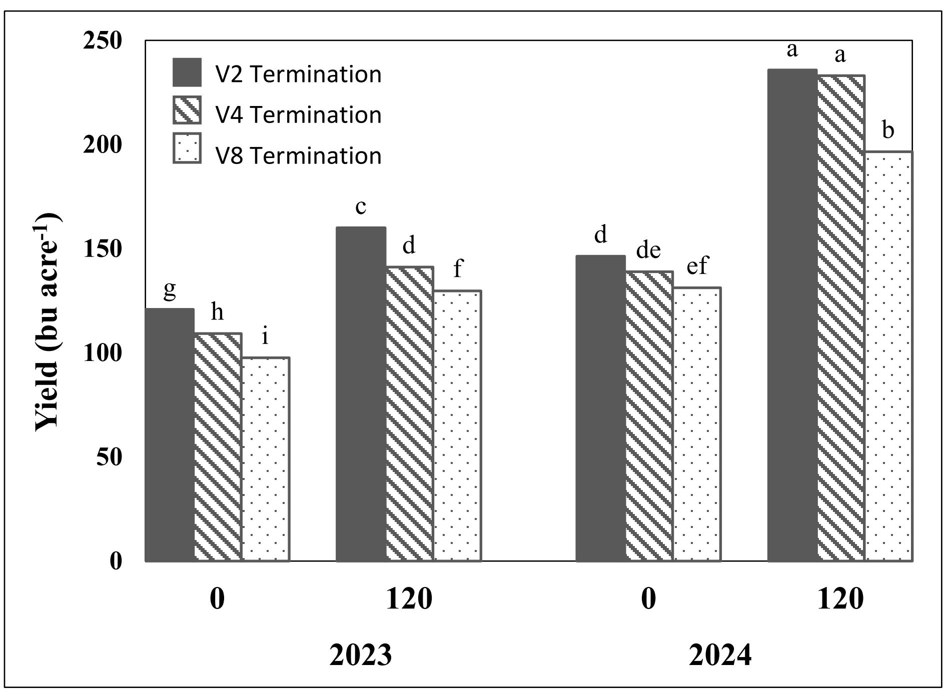

Figure 2. Effect of cover crop termination timing on corn yield at each nitrogen rate (0 or 120 lbs N acre^{-1}) in 2023 and 2024. Similar letters on top of bars indicate no statistical difference between means at α = 0.05.

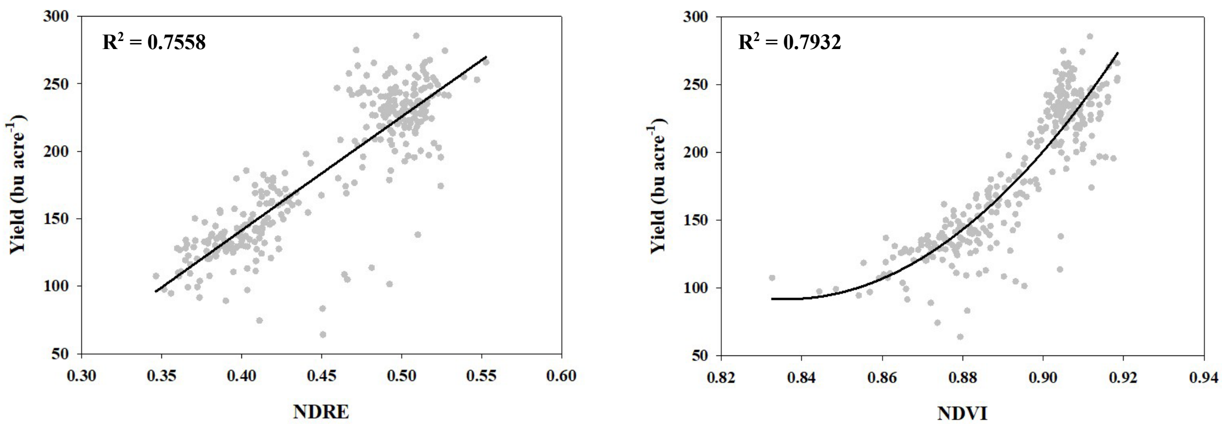

Figure 3. Corn yield correlation to NDRE (left) and NDVI (right) at the VT growth stage in 2024.

EVALUATION OF POLY4 AS A MULTI-NUTRIENT FERTILIZER SOURCE FOR SOYBEAN PRODUCTION SYSTEMS

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INTRODUCTION

Soybean production in Missouri requires balanced nutrient management to sustain high yields and maintain soil fertility. Missouri produced approximately 289 million bu of soybean from 5.84 million acres of soybean in 2024, making soybean one of the most economically important crops in the state (USDA-NASS, 2025). However, the high clay content of many Missouri soils can create temporary flooding and drought conditions, which can restrict the potassium (K) mobility and reduce plant uptake (Nelson & Motavalli, 2007). In addition, a decline in atmospheric sulfur (S) deposition into agricultural soils has occurred over the past few decades due to strict laws on safe industrial emissions and the use of high-analysis fertilizers with no or low S content. Reports have shown a nearly 80% reduction in S deposition across the Midwest US between 2000 and 2021 (USEPA, 2021). As a result, crops including corn and soybean have increasingly shown a response to S fertilization across the Midwestern region.

POLY4, a novel naturally occurring polyhalite fertilizer, has gained attention as an alternative multi-nutrient fertilizer source because it supplies 11.6% K, 19% S, 12.2% Ca, and 3.6% Mg in a single product (Mann et al., 2025). POLY4 also has gradual nutrient release properties, low chloride and salt index and minimal environmental impacts as compared with many conventional fertilizers (Gopinath et al., 2024; Sirius Minerals, 2016). Other available sources of K and S include ammonium sulfate (AMS), muriate of potash (MOP), and K-Mag, among which MOP and AMS are the commonly used K and S fertilizer sources, respectively, in Missouri. However, limited information is available regarding the performance of POLY4 in Missouri soybean production systems.

OBJECTIVE

The objective of this study was to evaluate the soybean response to K and S sources and POLY4 application rates.

PROCEDURES

Field experiments were conducted for three consecutive years (2023 - 2025). In 2023, the experiment was conducted at the grower's farm near Millard (Adair), whereas the experiments were conducted at the University of Missouri Ross Jones Farm near Bethel (Shelby County) in 2024 and 2025. The experimental design was a randomized complete block design with four replications. Treatments included different sources of K and S, as shown in Table 1, and S application rates from POLY4 (0, 10, 19, 28, and 38 lb S ac^{-1}). The fertilizer was broadcast applied before planting. Trial details related to important field operations are included in Table 2. In 2024 and 2025, the study included early and late planting of soybean with a gap of one month, with the same treatments. The soil series at the Bethel location was Putnam silt loam, characterized by claypan subsoil with poor hydraulic conductivity. The Millard location was dominated by Armstrong silt loam. The plot size was 10 by 40 ft with a row spacing of 15 inches at all the site-years. A late planting treatment was not included in 2023 therefore, all observations from that year were assigned to the early planting category based on their planting date. For the K and S source evaluation, the standard K rate in 2023 and 2024 was 62 lb K ac^{-1} while it was 50 lb K ac^{-1} in 2025 and S rate was 19 lb S ac^{-1} for all the site-years. At physiological maturity, the crop was harvested using a plot combine and yield was determined by automated yield monitor mounted on the plot combine. The yield data was adjusted to 13% moisture content.

The data was analyzed using GLIMMIX procedure at a significance level of 0.05 in the SAS software (SAS version 9.4, SAS Institute, Cary, NC). Separate analyses were conducted for the K source and S source evaluations. In each analysis, treatment, site-year, and their interaction (treatment × site-year) were included as fixed effects, whereas replication nested within site-year was treated as a random effect. Least-squares means were estimated and compared using Tukey's honestly significant difference (HSD) test at $P \leq 0.05$. Quadratic Plateau curve was fit to determine agronomic optimum S rate (AOSR) and yield at AOSR (YAOSR) using Sigmaplot (Systat Software Inc., San Jose, CA). The S rate at which the yield was highest and beyond which there was no yield increase was determined as AOSR, and the corresponding highest yield was referred to as YAOSR.

RESULTS

Both K and S sources significantly affected soybean grain yield across the site-years, whereas the yield differences were limited within individual site-years (Figure 1). The untreated control plots consistently produced the lowest yields, ranging from 55.7 to 63.0 bu ac^{-1} across environments. The greatest response to K sources was observed in 2024 in early planting, where MOP + AMS produced the highest yield of 71.7 bu ac^{-1}, followed closely by POLY4 with 70.6 bu ac^{-1}. In 2025, early-planted K-Mag + MOP produced the highest yield of 69.4 bu ac^{-1}. Across all the site-years, POLY4 consistently produced yields comparable to other K fertilizer sources including MOP, MOP + AMS, and K-Mag + MOP ranging from 59.0 to 70.6 bu ac^{-1}.

Among the S sources, early planting in 2024 yielded the greatest response. MOP + AMS produced the highest yield of 71.7 bu ac^{-1}, and POLY4 + MOP produced a comparable yield of 69.4 bu ac^{-1}. POLY4 + MOP application produced soybean yields ranging between 63.8 to 69.9 bu ac^{-1}, which are comparable to others. The comparable performance among fertilizer sources suggests that soybean yield was more strongly influenced by nutrient availability and environmental conditions than by the specific fertilizer source used. In the early planting, the AOSR value was 8.6 lb S ac^{-1} resulting in YAOSR of 67.0 bu ac^{-1} (Figure 2). For the late-planted soybean, the AOSR was 12.6 lb S ac^{-1} with a corresponding YAOSR of 64.6 bu ac^{-1}. This response indicates that sulfur requirements were satisfied at relatively low application rates and that additional S inputs provided limited agronomic benefit.

RECOMMENDATIONS

POLY4 can be recommended as an alternative fertilizer option for soybean farmers in Missouri. Using balanced K and S fertilizers helps to increase soyabean yields compared to the untreated control. Moderate S fertilization (8.6-12.6 lb S ac^{-1}) may be adequate for maximizing productivity while avoiding unnecessary fertilizer inputs.

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Table 1. Treatment list for comparing K and S sources and the amounts of nutrients supplied by the fertilizer sources.

Treatments	K (2023, 2024)	K (2025)	S	Ca	Mg
	---lb ac^{-1}---				
K sources					
Control	0	0	0	0	0
MOP[a]	62	50	0	0	0
MOP + AMS	62	50	19	0	0
K-Mag + MOP	15 + 47[b]	15 + 35	19	9	0
POLY4	62	50	102/81[c]	65/53	20/15
S sources					
Control	0	0	0	0	0
AMS	0	0	19	0	0
MOP + AMS	62	50	19	0	0
K-Mag + MOP	15 + 47[a]	15 + 35	19	9	0
POLY4 + MOP	12 + 51	12 + 38	19	12	4

[a]Abbreviations: AMS, ammonium sulfate; K-Mag, langbeinite ($K_2Mg_2(SO_4)_3$); MOP, muriate of potash (KCl); POLY4, polyhalite ($K_2CaMg(SO_4)_4 \cdot 2H_2O$); K, potassium; S, sulfur; Ca, calcium; Mg, magnesium.

[b]K balanced with MOP.

[c]Values represent different application rates used in 2025.

Table 2. List of important field operations in each site-year during the growing period.

Parameter	2023	2024 Early	2024 Late	2025 Early	2025 Late
Cultivar	AG38XF1	GH3994E3	GH3994E3	X03705E	X03705E
Population (seeds ac^{-1})	180,000	180,000	180,000	180,000	180,000
Planting	18-Apr	15-Apr	13-May	16-Apr	14-May
Fertilizer application	11-May	8-Apr	8-Apr	11-Apr	10-Apr
Tissue sampling	19-Jul	23-Jul	23-Jul	8-Jul	17-Jul
Soil sampling	2-Nov	22-Nov	22-Nov	14-Nov	16-Nov
Harvesting	6-Oct	29-Sep	29-Sep	2-Oct	2-Oct

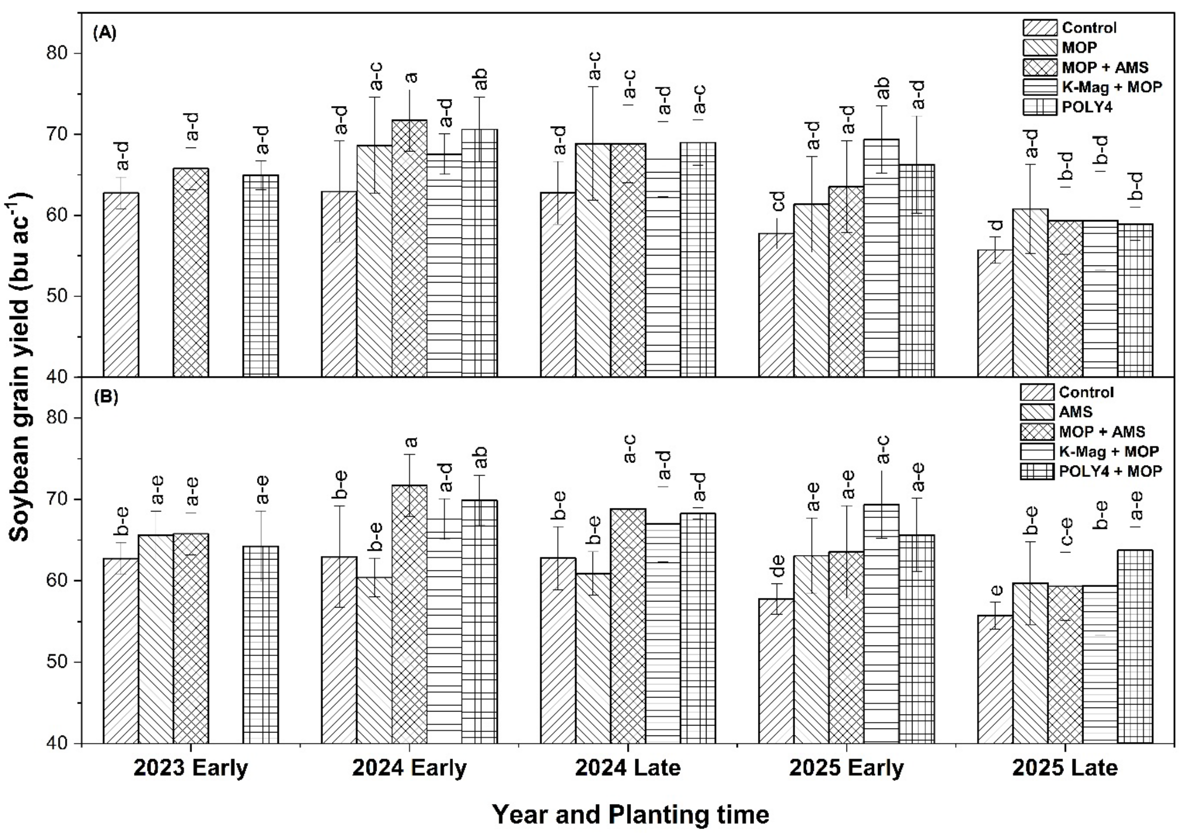

Figure 1. Soybean grain yield response to different sources of K (A) and S (B) across years and planting times (early and late). Bars with same letter are not significantly different from each other at 0.05 significance level. Error bars above the columns represent ±1 standard deviation (SD). Some treatments are absent in 2023 because they were not included in the experimental design during that year.

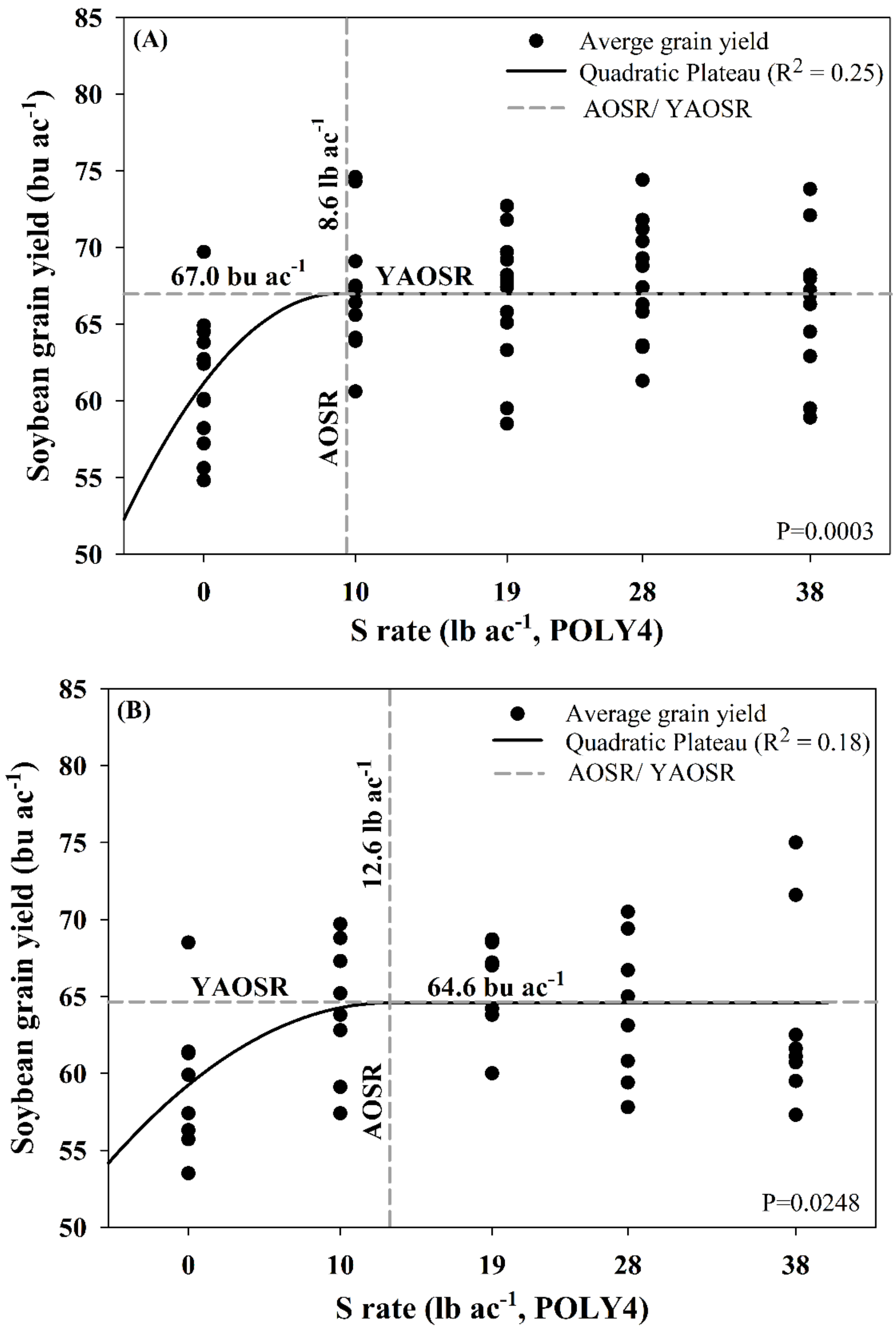

Figure 2. Quadratic-plateau model showing soybean seed yield response to S rates applied as POLY4 across planting times. (A) early planted soybean and (B) late-planted soybean. The plateau point indicates the agronomic optimum sulfur rate (AOSR) and the corresponding yield at AOSR (YAOSR). For early planting the data is pooled across the years 2023-2025 and for late planting the data included 2024-2025.

IN-SEASON POTASSIUM MANAGEMENT STRATEGIES FOR SOYBEAN PRODUCTION IN MISSOURI

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INTRODUCTION

Soybean production requires efficient potassium (K) management to sustain high grain yield and maintain crop nutritional status throughout the growing season. Potassium is involved in several physiological processes in plants including photosynthesis, enzyme activation, water regulation, and seed development. Soybean removes large quantities of K during reproductive growth stages, yet many Missouri soils contain high clay content and claypan layers that can restrict root growth and reduce K mobility under wet or dry conditions (Nelson & Motavalli, 2007). Current Missouri recommendations for soybean are based on exchangeable soil K and cation exchange capacity (CEC), where the desired soil-test K level for row crops is 220 lb K ac^{-1} plus five times the soil CEC (Buchholz et al., 2004).

Potassium deficiency is among the most common nutrient limitations in soybean production, and positive yield responses to K fertilization have been widely reported (Borges & Mallarino, 2000; Parvej et al., 2016). Previous studies showed that soybean leaf and petiole K concentrations decline progressively during reproductive development and are positively associated with soybean relative yield (Hanway & Weber, 1971; Parvej et al., 2015). Since soybean K demand continues throughout reproductive growth, temporary K deficiencies may develop during the growing season even when pre-plant fertilizer is applied. Therefore, in-season K applications may help maintain adequate tissue K concentrations and improve soybean productivity under conditions where soil K uptake becomes limited. However, limited information is available regarding the effectiveness of different K application timings on soybean yield, grain quality, and tissue K concentrations under Missouri growing conditions.

OBJECTIVE

The objective of this study was to evaluate effects of potassium fertilizer application timing and rate on soybean grain yield and tissue K concentration.

PROCEDURES

A field experiment was conducted in 2025 at the Ross Jones Farm near Bethel in Shelby County, Missouri. Soybean variety XO 3705E was planted on 17 April 2025 in plots measuring 10 × 50 ft. The study was designed as a randomized complete block with four replications. Treatments consisted of three K fertilizer application timings including pre-plant, 5 days after R1 growth stage (5DAR1), and 20 days after R1 growth stage (20DAR1), combined with multiple K application rates. Pre-plant K treatments included K application rates of 0, 25, 50, 75, 100, and 125 lb K ac^{-1}, whereas 5DAR1 and 20DAR1 treatments included 0, 50, and 100 lb K ac^{-1} application rates Fertilizer applications were made according to the designated treatment timing, with pre-plant fertilizer applied on 10 April 2025 and in-season K applications applied on 7 July 2025 (5DAR1) and 22 July 2025 (20DAR1). Fertilizer source was muriate of potash (MOP) which was broadcast. For leaf sampling, top fully expanded 20 trifoliate leaves were collected at 5, 20, 35, 50, and 65 days after R1 growth stage (DAR1). Leaf samples were analyzed for nutrient concentrations to evaluate soybean K dynamics during reproductive growth. Soybean grain yield was measured at harvest on 2 October 2025 using a plot combine.

Data were analyzed using the GLIMMIX procedure in SAS software (Version 9.4; SAS Institute Inc., Cary, NC) at a significance level of $\alpha = 0.05$. Potassium application timing, K rate, and their interaction (timing × rate) were considered fixed effects, whereas replication was treated as a random effect. Least-squares means were estimated and separated using Tukey's honestly significant difference (HSD) test at $P \leq 0.05$. Correlation analysis was used to evaluate relationships between tissue K concentrations and soybean grain yield. Coefficient of determination (R^2) was used to identify the sampling timing that is most strongly associated with soybean grain yield. Agronomic optimum potassium rate (AOKR), defined as the K fertilizer rate required to maximize soybean grain yield, and yield at the agronomic optimum potassium rate (YAOKR), defined as the corresponding predicted maximum grain yield, were estimated using quadratic-plateau regression models fitted in SigmaPlot (Version XX, Systat Software Inc., San Jose, CA).

RESULTS

Soybean grain yield responded positively to K application rates. The soybean yield was lowest in untreated control plots without any K fertilizer application (Table 1). For pre-plant K application treatments, the soybean yield increased from 58.8 to 67.9 bu ac^{-1} with increase in K application from 0 lb K ac^{-1} to 100 lb K ac^{-1} (Table 1). In-season K applications at 5 DAR1 and 20 DAR1 also improved soybean yields with the K application rates of 50 and 100 lb K ac^{-1}. Quadratic plateau curve showed an AOKR of 75.8 lb ac^{-1}, which produced a corresponding YAOKR of 67.3 bu ac^{-1} (Figure 1). This response indicates that soybean yield approached its maximum value at moderate K application rates and additional K inputs beyond the AOKR provided limited yield benefits.

Leaf K concentrations during reproductive growth were positively associated with soybean grain yield and generally declined as the crop progressed through reproductive development. Leaf K concentrations measured at 20 DAR1 showed the strongest relationship with yield, whereas tissue K concentrations measured at 65 DAR1 showed limited diagnostic value (Table 2). These results suggest that leaf K concentration measured during the early reproductive period is a more reliable indicator of soybean yield response to K fertilization than measurements collected later in the season. Leaf K concentration at 20 DAR1 ranged from 1.05 to 1.31% across application timings, while leaf K concentration at 35 DAR1 ranged from 1.21 to 1.44% (Figure 2). Leaf K concentrations declined throughout reproductive development across all treatments, reaching 0.62-0.73% at 65 DAR1.

RECOMMENDATIONS

1. Soybean grain yield increased with K fertilization, and the quadratic-plateau model identified an AOKR of 75.8 lb K ac^{-1}, corresponding to a YAOKR of 67.3 bu ac^{-1}.
2. In-season K applications at 5 and 20 DAR1 produced yields comparable to pre-plant applications when adequate K rates were supplied, indicating that application timing had less influence on yield than K rate.
3. Leaf K concentration measured at 20 DAR1 showed the strongest relationship with soybean grain yield, whereas tissue K concentrations measured later in the season had lower predictive value.

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Table 1. Effect of potassium application timing and rate on soybean grain yield. Means followed by different letters within a column are significantly different at $\alpha = 0.05$.

K Application Timing	K Rate (lb K ac^{-1})	Soybean Grain Yield (bu ac^{-1})
Pre-plant	0	58.8 cd
	25	65.3 ab
	50	64.9 ab
	75	67.2 a
	100	67.9 a
	125	67.4 a
5 DAR1	0	60.2 d
	50	63.9 bc
	100	66.2 ab
20 DAR1	0	61.4 d
	50	62.2 bc
	100	67.9 a
p-value		<0.0001

Abbreviations: DAR1, days after R1 growth stage; K, potassium.

Table 2. Correlation between leaf potassium concentration at different reproductive growth stages and soybean grain yield.

Sampling timing	r	P-value	R^2
5 DAR1	0.603	0.0003	0.364
20 DAR1	0.684	<0.0001	0.467
35 DAR1	0.525	0.0042	0.275
50 DAR1	0.641	0.0023	0.411
65 DAR1	0.411	0.0721	0.169

Abbreviations: DAR1, days after R1 growth stage; r, Pearson correlation coefficient; R^2, coefficient of determination.

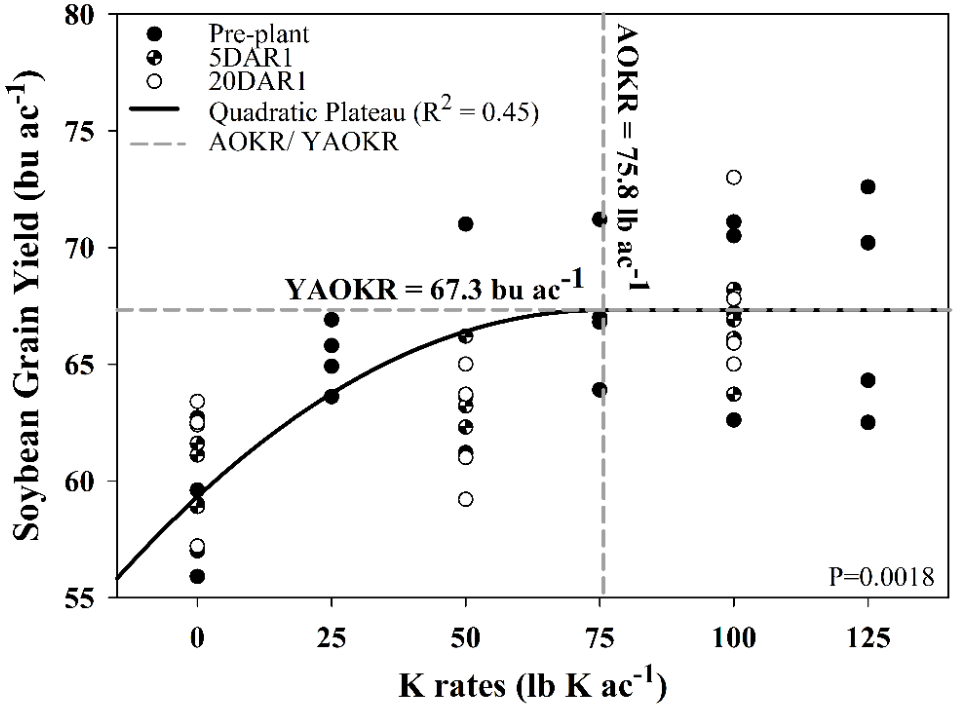

Figure 1. Quadratic plateau curve showing soybean yield response to K application rates at pre-planting. Different symbols represent different application timings where DAR1 = days after R1 stage, AOKR = agronomic optimum potassium rate, and YAOKR = yield at AOKR.

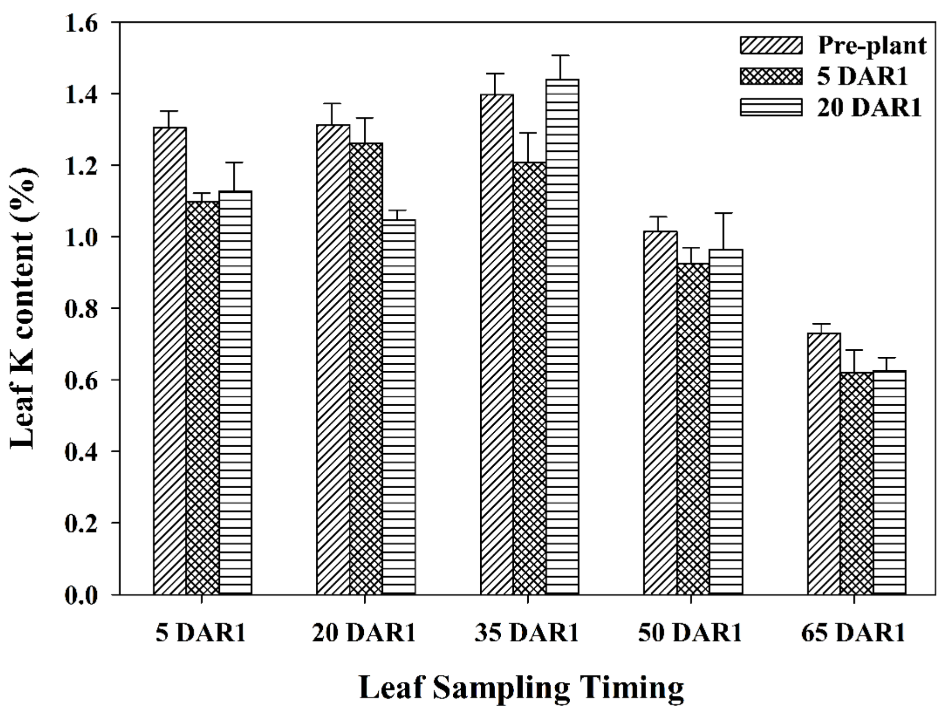

Figure 2. Leaf potassium (K) content in different fertilizer application timings at different reproductive stages. Abbreviations, DAR1, days after R1 growth stage. Error bars are representing ±1 standard deviation.

CORN YIELD RESPONSE TO NITROGEN RATE AND APPLICATION TIMING ACROSS DIFFERENT TOPOGRAPHIC POSITIONS

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INTRODUCTION

Efficient nitrogen (N) management is essential for profitable and sustainable corn production. The 4R nutrient stewardship principles have been developed to guide strategies for effective nutrient management. These principles include applying the right fertilizer source at the right rate, the right time, and the right place (Pandit et al., 2025). Proper N management focuses on synchronizing N applications with crop demand to minimize environmental loss and increase N use efficiency (NUE). Corn plants uptake N throughout the growing season, with peak demand in late vegetative and early reproductive growth stages (Bender et al., 2013). Delaying N application to the V6 growth stage can maximize plant N uptake, reduce N loss, and increase NUE without affecting yield (Walsh et al., 2012).

Poor drainage, variable precipitation, and differences in topography in Missouri soils make N management challenging. Differences in landscape position and slope affects water movement and N availability which influences corn yield response to N applications (Zhu et al., 2015). As a result, N requirements can vary throughout a field. Site-specific N management strategies based on topographic positions can target in-field variability to optimize N application rates, reduce N loss, and improve NUE.

OBJECTIVE

The objective of this study is to evaluate N rate and application timing across field topographic positions (shoulder, backslope, and footslope) to improve N management strategies for corn production in northeast Missouri.

PROCEDURES

A field trial was conducted at the Lee Greenley Jr. Memorial Research Farm located near Novelty, Missouri in 2025 and will continue in 2026. The soil series of this field is split between Kilwinning silt loam and Putnam silt loam. Both soils are deep and poorly drained with a prominent claypan layer. The field topography creates three landscape positions across the field (footslope, backslope, and shoulder). The experiment was a split-plot design with three replications. The whole-plot was landscape position, and the sub-plots were N rate and application timing. The field was 300’ x 1500’ and plots included 4 rows of corn with varying lengths depending on the landscape position. Nitrogen was applied as urea ammonium nitrate (UAN 32%) at 0, 60, 120, 180, and 240 lbs N acre^{-1} prior to planting or at the V6 growth stage. A custom fertilizer applicator built with a precision liquid rate control system (Precision Planting, Tremont, IL) was used to band UAN between corn rows at both application timings.

Corn, DKC 63-57, was planted at 35,000 seeds acre^{-1} in 30-inch rows following soybean. Monoammonium phosphate (MAP) and potash (KCl) were applied in the spring as maintenance fertilizer at 13-60-100 lb N-P-K acre^{-1}. Weed control included a burndown herbicide application of glyphosate at 1.5 lb a.i. acre^{-1} (Glypex 5 Extra), a premix of saflufenacil at 0.02 lb a.i. acre^{-1} and dimethenamid-P at 0.20 lb a.i. acre^{-1} (Verdict), methylated seed oil (MSO) at 12 fl oz acre^{-1}, and UAN at 8 fl oz acre^{-1}. In addition, there was a preemergent application of a premix of atrazine at 2.02 lb a.i. acre^{-1} plus S-metolachlor at 1.56 lb a.i. acre^{-1} (Bicep II Magnum), mesotrione at 0.16 lb a.i. acre^{-1} (Cavallo 4 SC), glyphosate at 1 lb a.i. acre^{-1} (Sunphosate 5 MAX), and crop oil at 4 oz acre^{-1}.

Corn was harvested with a commercial combine, and a yield monitor was used to collect point yield data. Yield data were cleaned, extracted, averaged for each plot, and adjusted to 15% moisture content prior to analysis. Partial factor productivity (PFP) was calculated for each plot to evaluate the efficiency of N use using the following equation: PFP = grain yield / N fertilizer rate. Nitrogen from the MAP fertilizer applied in early spring was included in the calculation. Data were analyzed using the GLIMMIX procedure in SAS statistical software at the 0.05 significance level. Least square means were separated using T-groupings. The agronomic optimal N rate (AONR) was calculated for each landscape position and application timing using quadratic and linear plateau curves. AONR is the N rate at which yield is maximized. The economic optimal N rate (EONR) was calculated based on the quadratic plateau curve using a corn price of $4 bu^{-1} and a N price of $1 lb^{-1}. EONR represents the N rate where profit is maximized. The EONR is equal to the AONR on the linear plateau curves. Y-AONR and Y-EONR represent the yield at the AONR and EONR.

RESULTS

Yield was 12 bu acre^{-1} higher when N application was delayed compared to the preplant application (p=0.0019). Yield was affected by an interaction between landscape position and N rate (p=0.0081). At the footslope, yield increased with each additional N rate. At the backslope, yield increased with each rate up to 180 lbs N acre^{-1} but did not change between 180 to 240 lbs N acre^{-1}. At the shoulder, yield increased up to 120 lbs N acre^{-1}, then leveled off (Figure 1). When no N was applied, yield did not differ between landscape positions. When N was applied, yield was 20 to 65 bu acre^{-1} higher at the shoulder and backslope compared to the footslope. As the N rate increased, the gap between yields in the footslope and yields at the backslope and shoulder decreased. At 240 lbs N acre^{-1} there was no difference in yields between the landscape positions (Figure 1).

Partial factor productivity (PFP) was significantly greater when N was delayed to V6 compared to the preplant application (p=0.0028). PFP was also influenced by an interaction between N rate and landscape position (p<0.0001). PFP decreased with increasing N rate on the footslope, backslope, and shoulder. At 60 and 120 lbs N acre^{-1}, PFP was higher at the shoulder and backslope and lower at the footslope. At 180 and 240 lbs N acre^{-1}, PFP did not differ among landscape positions (Table 1).

The AONR was lower when N was applied as a delayed application compared to a preplant application. This suggests that less N is needed to maximize yield when N application is delayed to V6. The AONR differs depending on whether a linear plateau or quadratic plateau model is used. At the footslope, the quadratic curve did not reach a plateau, so an AONR cannot be determined. The AONR based on the linear plateau was 57 lbs acre^{-1} lower with delayed N application (Figure 2). At the backslope, the AONR decreased 110 and 76 lbs acre^{-1} for the QP and LP model, respectively, with a delayed N application (Figure 3). The AONR at the shoulder for the QP and LP model decreased 50 and 45 lbs acre^{-1}, respectively, when N was delayed to V6 (Figure 4).

Similar to the AONR, the EONR was also lower with a delayed application of N indicating that less N was needed to maximize profits when N application was applied at V6. For the linear plateau model, the difference between EONR of the preplant and delayed application was 57, 76, and 45 lbs acre^{-1} for the footslope, backslope, and shoulder, respectively. The differences between the N application timings for the quadratic plateau model were 74 and 41 lbs acre^{-1} for the backslope and shoulder, respectively (Figures 2-4).

RECOMMENDATIONS

Our first-year data showed that delayed N application increased yield and NUE, while reducing the total amount of N needed to reach maximum yields and profits. Landscape positions have different yield responses to N application rates. Targeting the optimal rate for each landscape position can help make N applications more efficient.

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Table 1. Partial factor productivity (PFP) for each landscape and nitrogen (N) rate. Within a column, mean values with similar letters are not significantly different from each other at the 0.05 significance level.

N Rate (lb acre^{-1})	Landscape Position	PFP (lb lb^{-1})
60	Footslope	1.82b
	Backslope	2.72a
	Shoulder	2.54a
120	Footslope	1.37c
	Backslope	1.67b
	Shoulder	1.69b
180	Footslope	1.15de
	Backslope	1.27cd
	Shoulder	1.25cd
240	Footslope	0.94f
	Backslope	0.97ef
	Shoulder	0.96ef

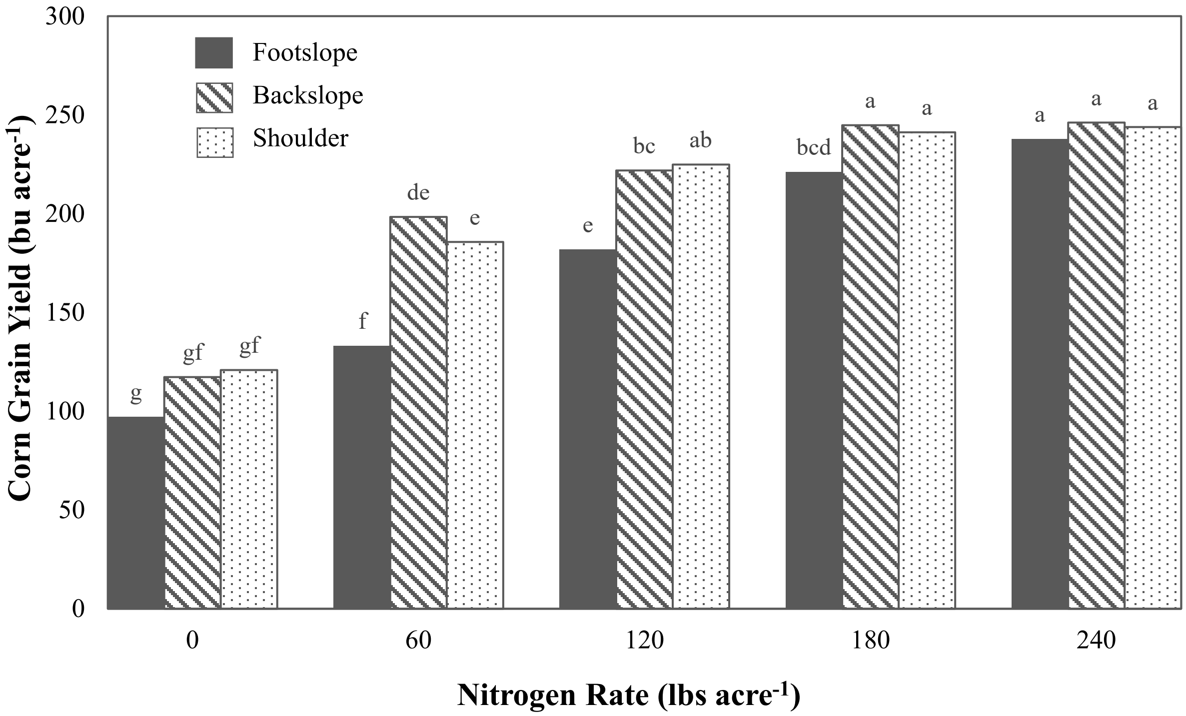

Figure 1. Corn grain yield at each landscape position and nitrogen application rate. Similar letter on top of bars indicates no statistical difference between means at the 0.05 significance level.

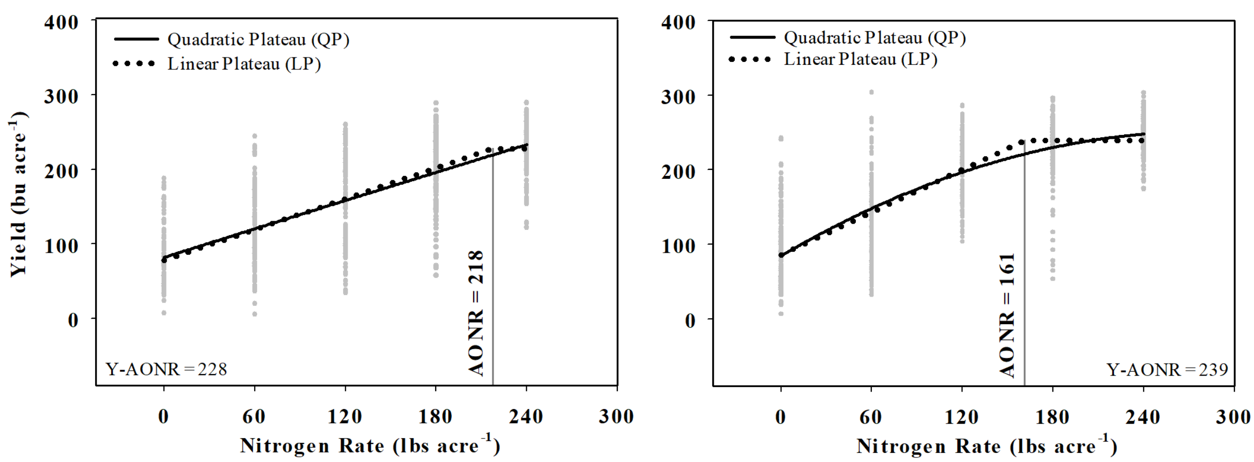

Figure 2. Corn yield response to nitrogen rate at the footslope topographic position with a preplant (left) or V6 (right) nitrogen application. Y-AONR and Y-EONR are yields at AONR and EONR.

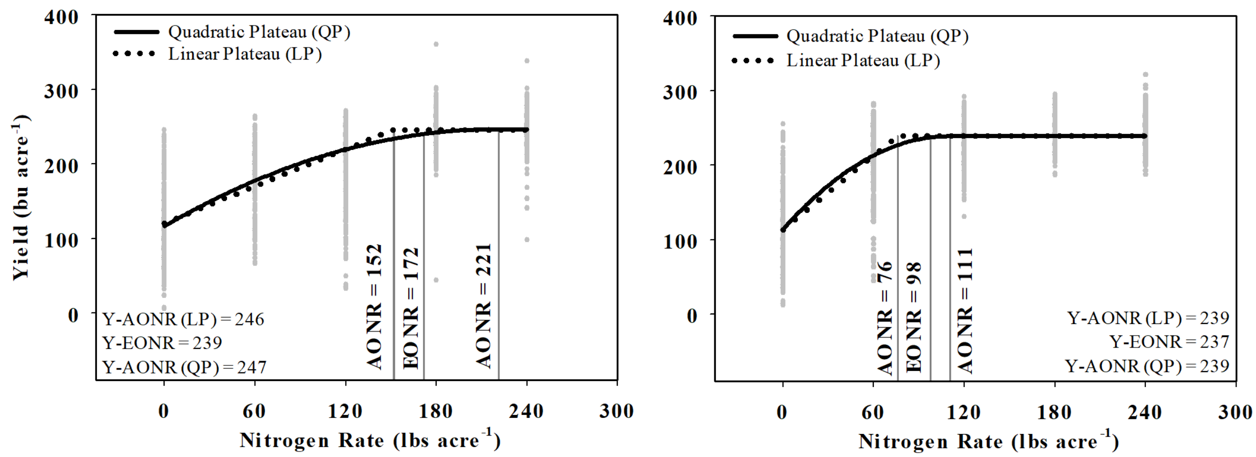

Figure 3. Corn yield response to nitrogen rate at the backslope topographic position with a preplant (left) or V6 (right) nitrogen application. Y-AONR and Y-EONR are yields at AONR and EONR.

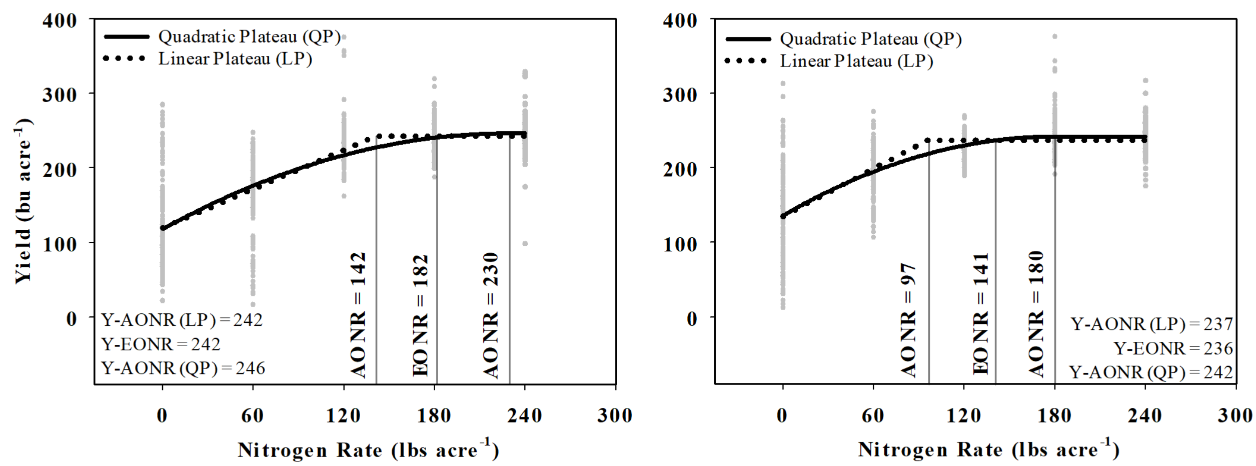

Figure 4. Corn yield response to nitrogen rate at the shoulder topographic position with a preplant (left) or V6 (right) nitrogen application. Y-AONR and Y-EONR is yield at AONR and EONR.

TOPOGRAPHIC POSITIONS AND NITRIFICATION INHIBITORS AFFECTS CORN GRAIN YIELD AND PRODUCTIVITY

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INTRODUCTION

Field topographic positions (TPs) affect the spatial distribution of soil organic matter, nutrients, and water. In Missouri, corn and soybean fields are highly variable in slope, ranging from 0 to 20% or higher, which creates high variability in soil and growing conditions for these crops. Topographic positions affect nitrogen (N) dynamics. Higher yields were typically observed in well-drained upper slopes and lower yields at the footslope due to water accumulation (Singh et al., 2022). However, lower TPs, such as the footslope, can outperform upper slopes during dry years because of increased moisture retention, particularly on claypan soils (Gentry et al., 2009). That indicates yield depends on weather conditions and precipitation received each year. A good productive zone in a dry year can be a low-productive zone in a wet year.

Adding a nitrification inhibitor (NI) to N fertilizer can address problems with nitrogen use efficiency (NUE) and reduce losses across slope positions under varying climatic conditions (Steusloff et al., 2019). Studies have shown that applying nitrapyrin with anhydrous ammonia (AA) on claypan soils can reduce N losses by 20 to 55% and increase corn yields 10 to 68 bu ac^{-1} under various conditions (Nelson et al., 2017). Given the topographic influences on soil properties, runoff, evapotranspiration, and N use efficiency, effective ways to incorporate spatial variation into N management for corn are not fully developed, and this needs to be addressed.

OBJECTIVES

This study aims to evaluate the efficacy of NI, nitrapyrin (N-Serve®) and pronitridine (Centuro™) on corn grain yield and productivity across three different TPs (shoulder, backslope, and footslope).

PROCEDURES

The field study started in 2023 and continued through 2026 at the University of Missouri Lee Greenley Jr. Memorial Research Farm near Novelty, MO. The soil series of the experimental field are classified as Kilwinning silt loam (fine, smectitic, mesic Vertic Epiaqualfs) and Putnam silt loam (fine, smectitic, mesic Vertic Albaqualfs) with a saturated hydraulic conductivity of <0.06 inches hr^{-1}. The experiment layout was a split-plot design with four replications. The main plots were three TPs, including shoulder, backslope, and footslope positions, were classified similar to Singh et al. (2022) using the Topographic Position Index (TPI) model. The subplots were N fertilizer applied at different application rates (0, 120 and 180 lb ac^{-1}) either alone or with NI (Centuro or N-Serve). The combinations with NI were 120 lb N ac^{-1} + pronitridine (120 N + Centuro), 120 lb N ac^{-1} + nitrapyrin (120 N + N-Serve), 180 lb N ac^{-1}+ pronitridine (180 N + Centuro), and 180 lb N ac^{-1} + nitrapyrin (180 N + N-Serve). Anhydrous ammonia was spring-applied using a John Deere 2510 (Moline, IL). Nitrification inhibitors were co-injected downstream with AA using an in-furrow injection system as described in Singh & Nelson (2019). Nitrapyrin was applied at 32 oz ac^{-1} and pronitridine was applied at 20 qt ton^{-1} of AA. The plot size was 10 ft wide and length varied based on the modeled TP layout. Corn was planted using a Kinze planter (Kinze Manufacturing, Williamsburg, IA) at a seeding rate of 35,000 seeds ac^{-1} and a row spacing of 30 inches.

Corn was harvested with a John Deere S780 commercial combine (Moline, IL, USA) equipped with a calibrated yield monitor for accurate weight measurements. The yield monitor collected point yield data every second, including parameters such as duration, swath width, travel distance, track angle, moisture content, and mass flow (Sudduth et al., 2015). The recorded yield data were processed using Ag Leader SMS software (Ames, IA, USA) adhering to quality control measures to filter out erroneous data points based on specific thresholds (duration: <0.99 s or >1.01 s, swath: ≠10 ft, distance: < 0.915 m, track degree: >10 ° & <170 °, >90 ° & <350 °, moisture: >22 %). Yield data for each treatment were extracted by overlaying TP and N-rate treatment maps in ArcGIS Pro v3.1 (ESRI, Redlands, CA, USA). Grain yield was standardized to a moisture content of 15% before data analysis.

The following formulas (Synder & Bruulsema, 2007) were used to calculate efficiencies for the N rates receiving the two NIs and expressed in lb lb^{-1}:

1. Agronomic efficiency (AE) = $\frac{\textbf{Grain yield with N fertilizer} - \textbf{Grain yield in control treatment}}{\textbf{Amount of N fertilizer applied}}$
2. Partial factor productivity = $\frac{\textbf{Grain yield with N fertilizer}}{\textbf{Amount of N fertilizer applied}}$

All data were subjected to normality analysis using the univariate procedure and were analyzed using the GLIMMIX procedure in the SAS software v.9.4 (SAS Institute, Cary NC) at a significance level of $p = 0.05$ for the Type-3 fixed effect model. The independent variables for the study were N application rate and topographic positions, and random variables were replications. The least squared mean differences and contrast comparisons were performed using T-grouping at $p = 0.05$.

RESULTS

Corn Grain Yield

The corn grain yield varied significantly ($p<0.0001$) across N treatments at each TP when averaged over three years (2023-2025) (Table 1). At the shoulder position, 180 N + Centuro had the highest yield, similar to 180 N applied alone. The addition of Centuro with 120 lb N ac^{-1} resulted in a 7% significantly higher yield than 120 lb N ac^{-1} applied alone. N-Serve didn't have a significant improvement in yield with 120 N and with 180 lb N ac^{-1}. At backslope position, there was only a slight improvement in yield with Centuro at 180 lb N (4%). N-Serve and Centuro did not provide any yield benefit when applied with 120 N and 180N at the footslope position. The shoulder positions yielded higher than the other two TPs ($p<0.0001$; data not reported).

Nitrogen Use Efficiencies

Partial factor productivity differed significantly among topographic positions ($p=0.0183$) and N treatments ($p=0.0003$; Table 2). Across topographic positions, the footslope position had lower PFP than the shoulder and backslope positions. This indicated more efficient grain production per lb of applied N at the upper topographic positions. Among treatments, 120 lb N ac^{-1} treatments exhibited greater PFP than the 180 lb N ac^{-1} treatments, regardless of NI application. The addition of NI with N didn't significantly improve PFP. Neither of the topographic positions nor N treatments had a significant improvement in AE (Table 2).

RECOMMENDATIONS

The effectiveness of NIs and N rates varies according to the topographic positions. For instance, Centuro performed better than N-Serve at some instances like moderate N rate (120 lb N ac^{-1}) and at higher topographic positions like shoulder position. Variable source applications of NI technology could help farmers grow corn in a more cost-effective manner.

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Table 1. Corn grain yields at shoulder, backslope, and footslope topographic positions averaged over three years (2023-2025). Means followed by different letters within a column indicate a significant difference at p≤0.05.

N Treatments†	Corn Grain Yield		
	Shoulder	Backslope	Footslope
	----------------------------bu ac^{-1}--------------------------		
NTC	82e	79 e	81 c
120 N	160 d	160 cd	140 b
180 N	187 ab	180 b	162 a
120 N + N-Serve	166 cd	156 d	140 b
120 N + Centuro	171 c	163 c	145 b
180 N + N-Serve	180 b	185 ab	165 a
180 N + Centuro	192 a	188 a	163 a
p-value	<0.0001	<0.0001	<0.0001

†Abbreviations: NTC; non-treated control, N; nitrogen.

Table 2. Nitrogen use efficiencies at shoulder, backslope, and footslope topographic positions or N treatments averaged over three years (2023-2025). Means followed by different letters within a column indicate a significant difference at p≤0.05.

Topographic Positions	Treatments †	Partial Factor Productivity‡	Agronomic Efficiency*
		lb lb^{-1}	lb lb^{-1}
Shoulder		70.8 a	41.3
Backslope		69.2 a	39.8
Footslope		60.4 b	31.0
p-value		0.0183	0.1605
	NTC	-	-
	120 N	74.1 a	34.4
	180 N	57.9 b	34.9
	120 N + N-Serve	73.8 a	35.4
	120 N + Centuro	77.6 a	38.5
	180 N + N-Serve	58.4 b	38.8
	180 N + Centuro	58.9 b	42.4
	p-value	0.0003	0.9136

†Abbreviations: NTC; non-treated control, N; nitrogen.
‡Partial factor productivity is the grain yield obtained per lb of N applied.
*Agronomic efficiency is the increase in grain yield over the non-treated control per lb of N applied.

CORN RESPONSE TO UREA AMMONIUM NITRATE AND BIOLOGICAL PRODUCTS

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INTRODUCTION

Modern corn production systems depend heavily on synthetic nitrogen (N) fertilizers to achieve high yields. Inefficient N management practices increase production costs and risk of environmental N losses through volatilization, leaching, and denitrification. These losses are much higher under variable precipitation and soil conditions common in the Midwestern crop production systems. One emerging strategy to address this challenge is the use of N-fixing biological products (BPs). These products consist of beneficial microorganisms capable of converting atmospheric nitrogen into plant-available forms such as ammonia through biological N fixation. The symbiotic N fixation by *Rhizobium* species in leguminous crops has been widely adopted for decades (Santi et al., 2013). In non-leguminous crops such as corn, the application of N-fixing microorganisms relies primarily on asymbiotic or associative mechanisms (Smercina et al., 2019). These microorganisms may colonize the rhizosphere or plant tissues and contribute to supplemental N during the growing season, potentially reducing fertilizer requirements and improving synchronization between N supply and crop demand. For these products to be adopted as a reliable component of corn N management systems, their performance must be demonstrated through repeated and consistent yield responses across years and varying conditions.

OBJECTIVES

This study aims to evaluate the effects of BPs with different N rates on corn response and their potential to reduce dependence on synthetic N fertilizer.

PROCEDURES

This field study was started in 2023 and continued through 2026 at the University of Missouri Lee Greenley Jr. Memorial Research Farm near Novelty, MO. The soil series of the experimental field is Putnam silt loam (fine, smectitic, mesic Vertic Albaqualfs) with a poor internal drainage. The experiment layout was a split-plot design with four replications. The treatments included N application at different rates (0, 60, 120, 180 and 240 lb ac^{-1}). The three BPs evaluated in the study included *Gluconacetobacter diazotrophicus* (BP1), *Methylobacterium symbioticum* (BP2), and the microbial consortium HopperThrottleTM (BP3). A detailed description of the BPs used is provided in Table 1. Urea ammonium nitrate (UAN) was side-dressed at the V6 (Abendroth et al., 2011) growth stage with a custom-made fertilizer applicator equipped with a vApplyHD liquid control module, a 2020 precision planting rate controller, and a liquid fertilizer pump (Precision Planting, Tremont, IL). Corn was no-till planted at 35,000 seeds ac^{-1} using a Kinze 4-row planter (Kinze Manufacturing, Inc., Williamsburg, IA) at a row spacing of 30 inches. Maintenance fertilizers were applied at 13-26-83 lb N-P-K ac^{-1}.

The center two rows of each plot were harvested for corn grain yield. A plot combine

(Wintersteiger Delta, Salt Lake City, UT) equipped with a Harvest Master GrainGage (SBDS800, Juniper Systems, Logan, UT) was used to measure grain yield and moisture content for every plot, and all grain yield data were adjusted to 15% moisture before data analysis. Agronomic Optimum Nitrogen Rate (AONR) and Economic Optimum Nitrogen Rate (EONR) were calculated using the Quadratic Plateau (QP) model in SigmaPlot Software v15 (Grafiti LLC, Palo Alto, CA). The AONR was defined as the N rate at the point where yield plateaued, while EONR was determined using economic parameters, including corn bushel price ($3.88 bu^{-1}) (USDA, NASS, 2025) and UAN price of $0.63 per lb. Therefore, the price ratio for EONR estimation was 0.162. Biological product costs were not included in the EONR calculation because they represented fixed per acre costs that did not vary with N rate. They would affect net economic return but not the estimated EONR. For Envita and Utrisha, three years of data are plotted for their AONR and EONR estimates, whereas for HopperThrottle, only two years of data are plotted for its AONR and EONR estimation.

RESULTS

Nitrogen Rate Responses

Agronomic optimum nitrogen rates and yield at AONR varied among UAN and BP treatments, reflecting differences in crop N response across evaluation periods (Table 2). After three years of study, it was found that BP1 reduced the AONR by 63.7 lb ac^{-1}, while BP2 reduced the AONR by 23 lb ac^{-1} compared to UAN applied alone. The yield reductions at AONR were 8.6 and 8.2 bu ac^{-1} for BP1 and BP2, respectively, when compared to UAN rates applied alone. The yield plateaus were similar between BP1 and BP2, but BP2 had 41.2 lb ac^{-1} higher AONR. After two years of evaluation, BP3 reduced AONR by 26.2 lb ac^{-1} compared to UAN applied alone while reducing the yield by 4.1 bu ac^{-1} (Table 2).

Economic optimum nitrogen rates differed among UAN treatments with and without BP (Table 2). The application of UAN alone exhibited a relatively high EONR value (179.6 lb N ac^{-1}), with a yield at EONR of 222.9 bu ac^{-1}. The addition of BP1 reduced the EONR by 40.6 lb ac^{-1} while decreasing the yield at EONR by 5.8 bu ac^{-1} compared to UAN applied alone. The reduction in EONR was 9.9 lb ac^{-1} with BP2 while decreasing the yield by 5.0 bu ac^{-1} compared to UAN applied alone. For BP3, it was found that it reduced the EONR by 24.4 lb ac^{-1} while reducing the yield by 6.3 bu ac^{-1}. However, the savings did not cover the cost of the BPs. These reductions in EONR indicate that biological products improved economic efficiency by lowering the N rate required to achieve near maximum economic yield.

RECOMMENDATIONS

The findings in this study suggest that biological products may reduce fertilizer requirements in UAN-based systems. These products should be considered supplemental tools to enhance N management rather than as replacements for fertilizer N.

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Table 1. Biological products' active ingredient/organism, trade name, application rate, and method.

Biological product / Active ingredient	Trade name	Application rate	Application method
Gluconacetobacter diazotrophicus	†Envita™	3.2 oz ac^{-1}	Postemergence foliar at V4
Methylobacterium symbioticum	‡Utrisha™ N	5 oz ac^{-1}	Postemergence foliar at V4
Azotobacter chroococcum + *Azotobacter vinelandii* + *Trichoderma harzianum* + *Bacillus amyloliquefaciens* + *Bacillus subtilis* + *Bacillus licheniformis* + *Bacillus pumilus* + *Bacillus megaterium* + *Methylobacterium gregans*	*HopperThrottle™	24 oz a^{-1}	Seed treatment

†Azotic North America. 2025. The Science Envita. https://azotic-na.com/science-behind-envita/.
‡Corteva. 2025. Utrisha™ N Nutrient Efficiency Biostimulant. https://www.corteva.ca/content/dam/dpagco/corteva/na/ca/en/files/brochure/DF-Utrisha-N-Technical-Brochure-English.pdf.
*Meristem Crop Performance 2024. HopperThrottle™. https://meristemag.com/wp-content/uploads/2024/08/Meristem_RHT-Corn_Foldout_8.26.24.pdf. Accessed 18 May 2026.

Table 2. Summary of AONR and EONR values of urea ammonium nitrate (UAN) treatments with and without biological products (BP), BP1 and BP2 for three years (2023-2025), and BP3 for two years (2024-2025).

N Treatments†	AONR	Yield at AONR	EONR	Yield at EONR	R^2	P value
	lb ac^{-1}	bu ac^{-1}	lb ac^{-1}	bu ac^{-1}		
UAN‡	220	228	180	223	0.53	<0.0001
UAN + BP-1	157	219	139	217	0.59	<0.0001
UAN + BP-2	198	219	170	218	0.55	<0.0001
UAN*	197	253	173	252	0.88	<0.0001
UAN + BP-3	171	249	149	246	0.88	<0.0001

†Abbreviations: UAN, Urea ammonium nitrate; BP1, *Gluconacetobacter diazotrophicus*; BP2, *Methylobacterium symbioticum*; BP3, Microbial consortium-HopperThrottle
‡Corn response to UAN rates from 2023-2025.
*Corn response to UAN rates from 2024 and 2025.

NITROGEN APPLICATION AND TOPOGRAPHIC POSITION IMPACTS ON CORN PRODUCTION

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INTRODUCTION

Managing nitrogen (N) application rates to balance economic returns and environmental stewardship is critical for sustainable agricultural production. Nitrogen is an essential nutrient for crop growth; however, it is also one of the most dynamic and mobile nutrients in the soil. As a result, its efficient utilization by crops depends heavily on proper management practices. Split N applications have been shown to improve crop yield potential while reducing nutrient losses by better synchronizing N availability with crop demand (Amado et al., 2017).

Landscape position is another important factor influencing N availability and crop productivity. Topography affects soil properties, water movement, and nutrient distribution across agricultural fields (Zhu et al., 2015). Lower landscape positions often experience greater water accumulation, making them more susceptible to N losses through leaching and denitrification. Consequently, site-specific N management strategies that account for landscape variability can improve nitrogen use efficiency (NUE) and optimize fertilizer applications (Pennock, 2005).

Nitrogen losses can occur through several pathways, including ammonia volatilization, nitrate leaching, and the off-site transport of nitrogen associated with soil erosion (Delgado, 2002). Among these pathways, nitrate leaching is of particular concern because of its impact on water quality. Nitrate leaching is defined as the downward movement of nitrate-nitrogen through the soil profile beyond the crop rooting zone (Kaur et al., 2020). Excessive nitrate leaching can contaminate groundwater resources, posing risks to both environmental quality and human health (Chiwa et al., 2012; Cameron et al., 2013).

Groundwater contamination resulting from N fertilization has been reported even in regions with claypan soils, which are characterized by relatively low hydrologic conductivity. For example, a study conducted in northern Missouri found that 38% of sampled wells exceeded the drinking water standard of 10 ppm nitrate concentration (Al-Qudah et al., 2016). In the Midwest US, where corn production dominates agricultural landscapes, N management remains a significant challenge because of high fertilizer inputs, variable precipitation patterns, and poorly drained soils. These factors can increase the risk of nitrate movement beyond the rooting zone and contribute to groundwater contamination. Therefore, improving N management practices through approaches such as split applications and site-specific management is essential for enhancing crop productivity while minimizing environmental impacts.

OBJECTIVE

The objective of this research is to evaluate the impact of N application timing at different topographic positions on corn production.

PROCEDURES

The study was conducted at the University of Missouri's Lee Greenley Jr. Memorial Research Farm near Novelty, MO. The study was arranged in a split-plot design with three replications.

Plots were 10 by 30 ft. The main plots were the topographic positions including shoulder, backslope and footslope positions and split plots included N fertilizer application timing treatments (Table 1). N fertilizer application treatments included in the study were a non-treated control (NTC), pre-plant application (PP), split N application at PP and V6 growth stage, and split N application at the PP and V9 growth states. SuperU (46% N; Koch Agronomic Service LLC, Wichita, KS) was selected as an enhanced N efficiency source. SuperU includes 0.85% dicyandiamide (DCD), and 0.06% N-(n-butyl) thiphosphoric triamide (NBPT). Corn cultivars DK 63-91 was planted at a population density of 35,000 seeds ac^{-1} with row spacing of 30 inch. Data collected during the growing season included SPAD chlorophill readings at V6, V9 and VT growth stages by using chlorophyll meter. Plant population was determined by counting 2nd and 3rd rows plants and converting the values to plants per acre. Data were analyzed using the GLIMMIX procedure in SAS version 9.4 (SAS Institute, Cary, NC). Topographic position, N fertilizer treatment, and their interaction were included as fixed effects, whereas replication was treated as a random effect with significance level at <0.05.

RESULTS

At the V6 growth stage, the SPADmeter readings were affected by the main effects of topographic position and N treatments. Both shoulder and backslope had higher SPADmeter readings than the footslope at V6 growth stage. However, no such difference was obtained at the V9 and VT growth stage. At the VT stage, PP+V6 treatment has higher SPADmeter readings than the NTC and PP treatments.

Plant population was significantly affected by the topographic position, while N fertilizer treatment and their interaction had no significant effect. The shoulder position maintained a higher plant population compared to footslope. However, no significant differences in plant population were observed between the backslope and other landscape positions.

Corn dry matter production was affected by the main effects of topographic position and N treatment. Split N application treatments had higher biomass than the PP and NTC (Table 2). Foot slope position had lower dry matter production than the shoulder and backslope position. Corn grain yield was significantly affected by the interaction of topographic position and N treatments in 2025. At all topographic positions, N fertilizer treatments resulted in higher yield than the NTC. For the PP+V6 and PP+V9 treatments, corn grain yield was higher at shoulder position than at the foot slope position. No significant differences were obtained for split application of N fertilizer compared to the PP for corn grain yield at individual topographic positions (Table 2).

Corn grain starch and oil content was significantly influenced by N treatments. When data was averaged over landscape positions, NTC has greater starch and oil content than PP+V6 treatment (Figure 1).

RECOMMENDATION

Based on one year of data, split N application timing resulted in similar yields as with PP. Topographic positions have significant impact on corn response to N applications.

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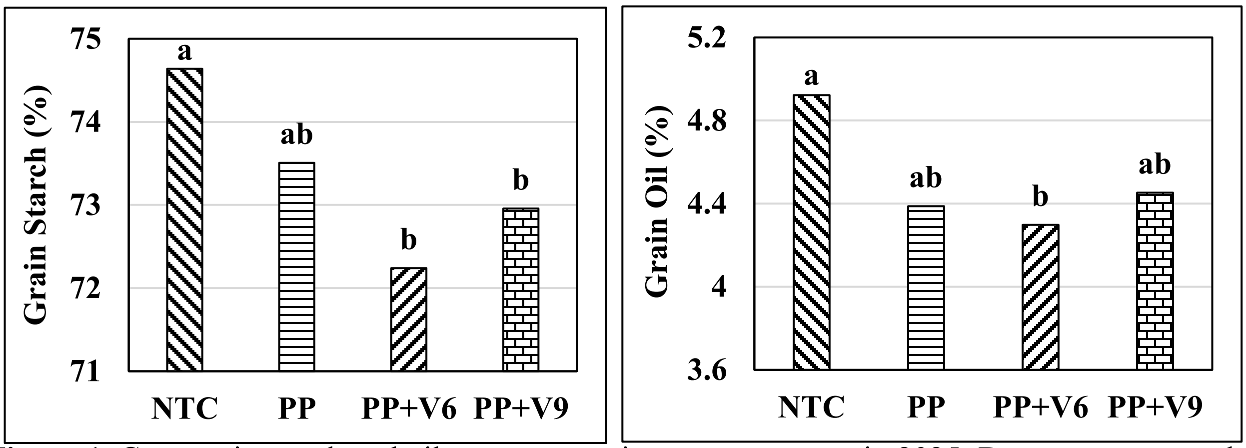

Figure 1. Corn grain starch and oil response to nitrogen treatments in 2025. Data were averaged over landscape positions. Similar letters on top of bars indicate no significant difference between means at p<0.05. Abbreviations: NTC – Non-treated Control; PP – Pre Plant

Table 1. Nitrogen treatments used in this study at different topographic positions in 2025.

Treatment No.	Landscape Position	Treatment Name	N Application Rate (lb ac^{-1})
1	Shoulder	NTC	0
2	Shoulder	SuperU – PP	210
3	Shoulder	SuperU – PP+V6	105 + 105
4	Shoulder	SuperU – PP+V9	105 + 105
5	Backslope	NTC	0
6	Backslope	SuperU – PP	210
7	Backslope	SuperU – PP+V6	105 + 105
8	Backslope	SuperU – PP+V9	105 + 105
9	Footslope	NTC	0
10	Footslope	SuperU – PP	210
11	Footslope	SuperU – PP+V6	105 + 105
12	Footslope	SuperU – PP+V9	105 + 105

Abbreviations: PP – Pre Plant; V – vegetative stage

Table 2. Corn grain parameters as affected by the topographic positions and N treatments and their interaction in 2025. Similar letters followed by mean within a column indicate no significant differences at $p<0.05$.

Topographic Position (TP)	Nitrogen Treatment (NT)	Corn Grain Yield	Dry Matter Production	Plant Population	SPADmeter readings		
					V6	V9	VT
		bu ac^{-1}	lb ac^{-1}	Plants ac^{-1}			
Shoulder		215a	23626a	30181 a	47.8 a	56.3	56.8
Backslope		189a	27510a	24373 ab	49.8 a	55.5	58.2
Footslope		140b	18596b	21313 b	42.4 b	52.4	55.5
	NTC	116b	18528b	25583 a	39.9b	48.0b	46.3c
	PP	199a	22168b	26482	50.1a	56.8a	55.3b
	PP+V6	208a	26363a	24304	49.1a	58.8a	63.6a
	PP+V9	203a	25916a	24788	47.5a	55.3ab	62.1ab
Shoulder	NTC	133cde	16749	30492	40.8	48.1	48.0
	PP	236ab	25745	29766	52.2	61.0	52.8
	PP+V6	249a	26794	31011	49.4	61.6	60.7
	PP+V9	241a	25217	29455	48.8	60.1	65.6
Backslope	NTC	115de	22362	25617	42.1	48.0	44.6
	PP	234ab	26456	26447	52.6	59.3	60.9
	PP+V6	207ab	30414	23128	52.0	58.9	65.6
	PP+V9	201abc	30806	22299	52.4	55.8	61.8
Footslope	NTC	100e	16474	20639	36.7	47.9	46.2
	PP	127de	14302	23232	45.6	50.1	52.3
	PP+V6	167bcd	21882	18722	46.0	61.6	64.5
	PP+V9	166bcd	21724	22610	41.3	50.1	58.9
Source of Variation	*df*	-----------------------------*P- values*--------------------------------					
TP	2	0.0034	0.0036	0.034	0.008	0.3097	0.7452
NT	3	<0.0001	<0.0001	0.6234	<0.0001	0.0092	0.0001
TP*NT	6	0.02	0.0865	0.703	0.6032	0.3259	0.5938

Abbreviations: NTC, non-treated control; PP, preplant; PP+V6, 50% of total N applied at preplant and 50% at V6 growth stage; PP+V9, 50% of total N applied at preplant and 50% at V9 growth stage.

CORN RESPONSE TO FLOODING STRESS AND POST-FLOOD RECOVERY NITROGEN MANAGEMENT

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INTRODUCTION

In the midwestern United States, flooding resulting from changing climate has become a serious challenge for corn production and contributes to annual yield losses estimated at 6-8 billion USD (Lindsey et al., 2024). In Missouri, excessive rainfall events, poorly drained claypan soils, and undulating topography, frequently result in prolonged waterlogged conditions that negatively affect corn growth and productivity (Hammer et al., 1995; Jamison et al., 1967). The severity of flooding damage is influenced by the timing, duration, and frequency of flooding events, particularly during the early vegetative growth stages when crops are sensitive to anaerobic conditions (Kaur et al., 2017). Waterlogged soils create hypoxic (oxygen-deficient) and eventually anoxic (absence of oxygen) environments that inhibit root respiration and limit nutrient uptake and contribute to yield losses (Kaur et al., 2017; Wegner, 2010). In corn, flooding restricts physiological processes such as photosynthesis and biomass accumulation, resulting in reduction in plant growth and recovery. Moreover, nitrogen (N) losses intensify under saturated conditions through denitrification and leaching, significantly reducing N availability to the crop (Aslam et al., 2023; Dill et al., 2020). Since N plays important roles in chlorophyll formation, canopy development, and overall metabolic activities, N deficiency following flooding can further exacerbate yield reduction (Fathi, 2022). Therefore, post-flood N applications can help enhance crop growth, improve recovery, and sustain productivity following flooding stress.

OBJECTIVE

The objective of this study was to evaluate the impact of flooding stress and post-flood recovery N application on corn production.

PROCEDURES

The experiment was conducted at the University of Missouri Lee Greenley Jr. Memorial Research Farm near Novelty, MO in 2025. The study was designed as a randomized complete block with a split-plot arrangement and three replications. The main plots were flooding treatments including no-flood control (0 days), 7 days flooding initiated at V2-V3, and 7 days flooding event initiated at V6 stage of corn. The sub-plot treatments included recovery N application (0 kg N ha^{-1} and 100 kg N ha^{-1}). Corn was hand planted on 16th May at seeding rate of 35000 seeds per acre and row spacing of 30 inches (Table 1). Flooding at V2-V3 and V6 growth stage started on 12th June and 30th June, respectively. Post-flood recovery fertilizer treatment was applied one week after flood termination on 26th June and 15th July, respectively. SPAD meter readings were recorded at the VT growth stage using a SPAD-502 chlorophyll meter by taking measurements from the ear leaves. Plant population was determined at the R7–R8 growth stage by counting the number of plants of each row in each plot and converting the counts to plants per acre. Crop was harvested using plot combine from center two rows of each sub-plot at physiological maturity to determine grain yield. The grain yield data was adjusted to 15% moisture content before statistical analysis. Data was analyzed using the Glimmix procedure in SAS software (SAS Institute Inc., Cary, NC). T-grouping of least-square differences was used for mean comparisons at $\alpha < 0.05$.

RESULTS

Corn SPADmeter readings, plant population, seed yield, and seed starch concentration were significantly affected by the main effect of flooding treatment in 2025. However, recovery N application did not significantly affect any of the evaluated parameters. SPAD meter showed reduction in chlorophyll content in plants flooded for 7-days at the V6 growth stage by 29% compared to control (Figure 1a). Flooding for 7 days at the V2-V3 and V6 growth stages reduced plant population by 38% and 39%, respectively, compared to the non-flooded control (Figure 1b). The reduction in plant population was subsequently reflected in grain yield. Grain yield decreased by 47 and 49% when corn was flooded at V2-V3 and V6 growth stage compared to non-flooded corn, respectively (Figure 1c). Among the grain quality parameters, corn showed significant reduction in starch concentration when flooded for 7 days at V6 growth stage compared to corn flooded at the V2-V3 growth stage and the control (Figure 1d). However, no significant effect of flooding treatment was observed on protein and oil concentrations.

CONCLUSIONS

Flooding negatively affected corn growth and production. Post-flood nitrogen applications did not help in recovery from flooding stress. The study will be continued in 2026 to assess the impact of flooding and recovery nitrogen application on corn growth.

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Table 1. Information related to different field operations conducted for the research study in 2025.

Field Operations		2025
Tillage		Vertical tilled – Once Culti-packed – Once
Planting Date		05/16/2025
Variety		DKC65-95 RIB (35,000 seeds acre^{-1})
Sub-Plot Size		10 × 20 feet
Row Spacing		30 inches
Herbicides/Pesticides	Pre-Emergence	Verdict + Roundup + UAN + MSO -4/14/2025 Bicep II Magnum + Callisto – 5/16/2025
	Post-Emergence	Status + Atrazine – 6/24/2025
Bulk Fertilizer Source		180 lb N ac^{-1} (SuperU) – 5/16/2025 14-22-14 MAP + potash – 2/21/2025
Flooding Initiation		V2–V3: 6/12/2025 to 6/20/2025 V6: 6/30/2025 to 7/7/2025
Harvesting Date		10/08/2025

†Abbreviations: UAN, Urea Ammonium Nitrate; MSO, Methylated Seed Oil; MAP, Murate of Potash; ‡Status, Dicamba, 3,6-dichloro-2-methoxybenzoic acid; Diflufenzopyr, 1-(3,5-difluorophenyl)-1,2-dihydro-3-pyridinecarboxylic acid; Atrazine, 6-chloro-N-ethyl-N′-(1-methylethyl)-1,3,5-triazine-2,4-diamine; Verdict, Saflufenacil, N′-[2-chloro-4-fluoro-5-(3-methyl-2,6-dioxo-4-(trifluoromethyl)-3,6-dihydropyrimidin-1(2H)-yl)benzoyl]-N-isopropyl-N-methylsulfamide; Dimethenamid-P, (S)-2-chloro-N-(2,4-dimethyl-3-thienyl)-N-(2-methoxy-1-methylethyl)acetamide; Roundup, N-(phosphonomethyl) glycine; UAN, Solution of urea [$CO(NH_2)_2$] and ammonium nitrate [NH_4NO_3]; Bicep II Magnum, Atrazine; metachlor, 2-chloro-N-(2-ethyl-6-methylphenyl)-N-[(1S)-2-methoxy-1-methylethyl]acetamide; Callisto, 2-(4-mesyl-2-nitrobenzoyl)cyclohexane-1,3-dione;

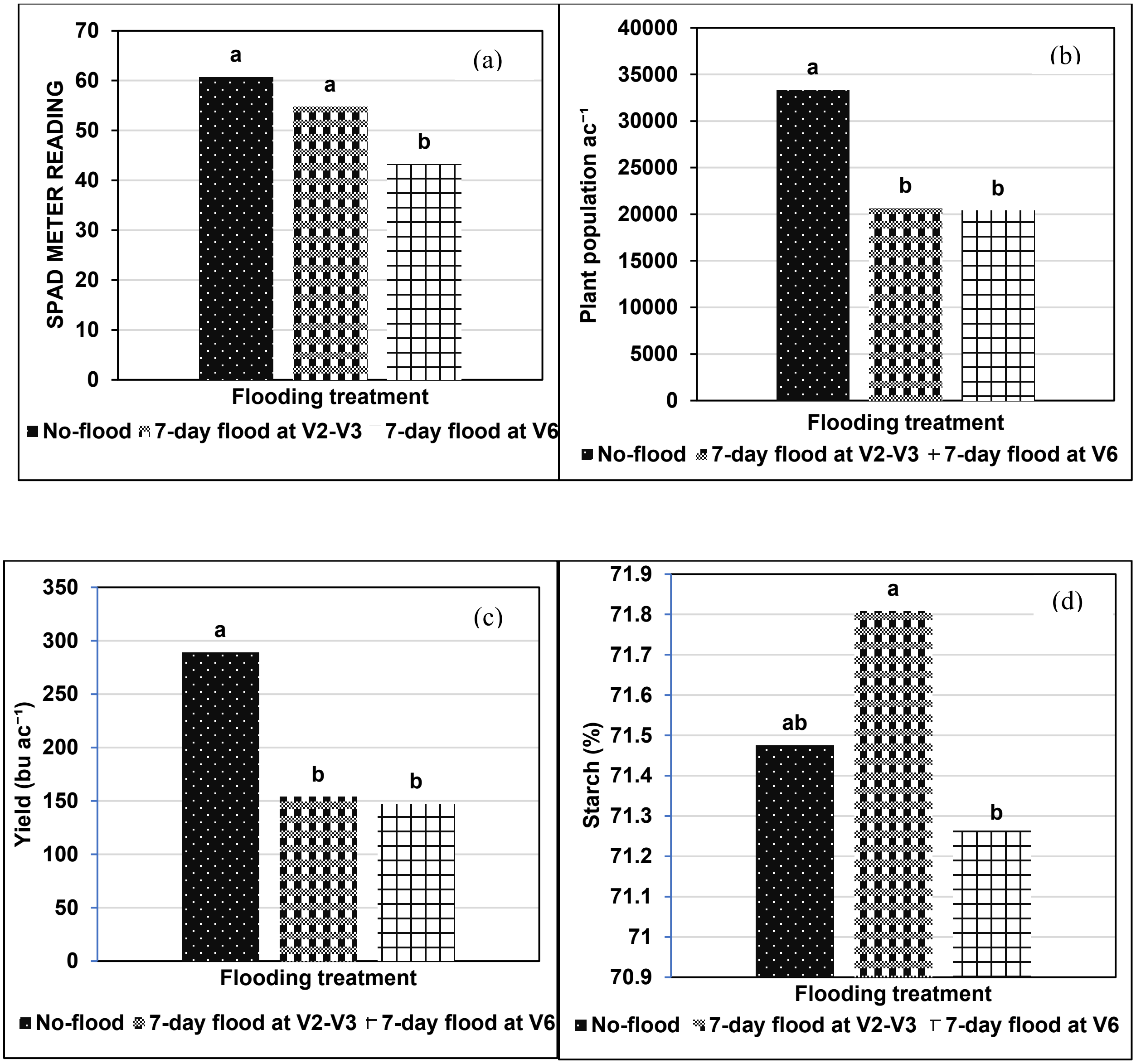

Figure 1. Corn SPADmeter readings (a), plant population (b), grain yield (c), and grain starch concentration (d) as affected by flood duration in 2025. Similar letters on top of bars represent no significant differences between treatment means at α = 0.05.

NITROGEN AND SULFUR APPLICATIONS TO SOYBEAN FOR FLOODING RECOVERY

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INTRODUCTION

In Missouri, flooding is one of the most detrimental abiotic stresses affecting crop growth, physiology, and productivity. Excessive rainfall events, combined with undulating topography (Hammer et al., 1995) and poorly drained claypan soils of Missouri (Jamison et al., 1967), exacerbate flooding stress across the region. Waterlogged conditions create hypoxic (oxygen-deficient) and eventually anoxic (absence of oxygen) environments in the soil that inhibit aerobic respiration and impair normal plant functioning (Wegner, 2010). As a result, it drastically reduces soybean survival, nodulation, nutrient uptake, and overall plant growth, leading to significant yield losses. Biological nitrogen fixation is especially affected under saturated soil conditions (Tiwari et al., 2016) which limits nitrogen (N) availability to the crop. In addition, sulfur (S) deficiency under flooding stress further disrupts nodulation, enzyme activity, and protein synthesis, negatively affecting plant recovery and productivity (Hu et al., 2023). Nitrogen and S deficiency intensifies flooding induced damage, as these nutrients play important roles in chlorophyll formation, canopy development, and metabolic processes (Fathi, 2022; Kopriva et al., 2019). Therefore, post-flood applications of N and S can help replenish essential nutrients, restore plant growth, and support crop recovery following flooding stress.

OBJECTIVE

The objective of this study was to evaluate the effects of post-flood N and S applications on soybean production as a recovery strategy from flooding stress.

PROCEDURE

The field experiment was conducted at the University of Missouri Lee Greenley Jr. Memorial Research Farm near Novelty, MO in 2025. The study was designed as a randomized complete block with a split-plot arrangement and six replications. Main plots included flooding duration [0 (non-flooded control), and 7 days]. The sub-plots had different combinations of N and S fertilizer rates using SuperU and ammonium sulfate as sources, respectively (Table 1). Soybeans were planted on 20th May at a row spacing of 15 inches and seeding rate was 140,000 seeds acre^{-1} on a Putnam silt loam soil. Flooding started on st July when soybeans were at the V3-V4 growth stage, and post-flood recovery fertilizer treatment was applied on 16th July. Root sampling was conducted twice during the growing season, one week after flood termination on 17th July, and then, at the R2-R3 growth stage on 12th August. Data on various root parameters, including root dry weight and number of nodules per plant, were collected. Plant height, plant population, and pods per plant were recorded at R7-R8 growth stage. Soybean was harvested from center two rows of each sub-plot using a plot combine and seed yield was collected and adjusted to 13% moisture content before statistical analysis. Data was analyzed using the Glimmix procedure in SAS software (SAS

Institute Inc., Cary, NC). T-grouping of least-square differences was used for mean comparisons at $\alpha < 0.05$.

RESULTS

Root morphological parameters at the V5–V6 and R2-R3 growth stage were significantly affected by flooding duration (Tables 2 & 3). Flooding for 7 days increased the number of root tips by 18%, total root length by 20%, average root diameter by 7%, root volume by 25%, and root surface area by 20% compared to the non-flooded control at the early sampling time. However, flooding did not significantly affect root dry weight or the number of nodules at this growth stage.

Flooded plants showed a 75% increase in the number of nodules and significant increases in average root diameter (18%), root volume (35%), and root surface area (21%) compared to the non-flooded control at the R2-R3 sampling time (Table 3). Root dry weight, number of root tips, and total root length were not significantly affected. Overall, soybean plants exhibited adaptive root morphological responses under prolonged flooding stress, characterized by increased root proliferation, diameter, and surface area.

Flooding for 7 days reduced soybean plant height and grain yield by 8 and 4% compared to the non-flooded control (Figure 1). Soybean plant population was significantly influenced by the interaction between flooding duration and fertilizer treatments (Figure 2). Under non-flooded conditions, higher plant populations were generally maintained across fertilizer treatments, whereas flooding for 7 days reduced plant stands in several fertilizer combinations. The greatest reduction in plant population under flooding was observed in the 90N+20S treatment, where plant population decreased by approximately 26% compared to the corresponding non-flooded treatment. In contrast, treatments receiving sulfur in combination with nitrogen generally maintained greater plant populations under flooded conditions.

CONCLUSIONS

Flooding impacted soybean growth and production. However, N and S applications did not help in the recovery from flooding stress and increase soybean yield. The study will continue in 2026 to further assess its role in post-flood soybean recovery.

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Table 1. List of treatments used in the study.

Treatment Number	Flooding duration	N + S application (lbs ac^{-1})
1	0	0 + 0
2	0	0 + 20
3	0	30 + 0
4	0	30 + 20
5	0	60 + 0
6	0	60 +20
7	0	90 +0
8	0	90 + 20
9	7	0 + 0
10	7	0 + 20
11	7	30 + 0
12	7	30 + 20
13	7	60 + 0
14	7	60 +20
15	7	90 +0
16	7	90 + 20

Table 2. Impact of flooding duration on soybean root parameters at the V5-V6 growth stage sampling time. Means followed by the same letter within a column are not significantly different at α=0.05.

Measured Parameters	units	Flooding duration (in days)		*p-value*
		0	7	
Root dry weight	lbs	0.00471	0.00499	*0.1237*
No. of nodules	# $plant^{-1}$	17	17	*0.907*
No. of root tip	# $plant^{-1}$	2582b	3045a	*0.0037*
Total root length	in	177.08b	212.33a	*0.0004*
Average diameter	in	0.076b	0.081a	*0.0437*
Volume	in^3	2.29b	2.87a	*0.0091*
Surface area	in^2	0.3b	0.4a	*0.0006*

Table 3. Impact of flooding duration on soybean root parameters at R2-R3 growth stage sampling time. Means followed by the same letter within a column are not significantly different at α=0.05.

Measured Parameters	units	Flooding duration (in days)		*p-value*
		0	7	
Root dry weight	lbs	0.00714	0.00775	*0.0741*
No. of nodules	# $plant^{-1}$	62b	109a	*<.0001*
No. of root tip	# $plant^{-1}$	2868	3179	*0.2391*
Total root length	in	219.48	250.5	*0.0956*
Average diameter	in	0.083b	0.098a	*0.0004*
Volume	in^3	3.86b	5.21a	*0.0116*
Surface area	in^2	0.4b	0.5a	*0.0197*

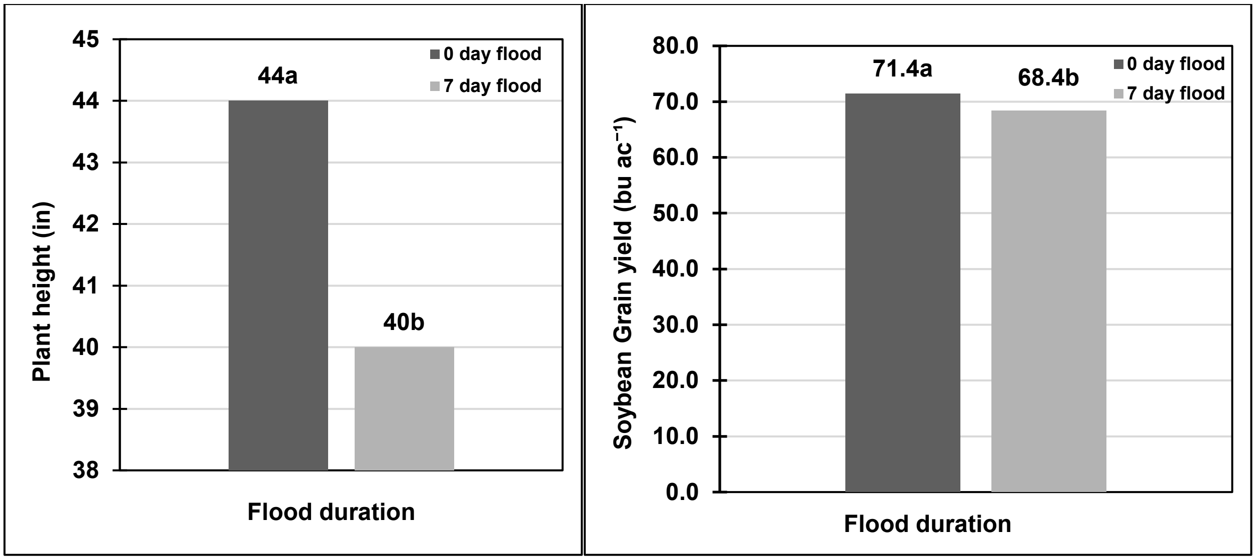

Figure 1. Soybean plant height and grain yield as affected by flooding duration. Similar letters on top of bars represent no significant differences between treatment means at $\alpha = 0.05$.

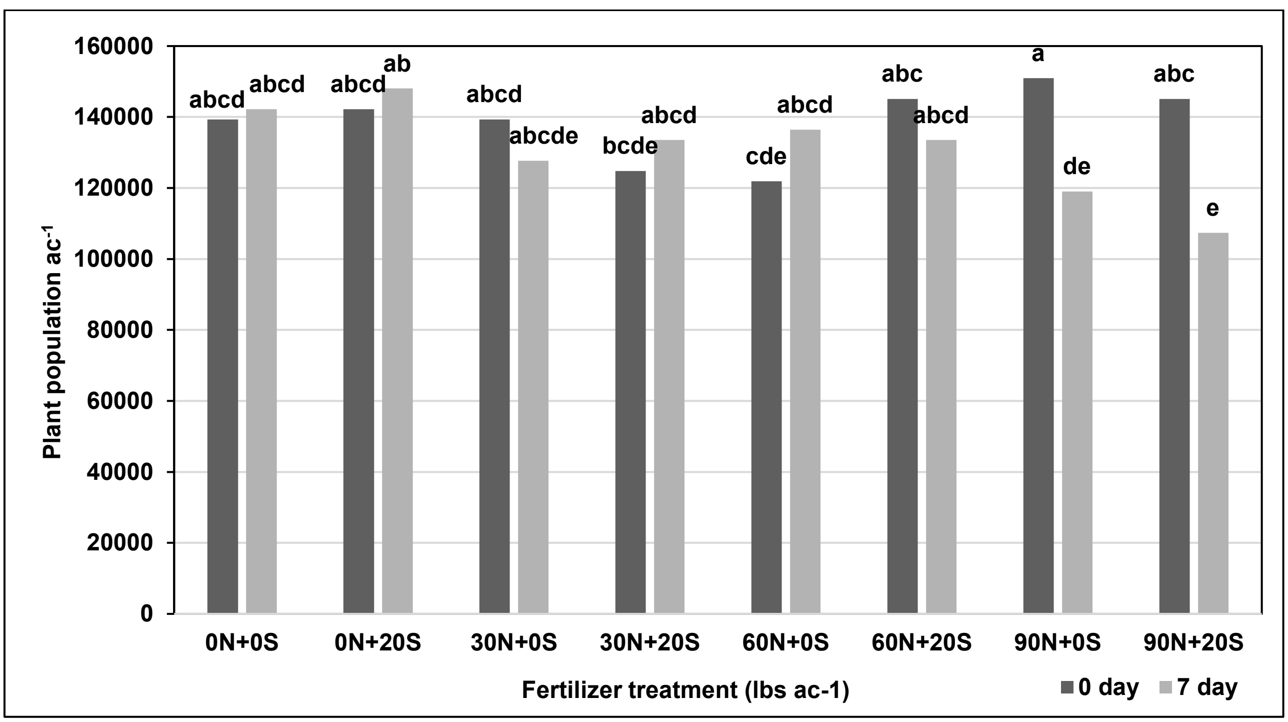

Figure 2. Soybean plant population as affected by flooding duration and fertilizer treatment. Similar letters on top of bars represent no significant differences between treatment means at $\alpha = 0.05$.

MULTILOCATION CULTIVAR TESTING FOR INDUSTRIAL HEMP PRODUCTION IN MISSOURI

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INTRODUCTION

Industrial hemp (*Cannabis sativa* L.) has re-emerged in the United States as a high-value specialty crop grown for fiber, grain, and cannabidiol (CBD) production (Adesina et al., 2020). Following a 45-year prohibition, the Agricultural Act of 2014 (Public Law 113-79) authorized industrial hemp production through state pilot programs, facilitating renewed research and cultivation efforts (Mark et al., 2020). The Agriculture Improvement Act of 2018 (2018 Farm Bill) further expanded hemp production by defining industrial hemp as cannabis containing no more than 0.3% delta-9 tetrahydrocannabinol (THC) on a dry-weight basis. As interest in hemp continues to grow, identifying cultivars adapted to regional environments has become increasingly important for successful production.

In Missouri, Senate Bill 133 was enacted on June 24, 2019, permitting institutions of higher education to conduct research on the cultivation, production, and marketing of industrial hemp (Falkner et al., 2023). Although hemp was historically cultivated in Missouri as early as 1835 (USDA, 1914), decades without commercial production have resulted in limited information regarding cultivar adaptation and agronomic management practices. Therefore, evaluating industrial hemp cultivars across Missouri environments is essential to identify high-performing varieties and provide research-based recommendations that support the development of a sustainable hemp industry in the state.

OBJECTIVE

The objective of this study was to evaluate the effects of different environmental conditions on biomass and grain yield of industrial hemp cultivars across Missouri.

PROCEDURES

Field experiments were conducted in 2023, 2024 (Anjeeta et al., 2024; Anjeeta et al., 2025) and 2025 at five locations in Missouri including Lee Greenley Jr. Memorial Research Farm near Novelty, Hundley Whaley Extension and Education Center near Albany, Thompson Research Farm near Spickard, Fisher Delta Research, Extension and Education Center near Portageville, and Bradford Research Farm in Columbia. Similarly, five locations were planted near Novelty, Columbia, Fair Grove, Albany, and Spickard in 2025. This report will summarize the results from 2025.

The experiment was a randomized complete block design with four replications. Plot size was 10 by 20-30 feet at each location. Each plot had four rows of industrial hemp. A total of 13 varieties were evaluated at each location. The varieties included in the study were: Fibror 79, Futura, Jinma, Puma, Ferimon, Feline 32, Orion 33, Altair, Trichomo, Rajan, Tygra, Vega, and Yuma. Industrial hemp was planted in 30-inch-wide rows at each location. Varieties were seeded at 30 lbs ac^{-1} at all locations. The details of field operations are provided in Tables 1, 2 and 3. Plots were maintained weed-free using crop protection chemicals or hand weeding.

All varieties were tested for THC content before harvesting. For THC analysis, the top 6 to 8 inches of flowering parts of two plants per plot were collected before harvesting for biomass. Industrial hemp samples from all replications for each variety were mixed to have only one sample per variety at each location. The samples were sent to a laboratory (Agrozen Laboratory, Lebanon, IN) for TCH analysis using standard methods. Hemp plants were harvested for biomass from 10 ft of a middle row in each plot to determine biomass production and grain yield. The harvested biomass was threshed (Almaco, Nevada, IA) for grain yield. The grain yields were adjusted to 8% moisture before data analysis. The GLIMMIX procedure in SAS statistical software (Cary, NC) was used for data analysis and means were separated by least square difference (LSD) at alpha =0.05.

RESULTS

Establishment of industrial hemp can be challenging due to waterlogged conditions at the time of planting or later in the season. The plants did not emerge at Fair Grove and Columbia because of soil saturation due to rainfall events which resulted in crop failure and sites were abandoned. Therefore, no biomass or grain yield data were collected at Fair Grove and Columbia locations in 2025.

All varieties had a THC content lower than 0.3% at all sites (data not presented). The highest overall biomass for most of the cultivars was at Albany while the lowest was at Spickard (Figure 1). Puma, Yuma and Jinma resulted in the highest biomass production at all locations (Figure 1). The favorable climatic conditions and soils at Albany (northwest Missouri) resulted in higher biomass production.

Grain yield production among locations varied by location. The highest grain yields were observed at Novelty followed by Albany followed by Spickard (Figure 2). At Novelty, Futura 83, Orion 33 and Vega were the highest yielding variety whereas Felina 32 and Ferimon had the lowest grain yield. No significant differences were observed between varieties at Albany and Spickard. Environmental and soil conditions affect the performance of different cultivars in Missouri.

CONCLUSION

From this multilocation study we have concluded that genetic and environmental factors significantly influenced the agronomic performance of industrial hemp across Missouri. Farmers in northwestern Missouri should focus on fiber or biomass and use varieties like Puma or Yuma, while those in northern Missouri would benefit from grain or dual-purpose varieties like Futura 83 and Orion 33. Overall, these findings highlight the importance of matching cultivar selection with local soil and climate conditions.

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Table 1. Planting and harvesting dates in 2025

Location	Year	Planting date	Harvesting date
Albany	2025	6/2/2025	9/8/2025
Columbia	2025	5/23/2025†	----------
Novelty	2025	5/14/2025	8/28/2025
Fair Grove	2025	5/23/2025†	-----------
Spickard	2025	6/2/2025	9/10/2025

†Plants were affected by waterlogging conditions following planting. The site was terminated due to poor stand establishment.

Table 2. Fertilizer application dates, amounts, and sources in 2025.

Location	Date	Rate	Source
Albany	6/2/2025	60 lbs N ac^{-1}	SuperU®
Columbia	5/23/2025	60 lbs N ac^{-1}	SuperU®
Novelty	3/26/2025	178 lbs N ac^{-1}	Anhydrous ammonia
Fair Grove	5/23/2025	60 lbs N ac^{-1}	SuperU®
Spickard	6/12/2025	60 lbs N ac^{-1} 100 lbs N ac^{-1}	SuperU®

Note: SuperU: 45.5% Urea Nitrogen and 0.5% Other Water Soluble Nitrogen; Anhydrous Ammonia: 82% N (82-0-0)

Table 3. Weed management for the industrial hemp field trials in 2025.

Timing	Albany	Columbia	Novelty	Fair Grove	Spickard
PPI (Preplant incorporated)	5/29/25: Trifluralin @ 1 lb ai ac^{-1}	5/22/25: Trifluralin @ 1 lb ai ac^{-1}	4/14/25: Glyphosate at 2.03 lb ai ac^{-1} 5/13/25: Trifluralin @ 1 lb ai ac^{-1} (double applied)	5/22/25: Trifluralin @ 1 lb ai ac^{-1}	5/29/25: Trifluralin @ 1 lb ai ac^{-1}
Post-emergence	6/20/25: Clethodim at 0.125 lb ai ac^{-1}	None	None	None	6/20/25: Clethodim at 0.125 lb ai ac^{-1}

Note: Trifluralin: α, α, α-trifluoro-2,6-dinitro-N, N-dipropyl-p-toluidine; Clethodim: (E)-2-[1-[[(3-chloro-2-propenyl) oxy] imino] propyl]-5-[2-(ethylthio) propyl]-3-hydroxy-2-cyclohexen-1-one; Glyphosate: N-(phosphonomethyl)glycine

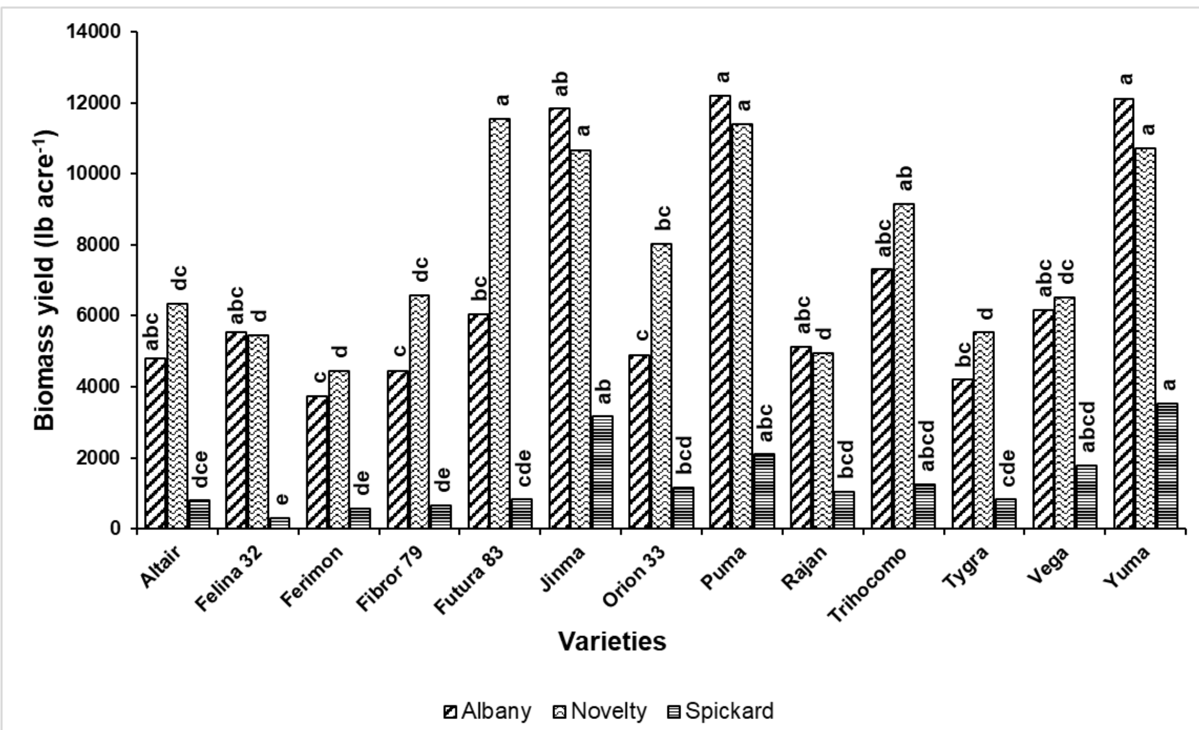

Figure 1. Industrial hemp biomass yield at three locations (Albany, Novelty and Spickard) in 2025. Within a location, bars with similar letters indicate no significant differences between means within a location at $p < 0.05$. The data has been analyzed separately for each location.

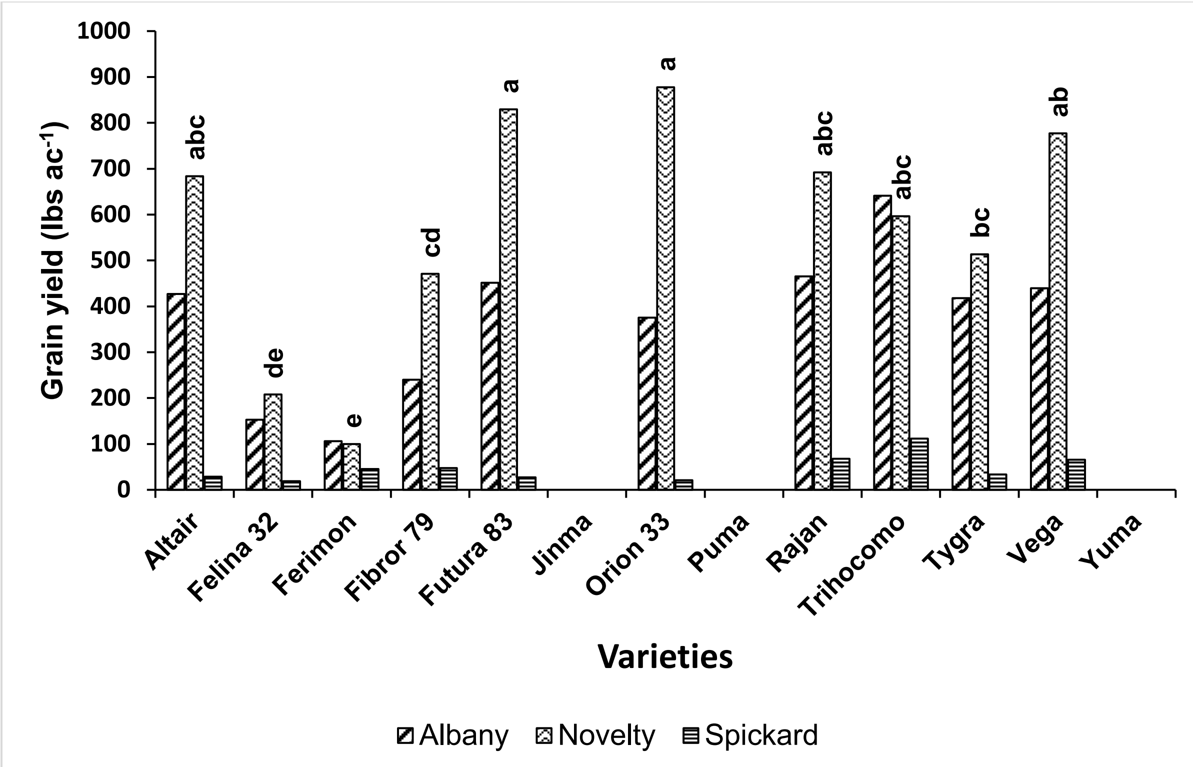

Figure 2. Industrial hemp biomass yield at three locations (Albany, Novelty and Spickard) in 2025. Within a location, bars with similar letters indicate no significant differences between means within a location at $p < 0.05$. The data has been analyzed separately for each location.

INDUSTRIAL HEMP RESPONSE TO NITROGEN APPLICATIONS IN MISSOURI

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INTRODUCTION

Nitrogen (N) is one of the most important nutrients affecting industrial hemp (*Cannabis sativa* L.) growth, biomass accumulation, and grain production. As a major component of chlorophyll, amino acids, and proteins, nitrogen plays a critical role in photosynthesis, plant development, and yield formation (Papastylianou et al., 2018; Kakabouki et al., 2021). Following a 45-year ban, the Agricultural Act of 2014 (Public Law 113-79) authorized states to establish pilot programs for hemp cultivation (Mark et al., 2020). This effort was further supported by the 2018 Farm Bill, which removed hemp from the list of controlled substances and defined legal hemp as containing no more than 0.3% delta-9 tetrahydrocannabinol (THC).

Previous studies in other states have shown that hemp responds positively to nitrogen fertilization; however, optimum N requirements vary widely among cultivars and growing environments (Aubin et al., 2015; Amaducci et al., 2015). Despite increasing interest in hemp production, limited information is available on nitrogen management under Missouri conditions. Differences in soil properties, climate, and cultivar genetics may influence nitrogen use efficiency and crop response to fertilizer application. Therefore, research is required to evaluate the response of industrial hemp cultivars to varying nitrogen rates across different regions in Missouri. The results of this study will help develop science-based nitrogen recommendations that improve productivity while promoting efficient and sustainable fertilizer use.

OBJECTIVES

The objective of this study was to evaluate the effects of different nitrogen applications on industrial hemp production in Missouri.

PROCEDURES

Field experiments were conducted in 2025 at two locations in Missouri including the Lee Greenley Jr. Memorial Research Farm near Novelty and Hundley Whaley Extension and Education Center near Albany. The experiment was a split-plot design with four replications. Main plots were industrial hemp varieties (Futura 83, Orion 33, Puma and Yuma) and sub-plots were N application rates (0, 40, 80, 120 and 160 lbs ac^{-1}). The sub-plot size was 10 by 20 feet at each location. SuperU® was used as N source, and it was broadcast applied at planting. Each plot had four rows of industrial hemp. Industrial hemp was planted in 30-inch-wide rows at a seeding rate of 40 lbs ac^{-1} at. Industrial hemp was planted on May 14th in Novelty and June 2nd at Albany. Hemp was harvested on September 2nd and September 8th in Novelty and Albany , respectively. Plant height and stem diameter were calculated by taking measurements from 10 random plants from each plot. The hemp plants were harvested for biomass from 10 ft of the middle row in each plot to determine biomass production and grain yield. The harvested biomass was threshed for grain yield. Grain yields were adjusted to 8% moisture content before data analysis. The GLIMMIX procedure in SAS statistical software (Cary, NC) was used for data analysis and means were separated by least square difference (LSD) at alpha = 0.05.

RESULTS

Stem diameter was significantly affected by both variety and nitrogen rate at both locations in 2025. Across locations, Puma and Yuma consistently produced the thickest stems, while nitrogen application increased stem diameter, with maximum values generally achieved between 80 and 120 lbs N ac^{-1} (Tables 1 & 2). Plant height was significantly influenced by both variety and nitrogen rate. 'Puma' consistently produced the tallest plants across locations, while increasing nitrogen rates enhanced plant height, with maximum growth generally observed between 80 and 160 lbs N ac^{-1} (Tables 1 & 2). Biomass yield was significantly affected by both variety and nitrogen rate. Across locations, Puma' consistently produced the greatest biomass yield, while increasing nitrogen application generally enhanced biomass production, with the highest yields observed at 120-160 lbs N ac^{-1} (Tables 1 & 2). Grain yield in 2025 was significantly affected by nitrogen rate at Novelty but was not influenced by variety or the variety x nitrogen interaction at either location. The highest grain yield was achieved at 160 lbs N ac^{-1}, producing substantially greater yields than the non-treated control and lower nitrogen rates (Table 1). These results indicate that increased nitrogen availability can enhance hemp grain production, regardless of cultivar.

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Table 1. Nitrogen rate and variety impact on industrial hemp plant population, height, stem diameter, aboveground biomass, and grain yield at Novelty in 2025. Means within a column followed by different letters are significantly different at α = 0.05.

Variety	N rate	Plant Population	Plant height	Stem diameter	Aboveground Biomass	Grain yield
	(lb ac^{-1})	(Plants ac^{-1})	(in)	(mm)	(lb ac^{-1})	(lb ac^{-1})
Futura 83		83400 b	76 a	6.7 bc	3700 bc	390
Orion 33		55100 c	61 b	5.1 c	2640 c	301
Puma		123000 a	84 a	8.4 ab	6790 a	-
Yuma		40300 c	78 a	10.1 a	5160 ab	-
	0	71300	53 c	4.7 c	1780 c	137 c
	40	72900	61 c	5.7 c	2350 c	168 bc
	80	72100	77 b	8.1 b	4850 b	368 b
	120	75700	82 b	8.2 b	5740 b	351 b
	160	85000	99 a	11.3 a	8140 a	704 a
Source of Variation		-----------------------------------*P-values*---------------------------------				
Variety (V)		<.0001	0.0007	<.0001	<.0001	0.1741
N		0.5889	<.0001	<.0001	<.0001	<.0001
N*V		0.1975	0.4692	0.7377	0.4547	0.752

Table 2. Nitrogen rate and variety impact on industrial hemp plant population, height, stem diameter, aboveground biomass, and grain yield as affected by varieties and N rates at Albany in 2025. Means within a column followed by different letters are significantly different at α = 0.05.

Variety	N rate	Plant Population	Plant height	Stem diameter	Aboveground Biomass	Grain yield
	(lb ac^{-1})	(Plants ac^{-1})	(in)	(mm)	(lb ac^{-1})	(lb ac^{-1})
Futura 83		51000	59 c	6.7 b	3330 b	266
Orion 33		65200	55 c	5.3 b	2500 b	238
Puma		61900	96 a	11.9 a	8580 a	-
Yuma		33100	80 b	12.5 a	5040 b	-
	0	46200	48 b	6.3 b	2080 b	76
	40	49400	63 b	8.5 ab	4750 ab	214
	80	53000	86 a	10.7 a	4760 ab	242
	120	65200	85 a	10.2 a	6760 a	320
	160	51000	79 a	9.7 a	5960 a	407
Source of Variation		--------------------------------------*P-values*----------------------------				
Variety (V)		0.0652	<.0001	<.0001	0.0002	0.7286
N		0.718	<.0001	0.0042	0.0334	0.126
N*V		0.9679	0.4803	0.3578	0.6216	0.9243

NRCS CEMA 216 SOIL HEALTH TESTING INCENTIVES AND INTERPRETATION FOR MISSOURI ROW-CROP SYSTEMS

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INTRODUCTION

Soil health testing complements routine fertility testing by measuring biological and physical functions that influence nutrient cycling, water infiltration, erosion resistance, and resilience to weather stress. Common soil health indicators include total organic carbon (TOC), permanganate oxidizable carbon (POXC), short-term soil respiration, wet aggregate stability (WAS), autoclaved citrate-extractable (ACE) soil protein, and potentially mineralizable nitrogen (PMN). These tests represent different but related soil functions: TOC reflects longer-term carbon status; POXC reflects a more management-sensitive reactive carbon pool; respiration, ACE protein, and PMN reflect microbial activity and nitrogen-cycling capacity; and WAS reflects the physical stability of soil structure (Culman et al., 2012; Hurisso et al., 2018; Weil et al., 2003).

A major limitation to soil health testing has been interpretation. Soil health indicator values are affected by soil texture, sampling depth, season, laboratory method, crop rotation, tillage, cover crops, and amendment history. The University of Missouri (MU) Soil Health Assessment Center (SHAC) used more than 17,000 producer-submitted samples collected across Missouri from 2015 through 2024 to develop Missouri-specific, percentile-based interpretive benchmarks. The Natural Resources Conservation Service (NRCS) Conservation Evaluation and Monitoring Activity 216 (CEMA 216) provides financial support for soil health sampling, laboratory testing, and interpretation across the United States (Table 1). Together, the incentive program, standardized sampling guidance, and Missouri benchmark framework can make soil health testing more useful for producers, conservation planners, and crop advisors.

OBJECTIVES

- Describe the NRCS CEMA 216 soil health sampling incentives, MU laboratory packages, and sample-submission process.
- Provide a consistent 0-6-inch depth sampling procedure for fertility and soil health testing in Missouri row-crop fields.
- Summarize Missouri-specific interpretive benchmarks and explain the effects of soil texture and field management on soil health indicators.
- Translate soil health test results into practical management and monitoring recommendations for producers and conservation professionals.

PROCEDURES

Current MU guidance is to collect field-crop soil samples from the 0-6-inch depth. The 0-6-inch protocol replaced the former shallow-depth (0-3-inch) soil health protocol in 2025 and aligns current soil health sampling with MU fertility-recommendation calibration. A clean soil probe or auger and a clean plastic bucket should be used. Remove surface debris, insert the probe vertically, and collect 15-20 cores from each sampling unit. Thoroughly mix the cores, remove stones and large plant material, and submit approximately 1 pint of soil in a labeled sample container. Grid sampling is appropriate when detailed spatial fertility information is needed; zone sampling is generally preferred for soil health because it can separate differences in soil series, texture, slope, drainage, and management; random composite sampling is acceptable in uniform fields (Figure 1). Repeated sampling must use the same depth, field area, season, and laboratory method. When sampling depth changes, the new depth should be treated as a new monitoring baseline rather than directly compared with older shallow samples (Parvej et al., 2026).

The Missouri benchmark dataset consisted primarily of producer-submitted annual row-crop soils from the Missouri cover crop cost-share program. Six indicators were evaluated using SHAC standard operating procedures. Because the indicator distributions were non-normal, interpretive classes were developed from empirical percentiles rather than from means and standard deviations. Soils were grouped as sandy, loamy, or clayey to evaluate inherent textural effects. Tillage classes were used as a known management gradient, and a field-level follow-up subset was used to evaluate changes after approximately 4-5 years of cover crop adoption. Package composition differs among programs; therefore, interpretation should always be based on the specific indicators and methods reported by the laboratory.

RESULTS

Soil texture was the dominant inherent source of variation (Figure 2). Median TOC was 9.1 g kg^{-1} in sandy soils, 18.5 g kg^{-1} in loamy soils, and 22.0 g kg^{-1} in clayey soils. Median WAS was 14%, 24%, and 40%, respectively. Sandy soils also had lower POXC, respiration, ACE protein, and PMN than the finer-textured groups. Loamy and clayey soils overlapped for several biologically mediated indicators, supporting a common statewide reporting framework supplemented by texture context rather than entirely separate scoring systems. These results emphasize that a sandy soil should not be expected to achieve the same absolute carbon and aggregation values as a clayey soil under otherwise similar management.

The operational classes in Table 2 and Figure 3 translate the statewide distributions into Very Low, Low, Medium, High, and Very High categories. These classes are relative to Missouri row-crop benchmarks, not to universal biological thresholds or stand-alone fertilizer recommendations. The indicators are correlated but not redundant. For example, TOC and POXC were strongly associated (Spearman $\rho = 0.71$), whereas the weaker relationship between TOC and WAS ($\rho = 0.36$) shows that acceptable carbon status does not automatically guarantee stable structure. The most defensible interpretation, therefore, considers the full indicator profile, soil texture, pH, and fertility constraints, and the field's management history.

Management validation revealed clear, agronomically consistent differences (Figure 4). The paired follow-up analysis provided the strongest evidence that soil health indicators can respond within a practical conservation-planning time frame. After approximately 4-5 years of cover crop adoption, mean TOC increased from 17.7 to 21.3 g kg-1 (+3.6), POXC from 443.7 to 558.5 mg C kg-1 (+114.8), WAS from 25.1% to 43.3% (+18.1 percentage points), and PMN from 72.3 to 102.0 mg N kg-1 (+29.7); all paired comparisons were significant at $P < 0.001$. POXC, WAS, and PMN changed more than TOC, as expected because reactive carbon, aggregation, and mineralizable nitrogen respond more rapidly than total carbon. Descriptive scores also tended to improve with longer cover-crop history, particularly after five or more years, reinforcing the need for sustained rather than intermittent adoption of cover crops. Likewise, the core soil health score was higher under no-till than under tillage history.

County-level maps show that indicator-specific (Figure 5) and overall (Figure 6) soil health scores vary substantially across Missouri. These maps are useful for identifying broad regional patterns and counties with limited data, but they should not be used to diagnose an individual field. County medians combine differences in texture, crop history, management, and sample density. Field decisions should be based on a representative field sample, its texture-specific context, and comparison with the field's own baseline.

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Table 1. Soil health test packages and payment information.

Program or package	Major analyses included	MU SHAC charge	NRCS incentive
Missouri cover crop cost-share package	TOC, POXC, WAS, 3-day respiration, ACE protein, PMN, particle-size texture, plus a soil-fertility package	$110/sample	Not applicable
NRCS CEMA 216 Basic	TOC, POXC, WAS, 4-day respiration, ACE protein, soil pH, and particle-size texture	$110/sample	$520/3 samples
NRCS CEMA 216 Advanced	Basic package plus PLFA or any three selected enzyme assays for C, N, P, or S cycling	$180/sample	$770/3 samples

Table 2. Operational Missouri benchmark classes used in the Soil Health Assessment Center (SHAC) soil health reporting framework.

Indicator (unit)	Very Low	Low	Medium	High	Very High
TOC (g kg^{-1})	≤7.5	7.6-15.0	16.0-25.0	26.0-35.0	≥36.0
POXC (mg C kg^{-1})	≤200	201-400	401-600	601-800	≥801
Respiration (mg CO_2 kg^{-1}, 3 d)	≤300	301-550	551-950	951-1350	≥1351
WAS (%)	≤10	11-25	26-45	46-70	≥71
ACE protein (g kg^{-1})	≤2.5	2.6-4.0	4.1-7.0	7.1-11.0	≥11.1
PMN (mg N kg^{-1})	≤30	31-60	61-100	101-140	≥141

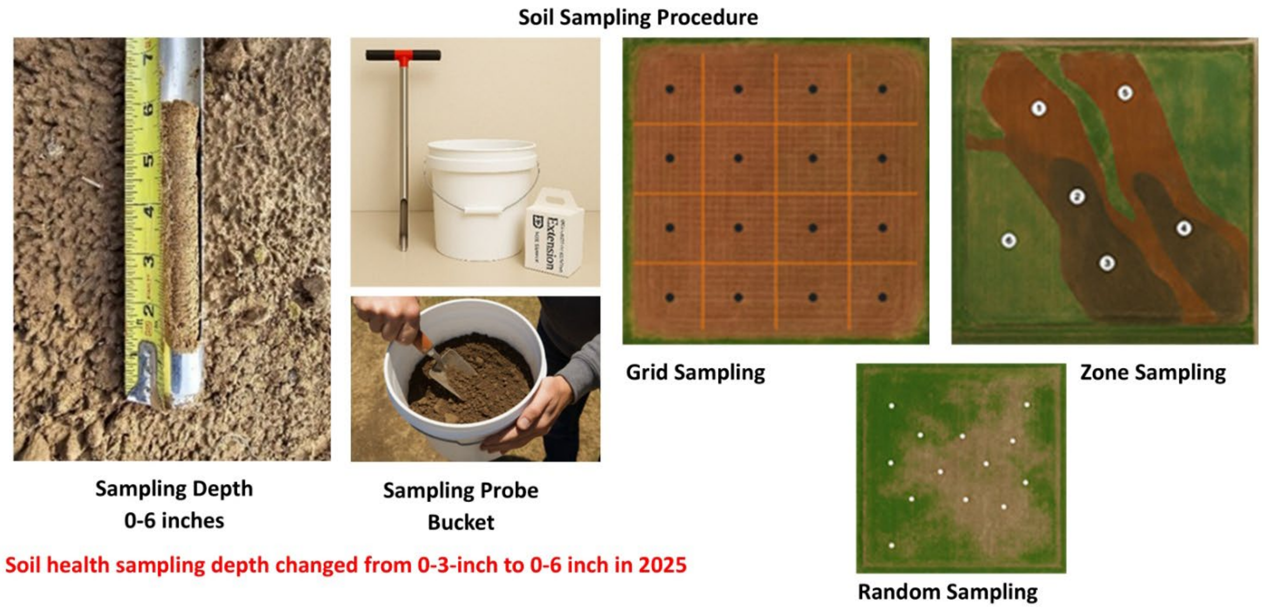


Figure 1. Current MU soil sampling procedure, including the 0-6-inch depth, sampling equipment, and grid, zone, and random sampling designs.

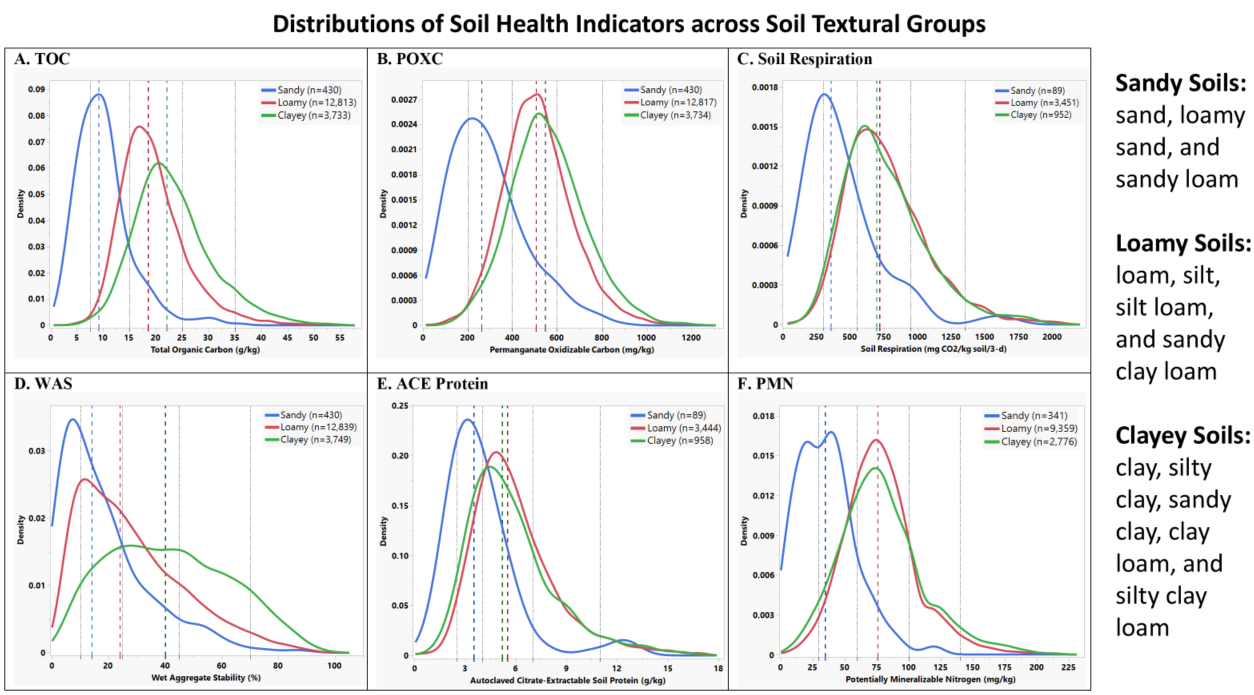
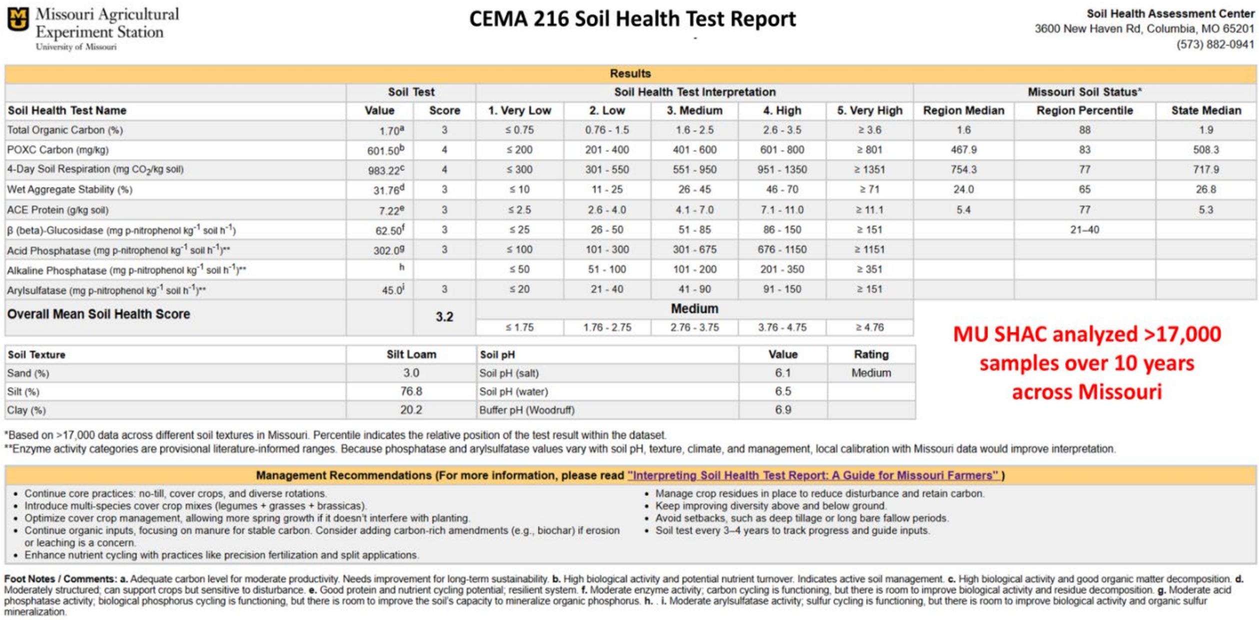


Figure 2. Distributions of TOC, POXC, respiration, WAS, ACE protein, and PMN across sandy, loamy, and clayey Missouri soils.



Missouri Agricultural Experiment Station
University of Missouri

CEMA 216 Soil Health Test Report

Soil Health Assessment Center
3600 New Haven Rd, Columbia, MO 65201
(573) 882-0941

Results											
	Soil Test		Soil Health Test Interpretation					Missouri Soil Status*		
Soil Health Test Name	Value	Score	1. Very Low	2. Low	3. Medium	4. High	5. Very High	Region Median	Region Percentile	State Median
Total Organic Carbon (%)	1.70[a]	3	≤ 0.75	0.76 - 1.5	1.6 - 2.5	2.6 - 3.5	≥ 3.6	1.6	88	1.9
POXC Carbon (mg/kg)	601.50[b]	4	≤ 200	201 - 400	401 - 600	601 - 800	≥ 801	467.9	83	508.3
4-Day Soil Respiration (mg CO_2/kg soil)	983.22[c]	4	≤ 300	301 - 550	551 - 950	951 - 1350	≥ 1351	754.3	77	717.9
Wet Aggregate Stability (%)	31.76[d]	3	≤ 10	11 - 25	26 - 45	46 - 70	≥ 71	24.0	65	26.8
ACE Protein (g/kg soil)	7.22[e]	3	≤ 2.5	2.6 - 4.0	4.1 - 7.0	7.1 - 11.0	≥ 11.1	5.4	77	5.3
β (beta)-Glucosidase (mg p-nitrophenol kg^{-1} soil h^{-1})	62.50[f]	3	≤ 25	26 - 50	51 - 85	86 - 150	≥ 151		21–40	
Acid Phosphatase (mg p-nitrophenol kg^{-1} soil h^{-1})**	302.0[g]	3	≤ 100	101 - 300	301 - 675	676 - 1150	≥ 1151			
Alkaline Phosphatase (mg p-nitrophenol kg^{-1} soil h^{-1})**	[h]		≤ 50	51 - 100	101 - 200	201 - 350	≥ 351			
Arylsulfatase (mg p-nitrophenol kg^{-1} soil h^{-1})**	45.0[i]	3	≤ 20	21 - 40	41 - 90	91 - 150	≥ 151			
Overall Mean Soil Health Score		**3.2**	**Medium**							
			≤ 1.75	1.76 - 2.75	2.76 - 3.75	3.76 - 4.75	≥ 4.76			

Soil Texture	Silt Loam	Soil pH	Value	Rating
Sand (%)	3.0	Soil pH (salt)	6.1	Medium
Silt (%)	76.8	Soil pH (water)	6.5	
Clay (%)	20.2	Buffer pH (Woodruff)	6.9	

MU SHAC analyzed >17,000 samples over 10 years across Missouri

*Based on >17,000 data across different soil textures in Missouri. Percentile indicates the relative position of the test result within the dataset.
**Enzyme activity categories are provisional literature-informed ranges. Because phosphatase and arylsulfatase values vary with soil pH, texture, climate, and management, local calibration with Missouri data would improve interpretation.

Management Recommendations (For more information, please read "Interpreting Soil Health Test Report: A Guide for Missouri Farmers")

- Continue core practices: no-till, cover crops, and diverse rotations.
- Introduce multi-species cover crop mixes (legumes + grasses + brassicas).
- Optimize cover crop management, allowing more spring growth if it doesn't interfere with planting.
- Continue organic inputs, focusing on manure for stable carbon. Consider adding carbon-rich amendments (e.g., biochar) if erosion or leaching is a concern.
- Enhance nutrient cycling with practices like precision fertilization and split applications.
- Manage crop residues in place to reduce disturbance and retain carbon.
- Keep improving diversity above and below ground.
- Avoid setbacks, such as deep tillage or long bare fallow periods.
- Soil test every 3–4 years to track progress and guide inputs.

Foot Notes / Comments: a. Adequate carbon level for moderate productivity. Needs improvement for long-term sustainability. **b.** High biological activity and potential nutrient turnover. Indicates active soil management. **c.** High biological activity and good organic matter decomposition. **d.** Moderately structured; can support crops but sensitive to disturbance. **e.** Good protein and nutrient cycling potential; resilient system. **f.** Moderate enzyme activity; carbon cycling is functioning, but there is room to improve biological activity and residue decomposition. **g.** Moderate acid phosphatase activity; biological phosphorus cycling is functioning, but there is room to improve the soil's capacity to mineralize organic phosphorus. **h.** . **i.** Moderate arylsulfatase activity; sulfur cycling is functioning, but there is room to improve biological activity and organic sulfur mineralization.

Figure 3. Example MU CEMA 216 soil health test report. The MU Soil Health Assessment Center (SHAC) has analyzed more than 17,000 soil health samples across Missouri over approximately 10 years.

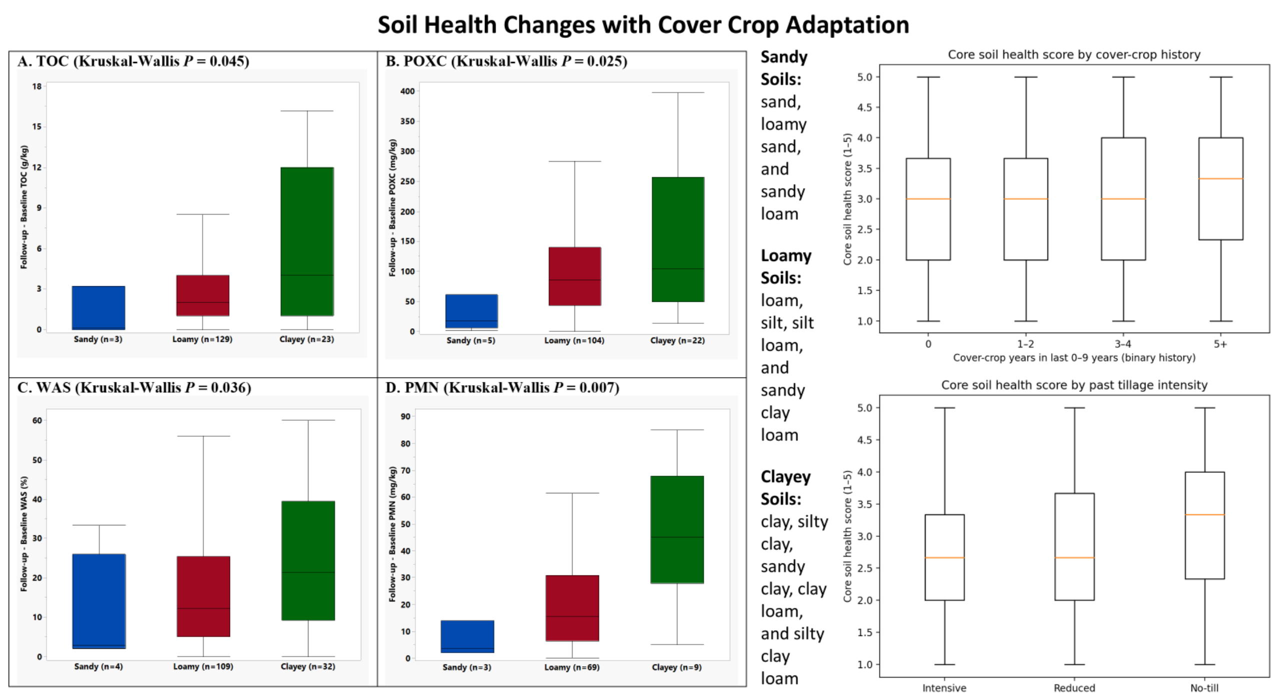


Figure 4. Soil health changes with cover crop adoption, including paired field-level changes in TOC, POXC, WAS, and PMN and core soil health scores by cover crop and tillage history.

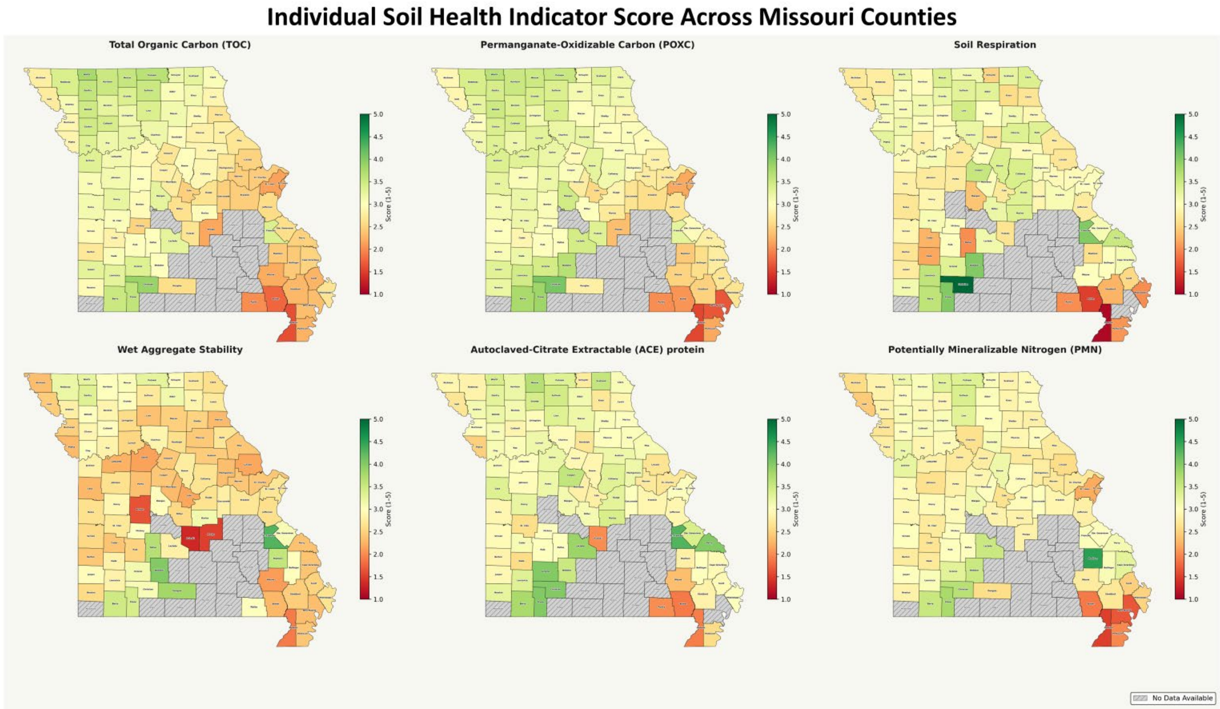


Figure 5. County-level maps of TOC, POXC, soil respiration, WAS, ACE protein, and PMN scores across Missouri.

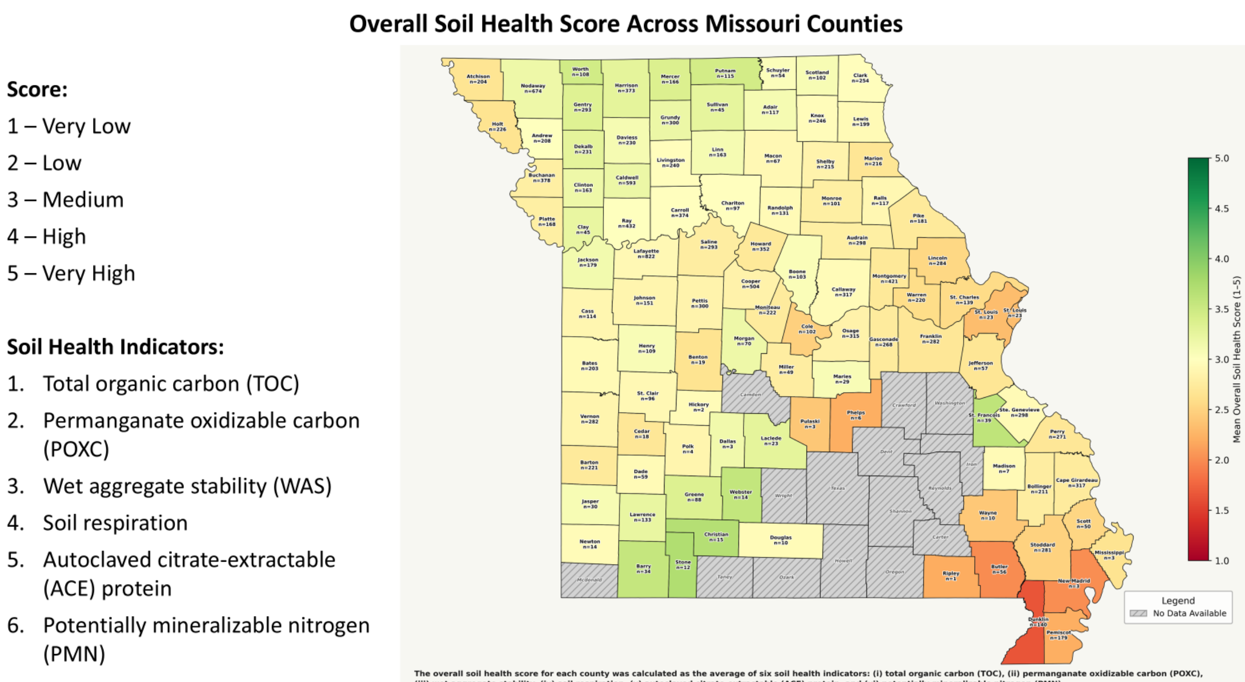


Figure 6. County-level overall soil health scores across Missouri based on six indicator classes.

GRAIN SORGHUM PRODUCTION IN THE SOLAR CORRIDOR CROPPING SYSTEM FOR LIVESTOCK UTILIZATION

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INTRODUCTION

Grain sorghum [*Sorghum bicolor* (L.) Moench] has gained popularity recently as a crop of choice for farmers with integrated cropping systems (livestock and crop production). Traditionally, grain sorghum was raised as a grain crop, mechanically harvested, and sold by the bushel. Alternatively, grain sorghum may be utilized to reduce winter feed costs for livestock operations in Missouri. In this system, a farmer raises a grain sorghum crop with the purpose of producing grain. The difference comes when harvesting with livestock rather than a mechanical harvester. Utilizing livestock to harvest grain sorghum has potential to reduce expenses and increase utilization of land resources.

A new idea for grain production is being called the solar corridor cropping system (SCCS). The SCCS utilizes wider crop row spacings to saturate the lower leaves of plants with solar radiation energy (Deichman et al., 2014; Nelson, 2014). This lower plant leaf saturation of light potentially allows increased individual plant performance at lower seeding rates. By transitioning to a SCCS, grain sorghum can be planted in 60-inch wide rows to allow use of currently available equipment. This leaves a greater space between rows than the common 30-inch row spacing. The increased space between crop rows may allow individual plants to compensate and produce yields similar to 30-inch row grain sorghum. With the introduction of a legume intercrop in the SCCS, lower sorghum leaves may become partially shaded depending on the intercropped species. However, an intercropping system could allow greater resource use and increase productivity (Feng et al., 2022), but it also limits weed control options (Nelson, 2014). Differing root systems including a combination of tap and fibrous roots may allow for more nutrients in the soil profile to be taken up by plants in the SCCS. The tap root of a dicot intercrop will potentially reach nutrients deeper in the soil profile, while the fibrous roots of the monocot grain sorghum will be primarily in the upper layers of the soil profile (Mengel, 1995).

OBJECTIVES

The objective of this research was to evaluate the effect of the SCCS on sorghum grain yield and forage mass in the presence and absence of an intercrop for subsequent livestock grazing.

PROCEDURES

This study was conducted in 2022 and 2023 at the University of Missouri Bradford Farm (38.9° N, 92.2° W) near Columbia, MO. The soil series at the experiment site was Mexico silt loam (fine, smectitic, mesic Vertic Epiaqualfs). Average daily air temperature, daily rainfall, and cumulative rainfall was collected on-site from a weather station (University of Missouri Mesonet, 2026) (Figure 1).

Different field locations were used each year. The experiment was arranged in a randomized complete block design with four replications. Individual plots were 20 ft by 35 ft. The study included four treatments: 1) grain sorghum (Pioneer 84P72) planted in 30-inch rows at 120,000 seeds ac^{-1} as a control (GS76); 2) grain sorghum planted in 60-inch wide rows at 60,000 seeds ac^{-1} (GS152); 3) grain sorghum planted in 60-inch wide rows at 60,000 seeds ac^{-1} with forage soybean (Laredo) intercropped at 70,000 seeds ac^{-1} (GS152FS); and 4) grain sorghum planted in 60-inch wide rows at 60,000 seeds ac^{-1} with cowpea (Iron Clay) intercropped at 70,000 seeds ac^{-1} (GS152CowP). The plots were tilled with a John Deere 960 (Deere and Company, Moline, IL) field cultivator for seedbed preparation. Grain sorghum and intercrops were planted with a John Deere 7100 planter with cone units. The grain sorghum seed was treated with fluxofenim[1-(4-chlorophenyl)-*N*-(1,3-dioxolan-2-ylmethoxy)-2,2,2-trifluoroethanimine] as a safener for use of *S*-metolachlor [2chloro-N-(2ethyl-6-methylphenyl)-N-[(1S)-2-methoxy-1-methylethyl] acetamide]. Following planting, plots were sprayed pre-emergence with *S*-metolachlor at 1.3 pts ac^{-1}. Nitrogen (SuperU, Koch Agronomic Services, Wichita, KS) was broadcast applied at 100 lbs. N ac^{-1} two weeks after planting. Plots were maintained weed free during the growing season by two inter-row mechanical cultivation passes. Field management is summarized in Table 1.

Grain sorghum was harvested for grain in November using a Massey Ferguson 8XP plot combine (Massey Ferguson, Duluth GA). Grain yield was determined by harvesting an interior area of the plot from an area measuring 5ft x 35 ft. In the 30-inch treatments, this consisted of two rows of grain sorghum. In the 60-inch treatments, this consisted of only one row of grain sorghum. Grain sorghum forage biomass was harvested four times (December, January, February, and March) each year during the winter after plant growth. Intercrop biomass was harvested once each year in January. The same intercrop biomass data was then used for each month in subsequent analysis. Harvest dates are listed in Table 1. Biomass samples were harvested to represent plant tonnage and forage quality analysis. Samples were separated into three different plant part categories of head, leaf, and stem material. Samples were dried at 110º F, ground using a Thomas-Wiley mill® (Swedesboro, NJ), and analyzed for nutritive values including crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and total digestible nutrients (TDN) (Dairy One, Ithaca, NY).

RESULTS

Sorghum grain yield had a significant year by treatment interaction (P=0.0025). Data were presented separately by year and solar corridor cropping systems (Figure 2). GS76 in 2022 yielded higher than all other treatments at 137 bu ac^{-1}. GS76 in 2023 yielded similar to all other treatments. GS152, GS152FS, and GS152CowP all yielded similar across 2022 and 2023 apart from GS152CowP in 2022 yielding the lowest (68 bu ac^{-1}). In 2022, GS76 yield was 39% more than GS152. This aligns with findings from a study conducted by Wortmann et al. (2009). They determined that in a yield potential environment for grain sorghum of 80 bu ac^{-1} or higher, a skip row planting style would yield lower than when all rows were planted. Even under water deficit conditions, grain sorghum has adapted to still perform and produce stable grain yields (Norwood, 1999; Rai et al., 2008; Wortmann et al., 2009; Rogers et al., 2019).

Total biomass yield was compared among SCCS treatments and harvest dates (P=0.0019) (Figure 3). GS76 produced the highest biomass yield (6,310 to 13,945 lbs. ac^{-1}) compared to all treatments in December, January, and February. In March, there was no difference in biomass yields across all treatments. Within each harvest date, GS152FS and GS152CowP whole plot biomass yields were similar. All treatments showed a decline in biomass yield from December to

March. GS76 forage biomass declined 55% from December to February and 72% from December to March. GS152 also showed a significant decline from December to February and March of 60% and 73%, respectively. GS152FS and GS152CowP had similar declines in biomass during this period when compared to GS152. Both GS152FS and GS152CowP showed a decline of 50% and 64% from December to February and March, respectively. This decline of recoverable biomass (Figure 3) in later harvest dates was due to environmental (Figure 1) and wildlife factors affecting the biomass. These factors included freezing conditions, weathering, lodging, seed rotting, and animal predation (visual observation). Individual plant part quality concentrations listed as well (Table 2).

There were different levels of CP in the intercrops between years (P=0.0017), which could be due to differences in the amount of seed present at the time of sampling. Forage soybean CP was 15.7% and 6.4% in 2022 and 2023, respectively. Cowpea CP was 14.1% and 8.9% CP in 2022 and 2023, respectively. Data not presented.

Total CP produced per acre had a significant interaction between SCCS treatments and harvest dates (P=0.0162, data not presented). Across all treatments, total CP produced per acre was highest in December and January. The addition of a leguminous intercrop in previous research increased protein content of the harvested biomass (Kadziulienė et al., 2011; Thomas et al., 2024). However, GS76 and GS152 produced more CP than treatments with leguminous intercrops present. In GS76, there was a 51% decrease in CP from December (985 lbs. ac^{-1}) to February (486 lbs. ac^{-1}) and a 79% decrease in March (211 lbs. ac^{-1}) compared to December. GS152 CP decreased 61% from December (946 lbs. ac^{-1}) to February (373 lbs. ac^{-1}) and 80% in March (191 lbs. ac^{-1}) compared to December. GS152FS CP decreased 48% in February (409 lbs. ac^{-1}) and 66% in March (271 lbs. ac^{-1}) compared to December (792 lbs. ac^{-1}). Finally, GS152CowP CP decreased 51% in February (377 lbs. ac^{-1}) and 67% in March (252 lbs. ac^{-1}) compared to December highs (766 lbs. ac^{-1}).

Total digestible nutrients (TDN) showed a significant interaction between SCCS treatments and harvest dates (P=0.0007, data not presented). Across all treatments, December and January TDN production was similar. February and March TDN levels across all treatments declined from the December and January highs. GS76 produced the highest TDN yield among treatments in December and January. After weathering and wildlife predation of plants, TDN levels were similar across treatments in March. GS76 saw declines from December (10,045 lbs. ac^{-1}) of 61% and 80% in February (3,894 lbs. ac^{-1}) and March (1,984 lbs. ac^{-1}), respectively. GS152 had TDN declines from December (7,961 lbs. ac^{-1}) of 67% and 82% in February (2,633 lbs. ac^{-1}) and March (1,452 lbs. ac^{-1}), respectively. When intercrops were introduced, there was still substantial declines in TDN values across harvest dates. GS152FS TDN levels declined from December (6,495 lbs. ac^{-1}) by 56% and 72% in February (2,826 lbs. ac^{-1}) and March (1,832 ac^{-1}), respectively. GS152CowP TDN levels declined from December (6,694 lbs. ac^{-1}) by 59% and 74% in February (2,755 lbs. ac^{-1}) and March (1,737 lbs. ac^{-1}), respectively.

CONCLUSIONS

Grain sorghum yields in conventional 30-inch-wide rows were highest or similar in all metrics compared to grain sorghum in wide rows (60-inch) with or without leguminous intercrops present. Compared across years and treatments, GS76 grain yield was highest in 2022, but it was similar to the other treatments in 2023. Over both years, the introduction of an intercrop in 60-inch-wide rows did not statistically affect grain yield, except for GS152CowP being lower in 2022. Removing every other grain sorghum row and half the plant population decreased total biomass production per acre. Total CP and TDN production per acre was reduced in all other treatments compared to grain sorghum in 30-inch wide rows.

Farmers that need to increase the CP of the grain sorghum ration through inclusion of high protein leguminous intercrops for livestock utilization can expect total production per acre of both protein and energy to decrease. As winter progressed, seed predation occurred (visual observation) of grain sorghum heads. We recommend grazing grain sorghum prior to February is necessary for the greatest utilization as a forage crop.

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Table 1. Field management and harvest dates in 2022 and 2023.

Field management	2022	2023
Maintenance fertilizer	None applied	None applied
Secondary tillage (John Deere 960)	7 June	24 May
Planting (John Deere 7100)	14 June	31 May
Preemergence herbicide	S-metolachlor† at 1.3 pts ac^{-1}	S-metolachlor at 1.3 pts ac^{-1}
N application	100 lbs. N ac^{-1} (Super U®, Koch Agronomic Services. Wichita, KS) 28 June	100 lbs. N ac^{-1} (Super U®) 14 June
Between-row cultivation	29 June + 11 July	15 June + 27 June
Grain harvest	29 Nov.	9 Nov.
Forage biomass harvests	30 Nov., 1 Jan. 2023, 11 Feb. 2023, 16 Mar. 2023	6 Dec., 2 Jan. 2024, 7 Feb. 2024, 11 Mar. 2024

†Abbreviations: S-metolachlor, 2-chloro-N-(2ethyl-6-methylphenyl)-N-[(1S)-2-methoxy-1-methylethyl] acetamide.

Table 2. Grain sorghum head, leaf, and stem plant part concertation quality. Metrics listed for individual plant parts are crude protein (CP), total digestible nutrients (TDN), acid detergent fiber (ADF), and neutral detergent fiber (NDF).

SCCS	Head				Leaf				Stem			
	CP	TDN	ADF	NDF	CP	TDN	ADF	NDF	CP	TDN	ADF	NDF
	---% ---											
GS76†	7.8	80.0	16.7	24.8	9.5	51.4	45.5	70.7	4.2	54.5	84.7	45.4
GS152	8.6	80.0	16.6	25.0	11.9	51.2	44.3	67.9	5.0	53.4	83.2	45.9
GS152FS	8.2	79.5	16.8	26.0	10.4	52.0	44.8	70.4	4.5	54.0	84.1	46.2
GS152CowP	8.1	79.3	17.7	26.4	10.3	51.8	44.9	69.8	4.5	54.8	84.5	46.2
LSD (*P=0.05*)	5	NS	NS	NS	1	NS	11	16	4	11	10	8

†Abbreviations; GS76, grain sorghum in 30-inch wide rows; GS152, grain sorghum in 60-inch wide rows; GS152FS, grain sorghum in 60-inch wide rows with forage soybean intercropped; GS152CowP, grain sorghum in 60-inch wide rows with cowpea intercropped; LSD, least significant difference; NS, not significant.

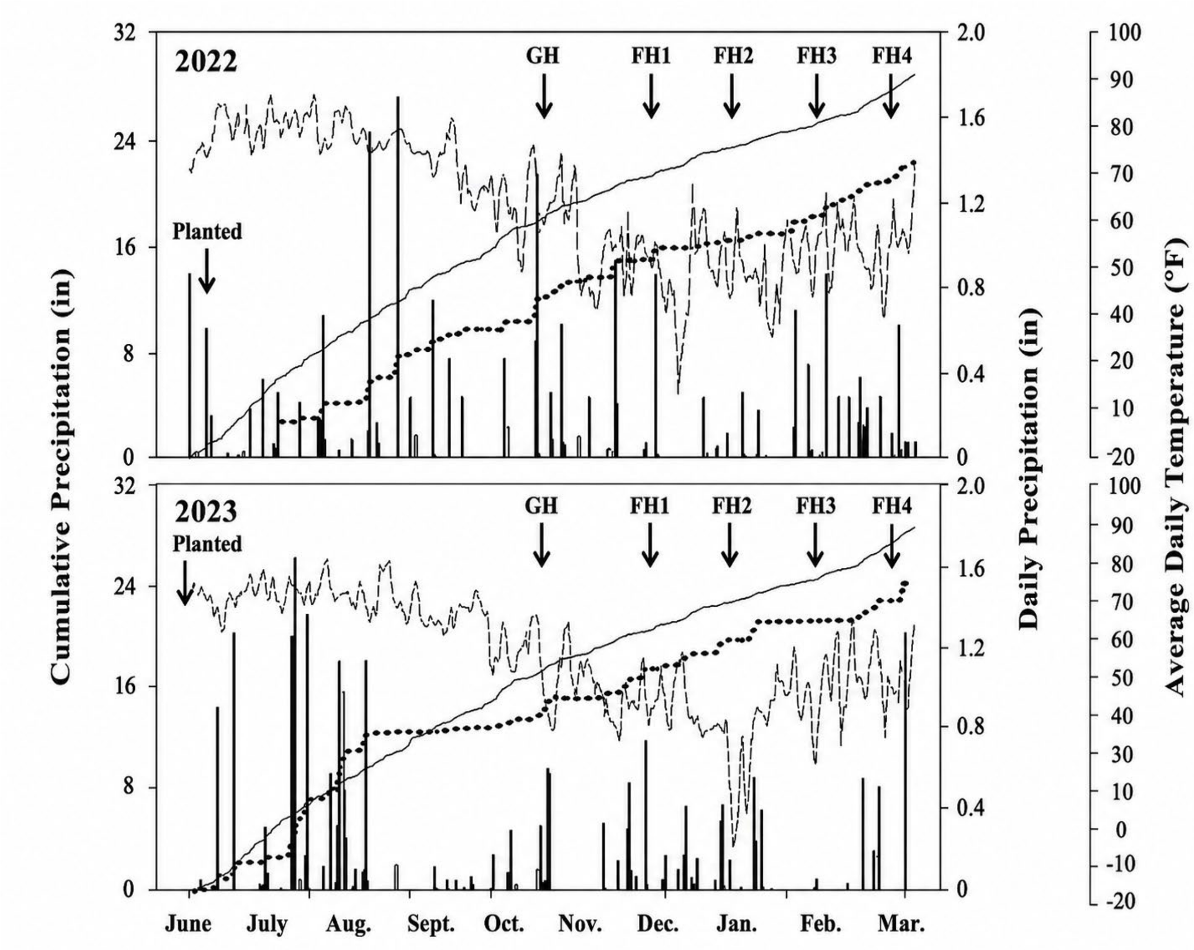

Figure 1. Daily precipitation (bars), cumulative precipitation (dotted line), 15-year average precipitation (solid line), and average daily temperature (dashed line) in 2022 and 2023. Planting date (Planted), grain harvest (GH), and the four forage harvests (FH) are marked on the figure.

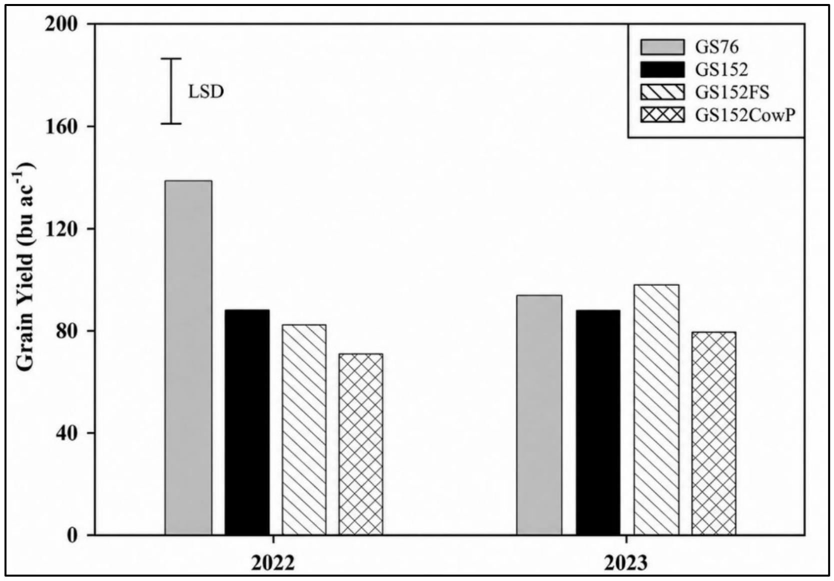

Figure 2. Sorghum grain yield of 30-inch-wide rows (GS76), 60-inch wide rows (GS152), and 60-inch-wide rows with intercropped forage soybean (GS152FS) or cowpea (GS152CowP) in 2022 and 2023. Whisker = least significant difference at α = 0.05.

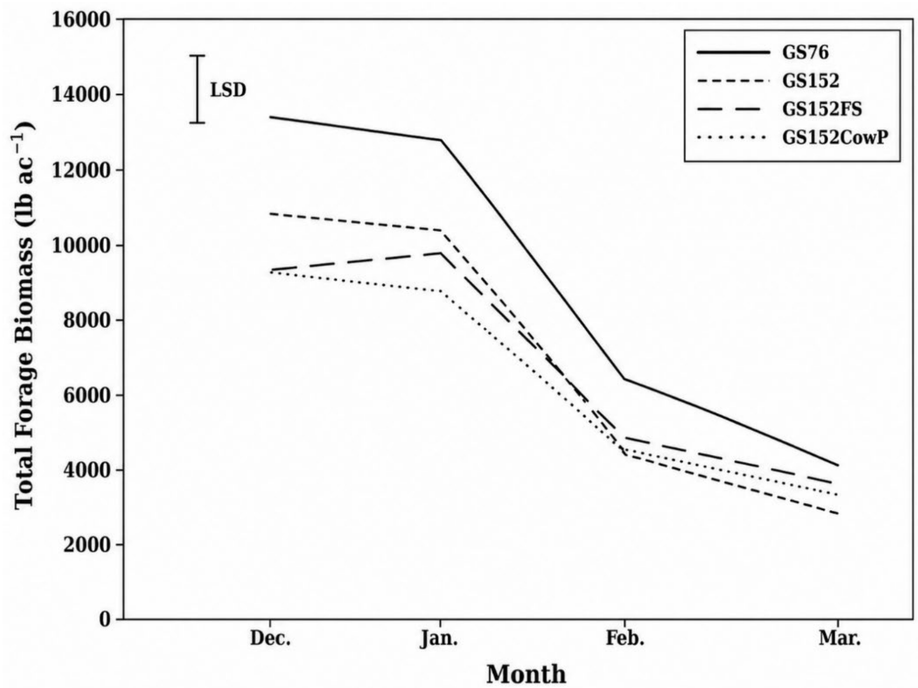

Figure 3. Total forage biomass of grain sorghum in 30-inch-wide rows (GS76), 60-inch-wide rows (GS152), and 60-inch-wide rows with intercropped forage soybean (GS152FS) or cowpea (GS152CowP) from December to March. Data was combined over years (2022 and 2023). Whisker = least significant difference at α = 0.05.

NITROGEN EFFECTS ON FORAGE BIOMASS, UTILIZATION, AND ECONOMIC RETURNS IN GRAZING AND HAYING SYSTEMS

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INTRODUCTION

Nitrogen (N) fertilization is a major factor influencing forage productivity and profitability in tall fescue (*Lolium arundinaceum*) production systems across Missouri. However, nutrient removal and recycling differ substantially between haying and grazing systems. Haying removes large quantities of nutrients through harvested biomass, whereas grazing recycles nutrients back to the soil through manure and urine deposition (Hutton et al., 1967; Henning et al., 1993). These differences suggest that optimum N management strategies may vary depending on harvest system.

Increasing fertilizer costs have heightened the need to identify management strategies that maximize forage productivity while maintaining economic returns. Previous studies have demonstrated that N fertilization can substantially increase forage production, but economic responses often depend on harvest method, nutrient cycling efficiency, and operational costs (Angima et al., 2009; Kallenbach et al., 2017). Grazing systems may improve nutrient-use efficiency through nutrient recycling, while haying systems may require greater fertilizer inputs to sustain productivity (Sigua et al., 2007).

Nitrogen response in forage systems is also affected by environmental conditions, management intensity, and soil characteristics (Pennings et al., 2005; Tröster et al., 2019). Reassessing N management strategies under grazing and haying systems is important for improving the profitability and sustainability of forage-based enterprises. The objective of this study was to determine the optimum N rate for tall fescue and evaluate the effects of N fertilization and legume interseeding on forage biomass, forage utilization, and net returns under grazing and haying systems in northern Missouri.

PROCEDURES

The study was conducted in 2025 at the University of Missouri Cornett Research Farm near Linneus, Missouri, on an Armstrong loam soil (Aquertic Hapludalfs). The experiment was a split-plot design with three replications. The harvesting system was the main plot factor with two levels: rotational grazing and haying. The subplot factor was applied at 0, 60, 120, and 180 lb N ac^{-1}, and 0 lb N ac^{-1} + overseeded birdsfoot trefoil (*Lotus corniculatus L.*).

Hay treatments were harvested using a self-propelled plot harvester (HEGE 212, Wintersteiger AG, Ried im Innkreis, Austria), while grazing treatments were managed under a rotational grazing strategy based on the principles of management-intensive grazing as explained by Pfost et al. (2000). Red or black angus heifers weighing 650 lbs were used for grazing. Forage samples were collected using 3 0.25 m^2 quadrats per plot to estimate forage biomass yield. Samples were collected before and after each grazing event. Forage utilization was calculated by subtracting pre-graze biomass from post-graze biomass.

Forage samples were oven dried at 120°F to constant weight and analyzed for forage quality using near-infrared reflectance spectroscopy (NIRS). Economic analyses included fertilizer costs, harvest costs, and estimated forage value to determine net returns for each treatment. In 2025, the economic analysis was calculated using the University of Missouri enterprise budgets for stockers and hay, assuming a value of gain of $2.19 lb^{-1}, a hay price of $120 ton^{-1}, and a N fertilizer cost of $0.60 lb^{-1}

Data were analyzed using mixed models in R Studio using the lme4 package (Bates et al., 2015). Mean separations and confidence intervals were estimated using the emmeans package (Lenth, 2023). Treatment effects were considered significant at $\alpha \leq 0.05$.

RESULTS

Precipitation patterns during the 2025 growing season were highly variable relative to the 30-year average. July received substantially greater precipitation than normal, while August conditions were considerably drier than average. These contrasting environmental conditions provided an opportunity to evaluate system responses under variable moisture conditions.

Forage Biomass

Forage biomass did not differ between grazing and haying systems across N rates ($p = 0.324$). This contrasts with Ning et al. (2025), who reported that grazing systems produced 17.6% greater forage biomass than haying systems over a two-year period. The lack of significant difference observed in this study may be attributed to the short duration of data collection, as these results represent only a single growing season. Ongoing long-term studies may capture cumulative system differences driven by nutrient cycling and management effects.

Nitrogen rate also did not significantly affect forage biomass. However, numerical trends indicated system-specific responses, with grazing systems achieving maximum biomass at 60 lb N ac^{-1} and haying systems peaking at 180 lb N ac^{-1} (Figure 1). The grazing system produced approximately 9001 lb ac^{-1} at 60 lb N ac^{-1}, whereas the haying system produced approximately 8221 lb ac^{-1} at 180 lb N ac^{-1}. Biomass in grazing systems declined at higher N rates, suggesting diminishing returns to fertilizer inputs.

The earlier peak under grazing indicates greater smarter N use at lower inputs, likely due to nutrient recycling through manure deposition. Previous studies have shown that grazing systems return a substantial proportion of nutrients to the soil, enhancing productivity at reduced fertilizer rates (Hutton et al., 1967; Henning et al., 1993). In contrast, haying systems remove nutrients with harvested biomass, requiring higher external N inputs to sustain yield.

Forage Utilization

Forage utilization was significantly greater in haying systems compared to grazing systems (Figure 2). Haying resulted in approximately 76% greater forage utilization than grazing. Nitrogen rate did not significantly affect forage utilization. This observed difference reflects the fundamental contrast in harvest strategy rather than N response. Haying removes nearly all aboveground biomass, whereas grazing systems intentionally leave residual forage to maintain regrowth. As a result, utilization is driven primarily by management rather than fertilization, a pattern consistent with established grazing management principles.

Net Returns

Net returns differed significantly between harvest systems ($p = 9.07 \times 10^{-8}$). Grazing consistently generated greater economic returns than haying across all N rates (Figure 3). Peak returns occurred at 60 lb N ac^{-1} under grazing, while haying showed little economic response to increasing N rates.

Nitrogen rate alone did not affect net returns ($p = 0.246$). Increasing N rates in haying systems did not produce proportional economic gains, likely due to fertilizer cost, machinery expense, and operational costs associated with hay production. Grazing systems produced greater economic returns than haying due to lower input and operational costs ($p = 9.07 \times 10^{-8}$). In grazing systems, the greatest response occurred at 60 lb N ac^{-1}, where each pound of N increased forage yield by approximately 37.3 lb of forage compared with the unfertilized control. In contrast, although hay yield was greatest at 180 lb N ac^{-1} (8,221 lb ac^{-1}), the additional 2,604 lb ac^{-1} of forage produced relative to the unfertilized control represented only 14.5 lb of forage per pound of N applied. This increase in forage production was insufficient to offset the additional fertilizer and harvest costs.

These results suggest that moderate N fertilization under grazing management provided the best balance between forage production, fertilizer efficiency, and profitability. Nitrogen fertilization for hay was not warranted.

RECOMMENDATIONS

Grazing systems should be prioritized where feasible, as they demonstrated smarter N use and achieved comparable biomass at lower N inputs. Applying moderate N rates around 60 lb N ac^{-1} in grazing systems appears sufficient to optimize productivity while minimizing input costs. In contrast, haying systems required higher N inputs to reach maximum biomass but did not demonstrate improved returns, suggesting that using N fertilizer may not be economically justified. Producers relying on hay systems should therefore carefully evaluate fertilizer inputs relative to expected returns.

Overall, N management should be aligned with harvest strategy, with grazing systems benefiting from nutrient recycling and reduced dependence on external inputs. Continued long-term evaluation is recommended to better capture system-level differences and refine N recommendations under varying environmental conditions.

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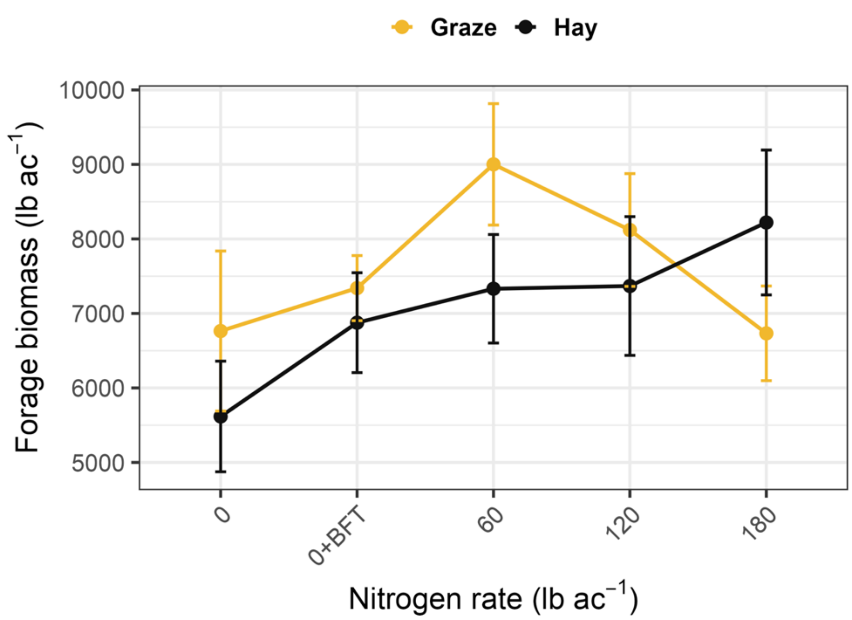

Figure 1. Forage biomass (lb ac^{-1}) by harvest type (grazing &. haying) across nitrogen rates, with 95% confidence intervals; University of Missouri Cornett Farm, Linneus, MO, 2025.

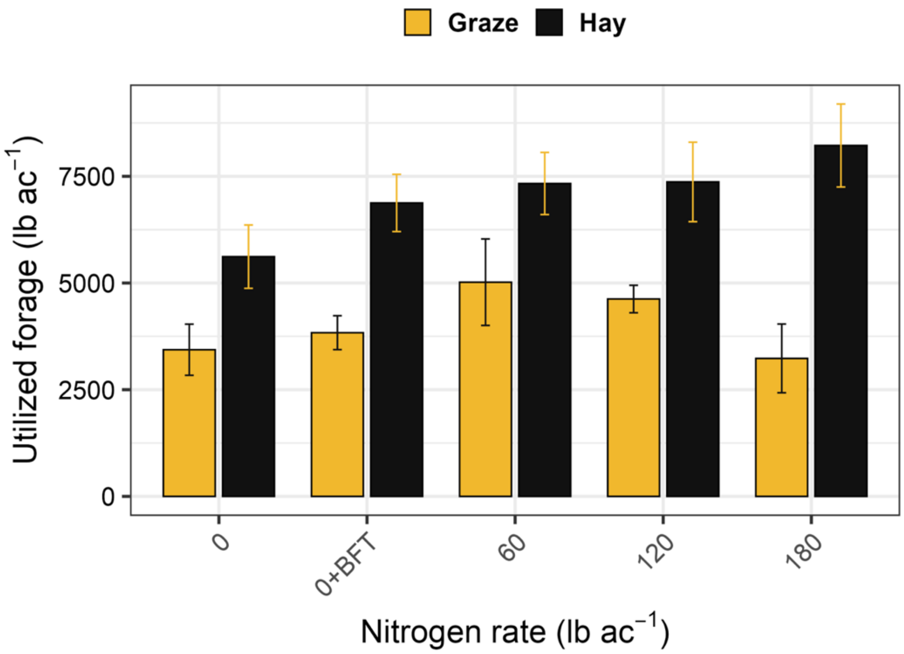

Figure 2. Forage utilization (lb ac^{-1}) by harvest type (grazing & haying) across nitrogen rates, with 95% confidence intervals; University of Missouri Cornett Farm, Linneus, MO, 2025.

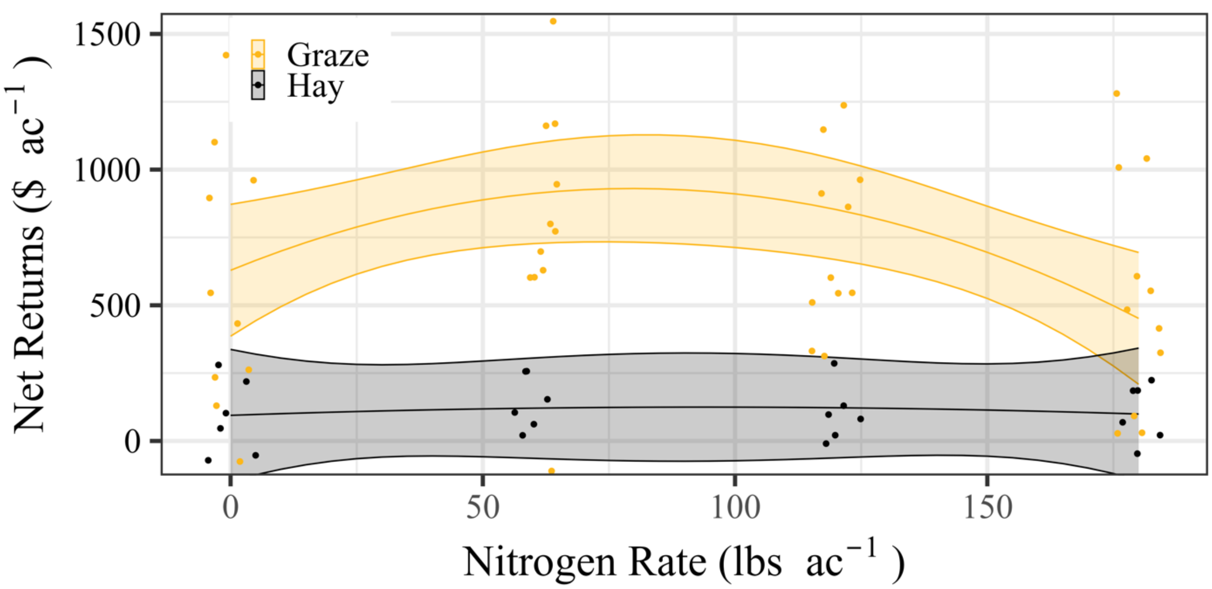

Figure 3. Net returns ($ ac^{-1}) by harvest type (grazing & haying) across nitrogen rates, with 95% confidence intervals; University of Missouri Cornett Farm, Linneus, MO, 2025.

EFFECTS OF NITROGEN RATE AND LIME ON ESTABLISHED NATIVE WARM-SEASON GRASSES IN MISSOURI

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INTRODUCTION

Balancing forage productivity and fertilizer inputs is essential for optimal forage production. Applying nitrogen (N) to native warm-season grasses (NWSG) without addressing underlying soil limitations may reduce input efficiency. Native warm-season grasses such as indiangrass (*Sorghastrum nutans*) and big bluestem (*Andropogon gerardii*) are increasingly important in Missouri forage systems because they provide reliable summer productivity when cool-season grasses decline. These benefits have led to rapidly increasing adoption of NWSGs for grazing and haying.

Little is known about optimal fertilizer management, particularly N and pH requirements. Nitrogen fertilization is commonly used to increase forage yield and quality, yet responses in NWSG systems are often inconsistent and highly dependent on site-specific factors such as soil fertility and pH (Kallenbach et al., 2017; Pennings et al., 2005).

Unlike many forage species, NWSG may be more tolerant of acidic soils, which may explain why lime management has not been as extensively studied in these systems. However, acid-tolerant species can experience suboptimal growth under low pH conditions, particularly when N is applied (Fageria & Baligar, 2008). Research on the effects of N and lime on established NWSG is limited.

This study aims to evaluate influence of N rate and lime application interaction on forage productivity, with the goal of improving input efficiency and providing practical recommendations for producers managing native grass systems.

PROCEDURES

The study was conducted in 2025 at the University of Missouri Cornett Research Farm near Linneus, Missouri, on an Armstrong loam soil (Aquertic Hapludalfs). Established stands of Indiangrass and big bluestem were used. The experiment was arranged as a randomized complete block design with a 2 × 6 factorial arrangement of treatments and four replications. Treatments consisted of N fertilizer rates (0, 30, 60, 90, 120, and 150 lb N ac^{-1}) combined with or without lime application rates at 2 tons ac^{-1}.

Forage biomass was harvested using a self-propelled plot harvester (HEGE 212, Wintersteiger AG, Ried im Innkreis, Austria) to obtain yield measurements. Subsamples were collected, oven-dried at 120°F to a constant weight, and ground to pass through a 1-mm screen. Forage quality was analyzed using near-infrared reflectance spectroscopy (NIRS) to determine crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF).

Returns after fertilizer expenses were calculated using the USDA's hay market report for Missouri. Crude protein was used to evaluate the forage value for each observation, and fertilizer expenses were calculated at prices for 2025 ($0.60 USD lb^{-1}). Data were analyzed using mixed-effects models, with treatment effects considered significant at $\alpha \leq 0.05$ (Bates et al., 2015).

RESULTS

Preliminary data showed dry matter increased with N rate, with yields more than doubling from 0 to 150 lb N ac^{-1} in plots without lime application. Lime application increased yield by approximately 18%, with the greatest response observed at 90 and 150 lb N ac^{-1}. (Figure 1). This pattern suggests that lime improves nitrogen-use efficiency at higher application rates by alleviating soil acidity constraints. This closely aligns with the work of Armelin et al. (2007) who also reported positive correlation of dry matter yield to liming. Similar responses have been reported where N effectiveness is enhanced under improved soil pH conditions (Fageria & Baligar, 2008). Increased yield with N is also consistent with previous findings showing that warm-season grass productivity responds positively to nitrogen fertilization, although responses are often site-specific (Muir et al., 2001; Mitchell et al., 2008).

Crude protein (CP) increased linearly with N rate, with an approximately 4% increase from 0 to 150 lb N ac^{-1}. Lime did not significantly affect CP concentration (Figure 2). The increase in CP reflects greater N uptake and incorporation into plant tissue, a response widely observed in forage systems under N fertilization (Puoli et al., 1991; Waramit et al., 2012). The lack of lime effect suggests that N availability, rather than soil pH, was the primary driver of CP concentration in this system.

Acid detergent fiber (ADF) declined slightly as N rate increased, with an approximately 3% decrease from 0 to 150 lb N ac^{-1} (Figure 3). This suggests a modest improvement in forage digestibility at higher N rates. This is comparable with works by Trach et al (1998) on rice straw where they found no effect of urea and lime on ADF. Lime did not affect ADF, indicating that lime primarily influenced biomass production rather than forage nutritive value.

Nitrogen fertilization can double yield and increase forage quality but may not be economically viable. Returns after fertilizer expense did not increase as rate increases (Figure 4). The cost of applying nitrogen has nearly doubled since last year, so expect returns after fertilizer expenses in 2026 may be highest where no nitrogen fertilizer was applied.

Nitrogen fertilization increased native warm-season grass yield and improved forage quality, while lime enhanced yield response mainly at higher nitrogen rates. These findings suggest that soil pH may influence nitrogen efficiency in established native warm-season grass systems.

RECOMMENDATIONS

Nitrogen fertilization should be applied at moderate rates to improve productivity and forage quality of native warm-season grasses; however, N applications will not improve profitability. Liming is recommended in acidic soils to enhance N response and overall forage performance. Integrating N and lime management has the potential to improve productivity and input efficiency in NWSG systems.

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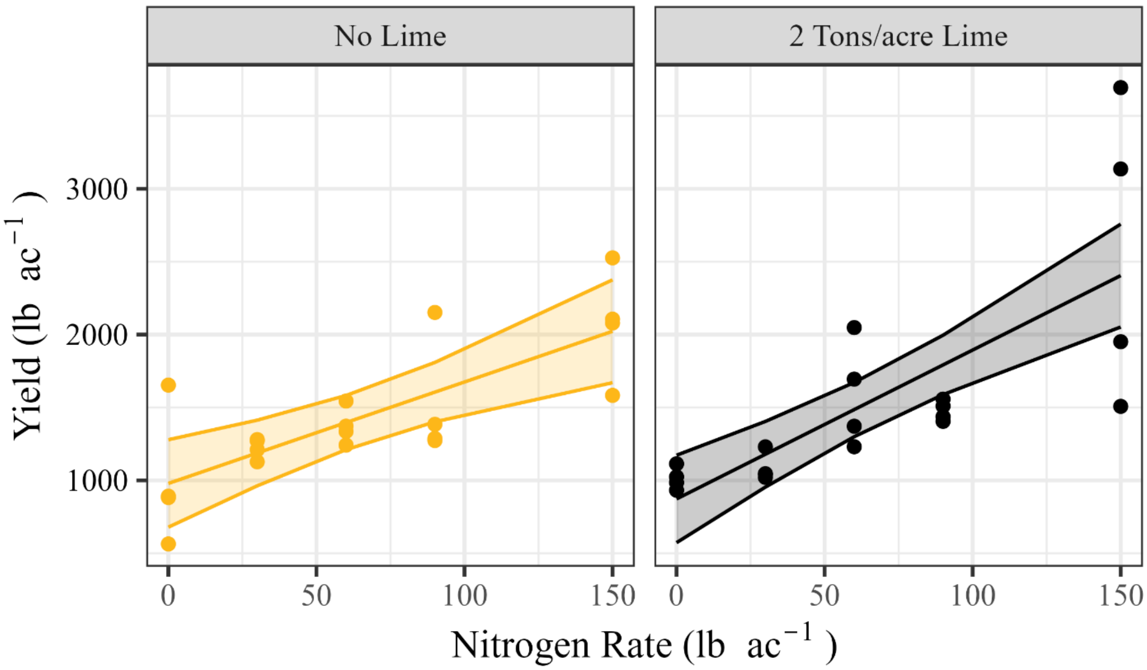

Figure 1. Dry matter yield of native warm-season grass with a 95% confidence interval of five nitrogen application rates with two liming regimens in Linneus, MO during 2025.

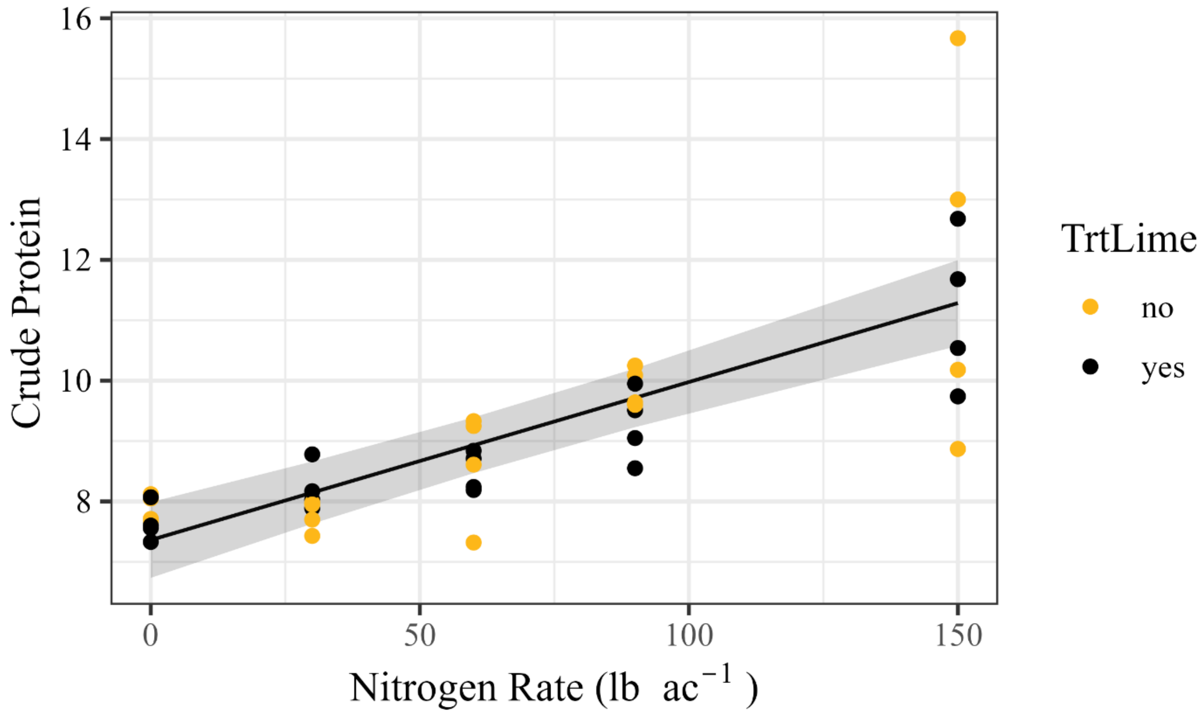

Figure 2. Crude protein of native warm-season grass with a 95% confidence interval for five nitrogen application rates and two liming regimens in Linneus, MO in 2025.

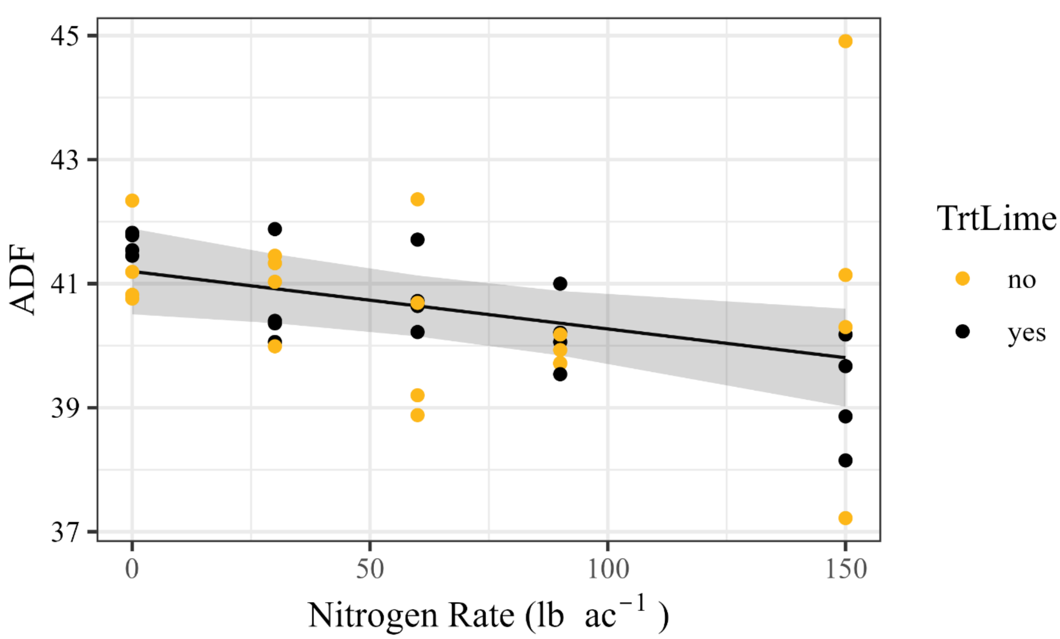

Figure 3. Acid detergent fiber (ADF) of native warm-season grass with a 95% confidence interval for five nitrogen application rates and two liming regimens in Linneus, MO in 2025.

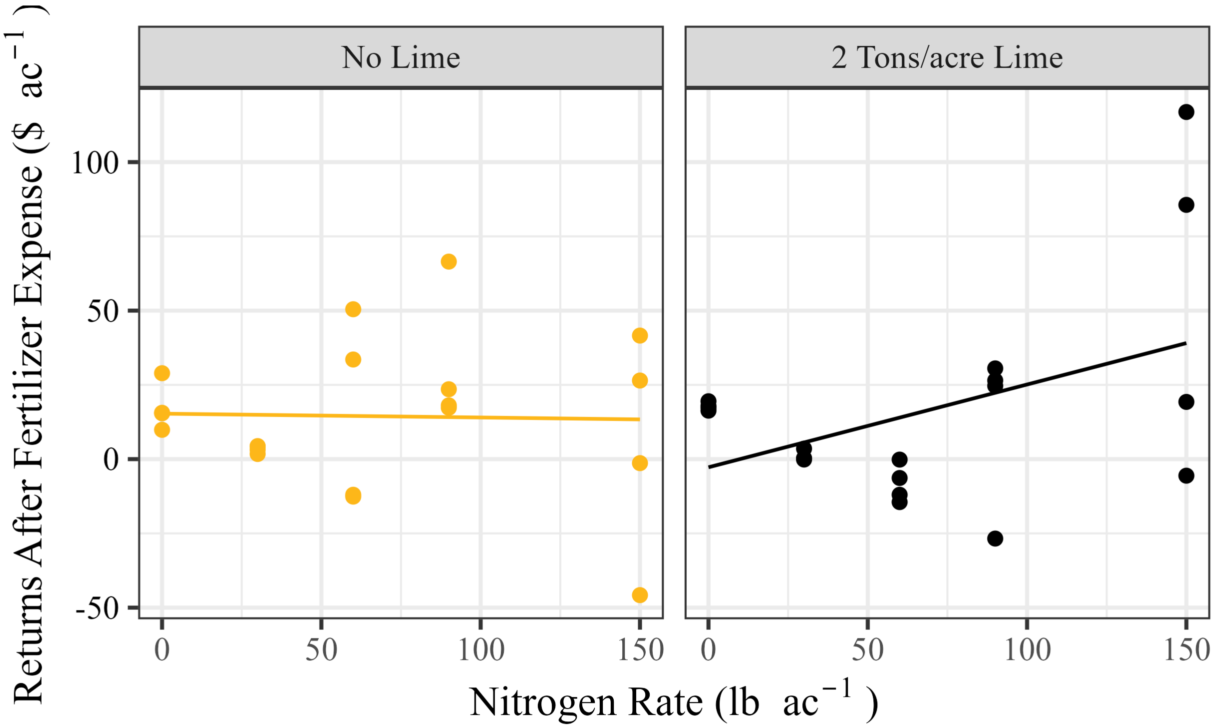

Figure 4. Returns after fertilizer expense for native warm-season grass for five nitrogen application rates and two liming regimens in Linneus, MO in 2025.

FROM THE GROUND UP: EVALUATING A NEW NITROGEN FERTILIZER SOURCE IN FARMER-LED PASTURE TRIALS IN SOUTHWEST MISSOURI

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INTRODUCTION

Nitrogen (N) is an essential nutrient for all plants, and it is often the limiting nutrient. Enough N is essential for efficient regrowth of forages that are grazed. Nitrogen fertilization rates for cool-season grass pastures in Missouri are management-driven, ranging from 40 to over 80 lbs N ac^{-1} depending on yield goal, legume mix, fall stockpiling grazing intensity and soil condition (Scharf & Lory, 2018). Despite the yield and quality benefits, N applications are often unprofitable. Farmers spend anywhere from 8-10% of their overall profit strictly on N fertilizers (Milhollin et al., 2024). Due to the necessity of N application, farmers must decide between the cost of N or having a lower forage yield. Nitrogen poses a problem for them, especially those who rely on agriculture as their main source of income and sustenance.

The Green Lightning (GL) product research emerged in the spring of 2024, when farmers involved in the "From the Ground Up (FTGUp)" project were asked about their research interests. They expressed interest in determining whether the GL product could serve as a reliable, low-cost alternative to N fertilizer. The manufacturer claimed that GL contains sufficient nitrate and ammonia to meet N requirements of grass and could serve as a cheap alternative N fertilizer source.

More than 78% of the atmospheric N exists as dinitrogen (N_2), which is highly stable and is not the right form for plant uptake to utilize for growth. Lightning is one example of how atmospheric N is naturally converted into ammonium and nitrate forms that plants can absorb. The inventors of GL developed a machine to mimic natural lightning-induced N fixation using plasma technology. Harber-Bosch is the current industrial method, which produces more than 90% of the world's ammonia, which is further used to manufacture most N fertilizers, such as urea, ammonium nitrate, and urea ammonium nitrate (Cherkasov et al., 2015). Plasma technology works by applying high-voltage electrical discharge across electrodes, creating a plasma field composed of high-energy electrons, ions and reactive free N species (Gong et al., 2024). These energetic particles can break the strong nitrogen-nitrogen (N≡N) bond found in atmospheric nitrogen (N_2), allowing it to react with oxygen and water (Gong et al., 2024). Through these reactions, N_2 is converted into plant-available forms such as nitrate and ammonium (Chen et al., 2021). Since this is a new technology with many claims, and farmers may be using it in their fields, it is important to test its effectiveness and highlight any setbacks the public should expect from its use. This article reports the performance results obtained from the GL prototype system and evaluates its outcomes in the context of current plasma ammonia synthesis research.

OBJECTIVE

The objective of this on-farm research was to evaluate the effectiveness of GL technology as a N fertilizer for pasture production by comparing its performance with conventional N sources in southwest Missouri.

PROCEDURES

An experiment was implemented at six on-farm pasture sites throughout southwest Missouri during the 2025 growing season. Treatments were applied in strips and randomly assigned to one of four fertilizer treatments: GL (20-gal ac^{-1}), superU (40 lb N ac^{-1}), ammonium nitrate (40 lb N ac^{-1}), and unfertilized control. Baseline soil samples were collected before treatment application (Table 1). Treatment applications were made using a utility drone at 3 farms in the last week of March 2025, and a second application was made across six farms in the first week of September 2025.

Forage samples were collected twice, at 30 and 60 days after spring application. Fall application biomass samples were collected only once after 86 days of stockpiling. Forage biomass was clipped from a randomly placed 2.7 ft^2 quadrat in each plot, with three replicates collected per plot. Samples were dried at 120°F to a constant weight. Forage biomass results were analyzed using a linear mixed model (treatment, month, and interaction as fixed effects; farm as a random effect), with p-values from the model ANOVA and treatment differences assessed using estimated marginal means with planned contrasts.

RESULTS

Forage biomass yield in April differed significantly between GL and conventional fertilizer treatments ($p = 0.0021$) and marginally between GL and the control ($p = 0.0548$). The GL product reduced forage yield by 20.6% compared to the control (Figure 1). SuperU and ammonium nitrate produced 39.9% and 31.5% higher yield than GL in April (Figure 1). Green lightning reduced forage yield compared to conventional fertilizers at the second harvest in May ($p = 0.0021$). Urea and ammonium nitrate produced 33.5% and 28.2% higher yield than GL (Figure 1).

Forage biomass yield in the fall differed significantly between GL and conventional fertilizer treatments ($p = 0.0004$), but there was no difference between GL and control. Compared to GL, urea and ammonium nitrate produced yields 14.3% and 43.2% higher, respectively (Figure 2). Fall treatment applications also showed a significant difference in yield between ammonium nitrate and urea. Ammonium nitrate produced 25.2% higher yield than urea in the fall season (Figure 2).

CONCLUSION

The results from two applications indicate that there was no difference in forage yield between the control plots and GL treatments, whereas conventional N fertilizer sources produced a higher yield than the control, suggesting that GL does not meet pasture N requirements. Since GL did not provide a yield benefit, it is not recommended as a substitute for conventional N fertilizers in forage production. Additionally, ammonium nitrate was more effective at meeting pasture N requirements than Super-U. The GL research was originally planned to continue for three more years; however, due to uncertainty about the manufacturer's support and based on observations and yield data, farmers involved in this research decided to discontinue GL in their trial and shift the focus of their on-farm trials to evaluating other N and biological products.

RECOMMENDATIONS

Considering the results of this study, GL as a source of effective N application in forage systems is not recommended. Green lighting, as a product, is highly acidic (Table 2), and to avoid negative effects, conventional N fertilizers should be considered to increase forage yield in pasture.

ACKNOWLEDGEMENT

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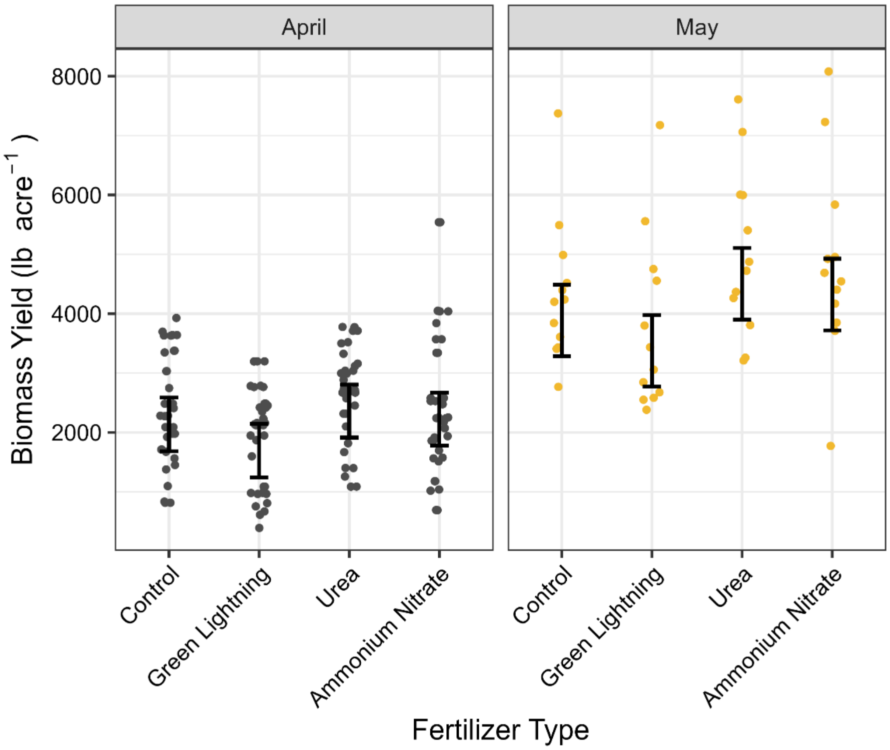

Figure 1. Forage yield in April and May from four nitrogen fertilizer treatments across three farms.

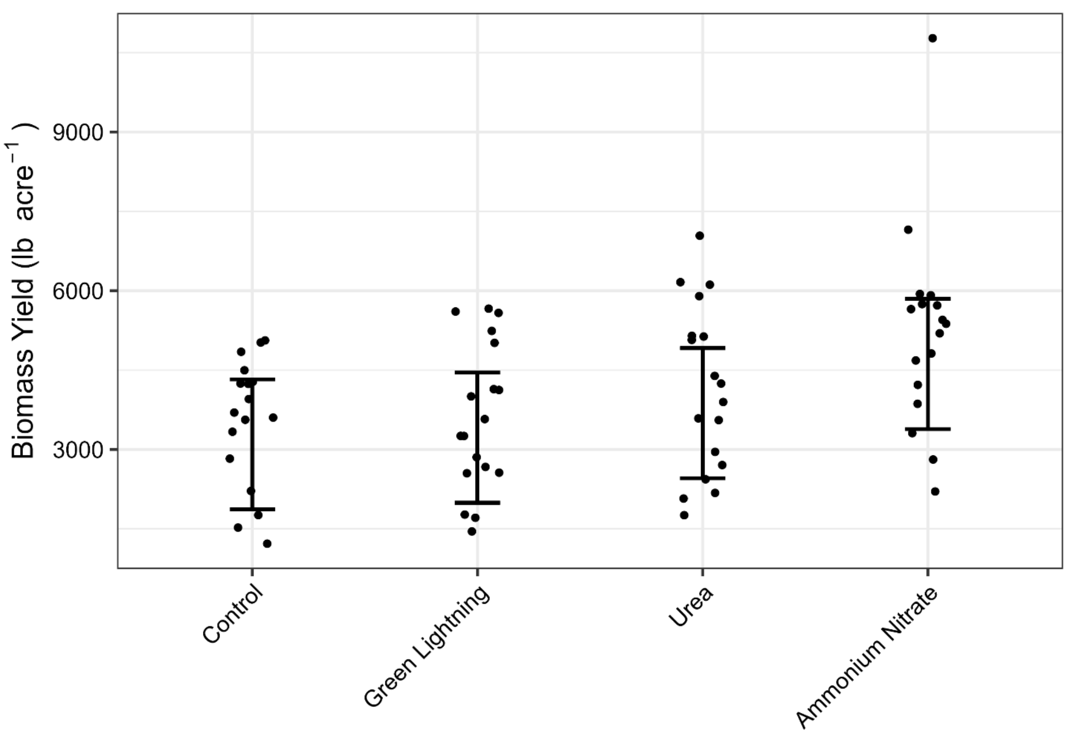

Figure 2. Forage yield in December from four nitrogen fertilizer treatments across six farms.

Table 1. Baseline soil chemical properties for four different treatment blocks (averaged across two farms). Note - Values are presented as mean ± standard deviation (SD) for each soil property, averaged across two farms for each treatment plot.

Soil Property	*Green Lightning*	*Ammonium Nitrate*	*SuperU*	*Control*
Total Exchange Capacity (meq/100 g)	12.06 ± 1.99	10.78 ± 1.08	12.80 ± 1.53	12.80 ± 2.11
pH	6.17 ± 0.36	6.32 ± 0.33	6.32 ± 0.64	6.67 ± 0.56
Organic Matter (%)	3.95 ± 1.33	3.75 ± 0.62	4.23 ± 0.82	5.01 ± 1.37
Estimated Nitrogen Release (lb N ac^{-1})	88.17 ± 11.89	87.50 ± 6.44	92.17 ± 8.18	97.17 ± 10.28
S (ppm)	9.33 ± 0.82	10.17 ± 0.75	11.50 ± 1.76	11.33 ± 2.07
P (ppm)	26.33 ± 10.52	28.33 ± 9.31	45.67 ± 20.43	45.67 ± 27.89
Ca (ppm)	1589.50 ± 206.25	1456.67 ± 315.92	1722.83 ± 476.64	1893.33 ± 545.15
Mg (ppm)	147.33 ± 55.36	160.17 ± 62.28	158.67 ± 47.50	166.17 ± 34.84
K (ppm)	172.17 ± 69.61	181.50 ± 43.74	237.83 ± 55.20	237.17 ± 73.71

Table 2. pH, electrical conductivity, nitrite, nitrate and ammonium-N concentrations in Green Lightning samples analyzed at Water quality lab at the Lee Greenley Jr. Memorial Research Farm, near Novelty, MO.

Sample Date	*pH*	*Conductivity (µS/cm)*	*Nitrite (mg/l)*	*Nitrate (mg/l)*	*NH_4-N (mg/l)*
04/25/2025	3.04	787.3	0.0302	66.47	0.13
04/25/2025	2.92	716.8	.	66.63	0.11
04/25/2025	2.87	696.5	.	66.44	0.11
04/25/2025	3.01	562.1	0.0317	51.26	0.44
04/25/2025	3.12	456.6	.	39.17	0.09
09/08/2025	2.40	2575.0	.	304.62	0.15
09/08/2025	2.92	660.4	.	66.55	0.06
04/08/2025	2.53	1732.0	0.0018	357.60	0.05

IS SPRINGTIME MAGNESIUM SUPPLEMENTATION TRULY NECESSARY IN NORTHERN MISSOURI TO PREVENT GRASS TETANY?

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Carson Roberts — Assistant Professor

INTRODUCTION

Grass tetany, or hypomagnesemia, is a significant metabolic disorder in cattle and other ruminants that is caused by low levels of blood magnesium (Mg) (*Grunes 1973, Grunes et.al 1970).* If left untreated, it can lead to animal paralysis and death, resulting in significant losses for producers. This disorder is most frequently observed in the early spring when forage species, such as tall fescue, are low in Mg uptake, and lactating cows in particular experience larger than normal Mg demand *(Grunes et.al, 1970).*

Management strategies that allow for better spring outcomes in cattle, such as the application of phosphorus (P) fertilizer that has been shown to increase Mg uptake and leaf concentrations in cool-season grass species. While prior studies on this topic have been conducted, none have been recent enough to reflect current farm management practices, nor were they conducted specifically in northern Missouri, a region with a highly variable continental climate that presents unique challenges for forage management. Additionally, little research has been conducted on whether springtime Mg applications are truly effective for springtime Mg uptake in tall fescue.

While Mg content in forage can provide a good indicator of the amount of nutrients available to grazing livestock, interactions between minerals found in plants can occur. Hence, a better metric is the tetany ratio (TR), which combines the interactions between Mg, potassium (K), and calcium (Ca) to determine an overall tetany risk for cattle. This can be written as TR = K / (Ca + Mg), with values above 2.2 indicating a significant risk of grass tetany in cattle, and values below 2.2 indicating that forage is likely safe *(Kemp and Hart, 1957; Kvasnicka and Krysl).* This metric indicates that not only a low Mg quantity in forage, but also low Ca and high K, can significantly increase the risk of grass tetany. In this study, we aim to determine the effect of fertilization and Mg treatment on forage Mg content and TR in northern MO.

OBJECTIVES

- Determine if springtime Mg supplement to pastures in northern Missouri increase the Mg content (decrease TR) of forage samples.
- Identify interactions between Mg supplements and fertilizers (N, P, and K).
- Assess the risk of grass tetany, as quantified by the TR, throughout the course of spring.

PROCEDURES

A magnesium study was conducted in the spring of 2026 in northern Missouri that specifically addressed Mg uptake in tall fescue. In the study, a single application of three fertilizers (N, P, and K) was analyzed alongside a single application rate of $MgSO_4$ on a mixed grass paddock at the Cornett Research Farm near Linneus, MO. This paddock is composed of various cool season grasses and legumes but is primarily dominated by tall fescue with patches of red and white clover. Each individual plot was 10’ x 20’. Each plot received a single treatment of either N, P, K, or a control with zero fertilizer, with half of the plots receiving 100 lbs ac^{-1} of Mg, and the other half receiving none. In total, 4 repetitions were performed, consisting of 4 fertilizer treatments and 2 Mg treatments. Applications of fertilizer and $MgSO_4$ were completed in mid-March 2026, shortly after spring green up. The plots were organized in a randomized complete block design.

Two forage harvests were completed, first on April 13th, followed by a second on April 28th. Harvests were performed with a randomly placed 0.25 m^2 quadrat. Samples were dried then ground to pass through a 0.5mm screen, and near-infrared (NIR) spectroscopy was used to analyze Mg content for each sample (Blue Sun Scientific- Phoenix 5000SL). A mixed-grass/legume calibration curve was used to analyze each sample. Mg content, as well as the tetany ratio, was then compared for all samples between the first and second harvests to determine whether there was a statistically significant difference between treatments and cuts. Additionally, several linear and mixed models were run to determine the influence of fertilizer treatment, Mg, harvest, and block had on the TR. Finally, interactions between Mg, Ca, and K sample content were analyzed alongside the four fertilizer treatments to determine whether there were any significant interactions that might impact the TR.

RESULTS

When comparing the impact of the Mg treatment on sample tetany ratio (TR), it was found that applying $MgSO_4$ there was no difference in TR or Mg content (Table 1). Additionally, application of N, P, or K did not improve TR or Mg content. When comparing the differences in TR and Mg content between harvests, it was found that the TR of the first harvest was 20% lower (less risk of tetany) than the second harvest (Table 1). This was contrary to expectations that the TR would decrease as forage matured throughout the spring. Likewise, the Mg content of 1st cut samples was 18% greater than for 2nd cut. It is unclear what may have caused the decrease in Mg content and increase in TR for the later harvest.

Baseline sample Mg values were well above tetany thresholds (>0.18 % Mg). Similarly, TR values below tetany thresholds (< 2.2) across all samples, indicating that grass tetany was not an issue for either harvest.

Cut was the single best predictor of TR, with an overall AIC of 10.68. ANOVA testing was run on this model, suggesting a statistically significant difference based on harvest, but not on fertilizer or Mg treatments ($p>F = 0.008216$), confirming that treatment effects were insignificant.

Fertilizer treatments were further investigated to determine whether they significantly impacted other components of the TR besides Mg (K and Ca). Figure 3 displays the effect of fertilizer treatments on K percentage in all studied samples. The application of fertilizer did not increase the K or Ca concentrations.

RECOMMENDATIONS

Based on the results of this study, the addition of springtime Mg does not always provide a benefit to forage quality, as was previously thought. It is strongly recommended that producers consider forage testing prior to purchasing Mg supplementation for pastures or livestock mineral, as this is likely to save a significant amount of money and time each spring.

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Table 1. Tetany Ratio and Mg content for Mg, N, P, and K fertilization treatments in 2026 near Linneus, MO.

Treatment	Tetany Ratio (TR)	Sample Mg content (%)	Number of samples (n)
Nitrogen	0.77	0.37	16
Phosphorus	0.83	0.32	16
Potash	0.78	0.36	17
Control (no fertilizer)	0.66	0.34	15
MgSO4 application	0.77	0.35	31
No $MgSO_4$	0.76	0.35	33
1st Harvest	0.68	0.38	31
2nd Harvest	0.84	0.32	33

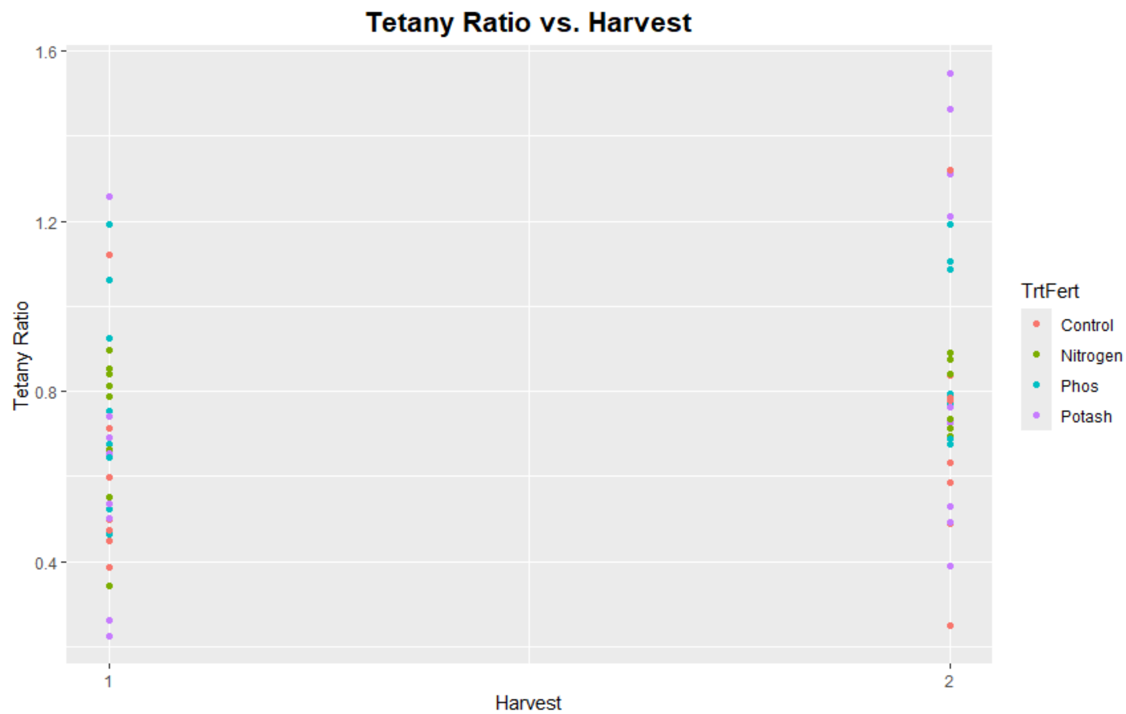

Figure 1. Tetany Ratio for the two early spring harvest times in 2026 near Linneus, MO.

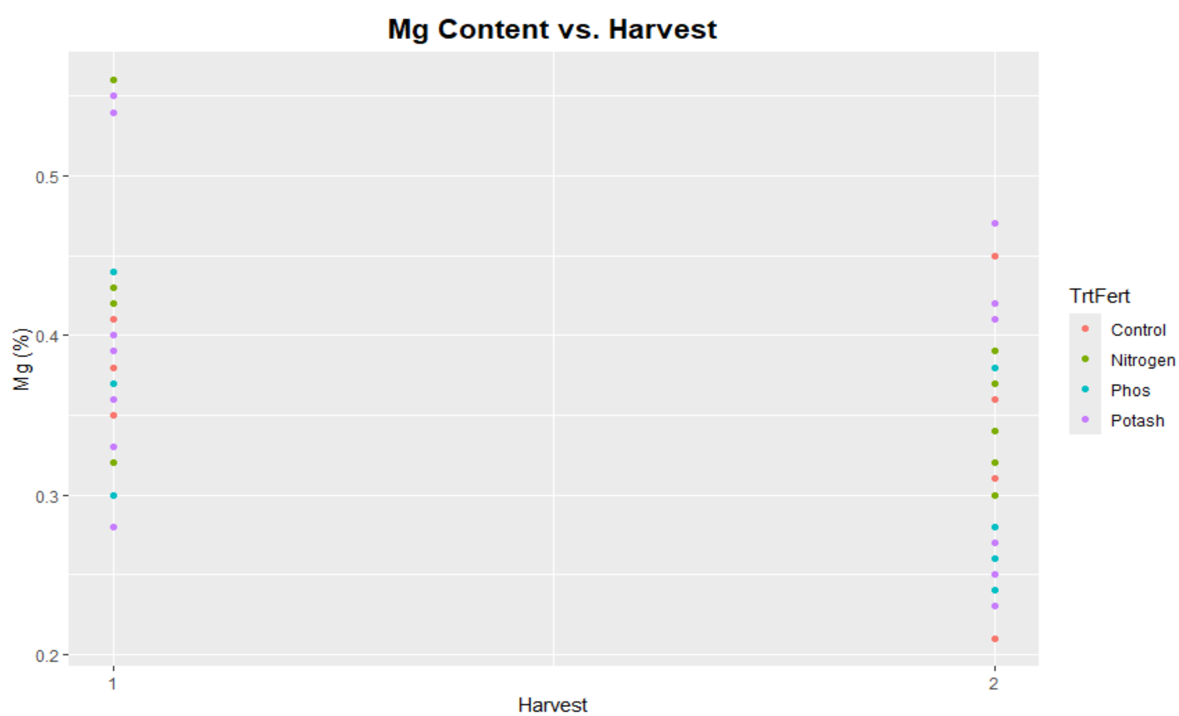

Figure 2. Magnesium (Mg) for the two early spring harvest times in 2026 near Linneus, MO.

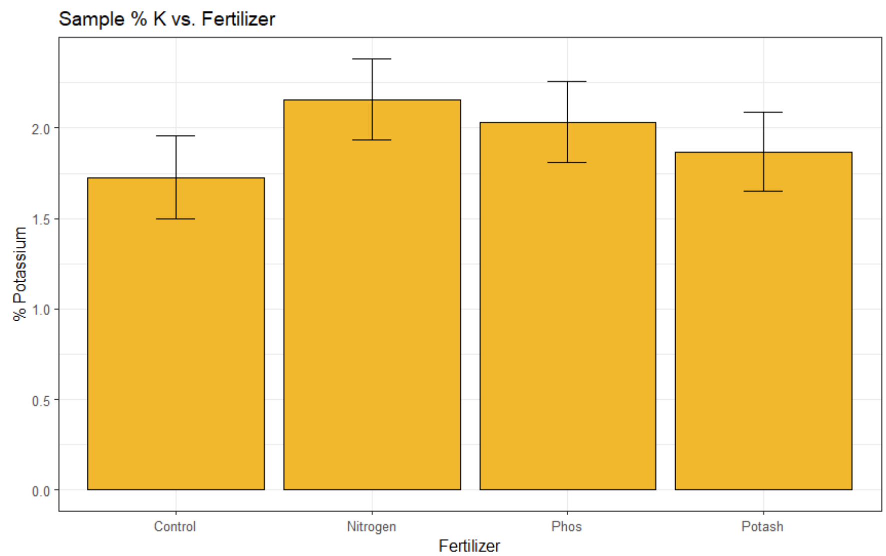

Figure 3. Potassium content for N, P, and K fertilization treatments in 2026 near Linneus, MO.

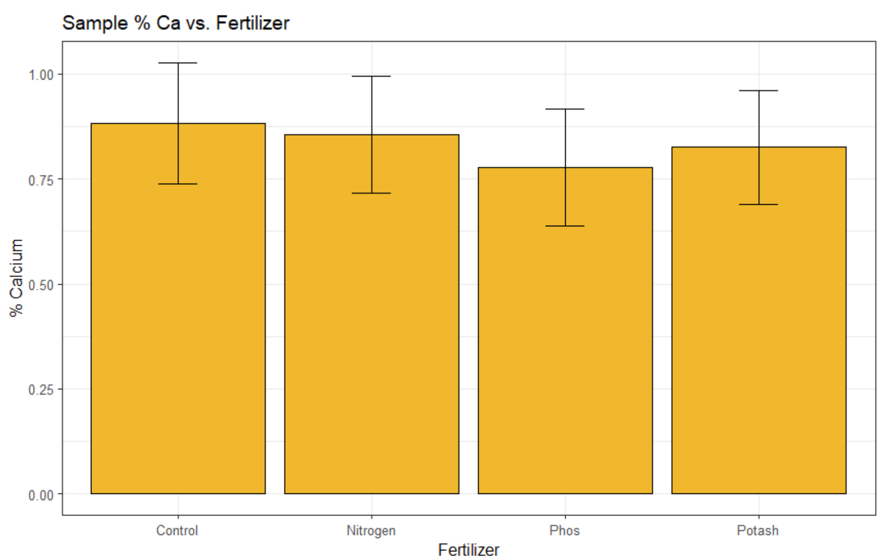

Figure 4. Calcium content for N, P, and K fertilization treatments in 2026 near Linneus, MO.

VIRTUAL FENCING FOR FORAGE MANAGEMENT AND CONSERVATION

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INTRODUCTION

Managed grazing is essential for maintaining pasture productivity and conserving soil. Properly managed grazing systems minimize bare ground, enhance root development, and promote soil structure. Despite these benefits, less than 40% of Missouri's cow-calf producers practice rotational grazing management. Labor demands, fencing, safety, and financial costs are all barriers to adoption.

Fencing costs for cross-fencing can vary from $4.09 to $0.81 per linear foot. One mile of this fencing can cost between $4,200 and $5,300, depending on terrain and labor. In addition, these fences require continued manual labor to maintain.

Virtual fencing offers a new approach. Collars worn by cattle deliver audio cues and harmless electric pulses to keep animals within designated boundaries. Producers can manage pastures remotely, adjusting boundaries in real time to match forage growth an protect sensitive areas. This enables unlimited paddock shifts with little additional labor, eliminating the need for most interior fencing.

There are currently 4 companies that offer virtual fencing solutions for farmers in Missouri. While there is a lot of interest in this technology, many are reluctant to invest. Virtual fencing requires initial investment, and a subscription plan. The virtual fencing companies require outright purchase or an extended lease agreement, requiring a long-term commitment to technology. The purpose of this research is to assess the cost effectiveness, longevity, and forage management capabilities of each virtual fence product to help producers make more informed purchase decisions.

OBJECTIVE

The objective of this research is to quantify the true costs of each product, assess longevity and maintenance, and showcase the forage management capabilities

PROCEDURES

A virtual fencing showcase is being conducted at the University of Missouri's Cornett Farm near Linneus, MO. The demonstration is testing systems from four leading providers—Halter, eShepherd, NoFence, and Monil—using groups of approximately 20 mature beef cows managed identically. This research will continue for three years to fully assess durability and forage improvements over time. Each virtual fence product will be tested to understand its shock voltage, weight, breaking strength, temperature extremes, water resistance, GPS accuracy, economic value, and structural durability.

RESULTS

The cost effectiveness of each virtual fence product varies depending on herd size and usage. The pricing structure for each company varies, so one size does not fit all circumstances. In general, the cost of virtual fencing goes down as herd size increases (Table 1). eShepherd offers a monthly subscription, allowing producers to save money if the collars will not be worn year-round. The cost advantages of virtual fencing compared to temporary electric fence depend on herd size. Virtual fencing is more favorable to small herds, and temporary electric fencing is more favorable for large herds.

Animals in the virtual fencing showcase at the Cornett Farm have readily adapted to virtual fence. Both mature cows and young, growing stockers are easily trained to the system, and the system can be confidently used with less than a week of training.

Each company has its own training protocol, but the core concept is similar. First, place newly collared cattle in a small, secure, well-fenced paddock with reliable network coverage. Position water and feed away from the training boundary. Next, set a virtual fence so the cattle only interact with it on one side, while the other sides are protected by physical fencing. Monitor the herd closely as they learn to respond to the audio cues before receiving a mild pulse. Move the virtual boundary gradually each day, starting close to the physical fence and shifting inward. Most cattle learn the system within 4–7 days. Once they consistently respect the boundary, transition them to larger pastures.

Each virtual fence option offers more than just mapping and moving virtual fences. Halter, Monil, and NoFence utilize artificial intelligence to detect estrus, and recognize patterns. Halter has the most advanced artificial intelligence learning models based on billions of hours of behavioral data, and each collar "learns" the individual cow based on how it responds to audio and electrical cues.

Each software application offers unique features:

Halter

- Strong artificial intelligence models
- Place pins to mark water, gates, etc.
- Schedule paddock shifts for up to 3 days
- Health insights, grazing patterns, and behavior insights
- Requires 12 minutes before any command becomes active in the field
- Create multiple herds/mobs

Monil

- Exclusion zones within a paddock
- Estrus detection, health monitoring, etc.
- Edit active paddocks in real time
- Activity heat map & electrical pulse tracking

eShepherd

- Manage virtual fences from both smart phone and desktop
- Create pins for water, gates, etc.
- Creates warning if watering point is not within the virtual boundary
- Create multiple herds/mobs

NoFence

- Bluetooth connectivity between collars and cell phone application for precise management
- Beacon for indoor structures
- Heatmap and herd replay to track activity
- Manage cattle, goats, and sheep in same system

The decision to use virtual fencing and to choose which product to use depends on the needs and size of each farm. Virtual fencing technology offers a promising solution to overcome traditional barriers to rotational grazing in Missouri. By significantly reducing the need for interior physical fencing and labor, these systems enable more flexible, responsive pasture management that can improve forage utilization and soil health.

Table 1. Annual cost for virtual fence in 2027. One-time costs are spread across 5 years, and labor is included in temporary electric fence calculations for once daily moves.

Herd Size	Halter (Satellite)	NoFence	eShepherd (cellular)	Monil	Temporary Electric Fence
10	-	$115	$94	$107	$402
30	-	$107	$84	$107	$152
60	-	$107	$74	$107	$89
120	$99	$97	$74	$107	$58
210	$97	$97	$74	$107	$44
410	$97	$97	$74	$107	$36
1000	$96	$97	$74	$107	$30

MISSOURI MESONET

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INTRODUCTION

From its modest beginnings in 1992, the Missouri Mesonet has evolved from a few 3-meter-tall weather stations at University Research Centers, collecting environmental data on an hourly and daily basis, to a sophisticated network of 45 weather stations across the Show-Me State. Primary monitoring variables include temperature, relative humidity, wind speed, wind direction, solar radiation, soil temperature, and rainfall. Supplemental variables include fuel moisture, leaf wetness, barometric pressure, and temperature inversion monitoring.

Missouri Mesonet is a collaborative effort among the University of Missouri Extension, the College of Agriculture, Food and Natural Resources, and the Missouri Climate Center. It provides:

- Near real-time weather (five-minute updates) and historic climate data to agriculture, energy, transportation, infrastructure, insurance, and legal sectors at the local, state, national, and global levels.
- Opportunities for educational programs, teaching, research, innovation, public safety, discovery, and service to communities.

Missouri Mesonet has not only been successful in the agricultural realm, but its application has transcended numerous other vocations and interests and has become an important environmental data resource for the citizens of Missouri and beyond. In 2022 alone, Missouri Mesonet real-time web pages received over 26,000,000 hits.

In 2010, the National Oceanic and Atmospheric Administration (NOAA) implemented a multi-state project in which metadata and near-real-time data were collected from various state mesonets, including the Missouri Mesonet, and used by NOAA to assess the quality of the network and improve forecasting ability. The program has since expanded and become a part of the National Mesonet Program (NMP). The Missouri Mesonet continues to be a proud partner.

For access to the Missouri Mesonet, please visit:

mesonet.missouri.edu

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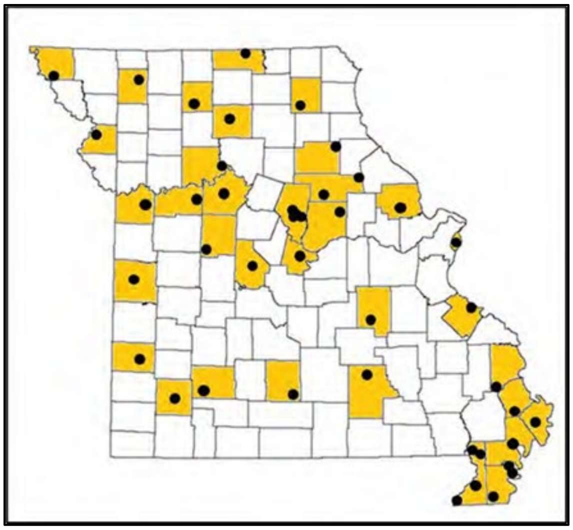
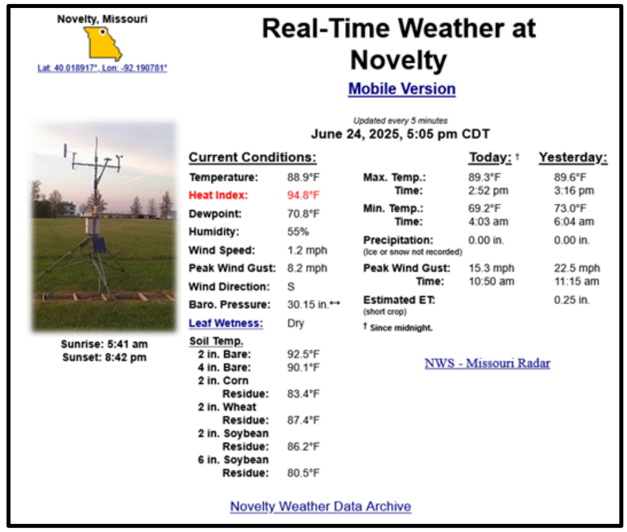
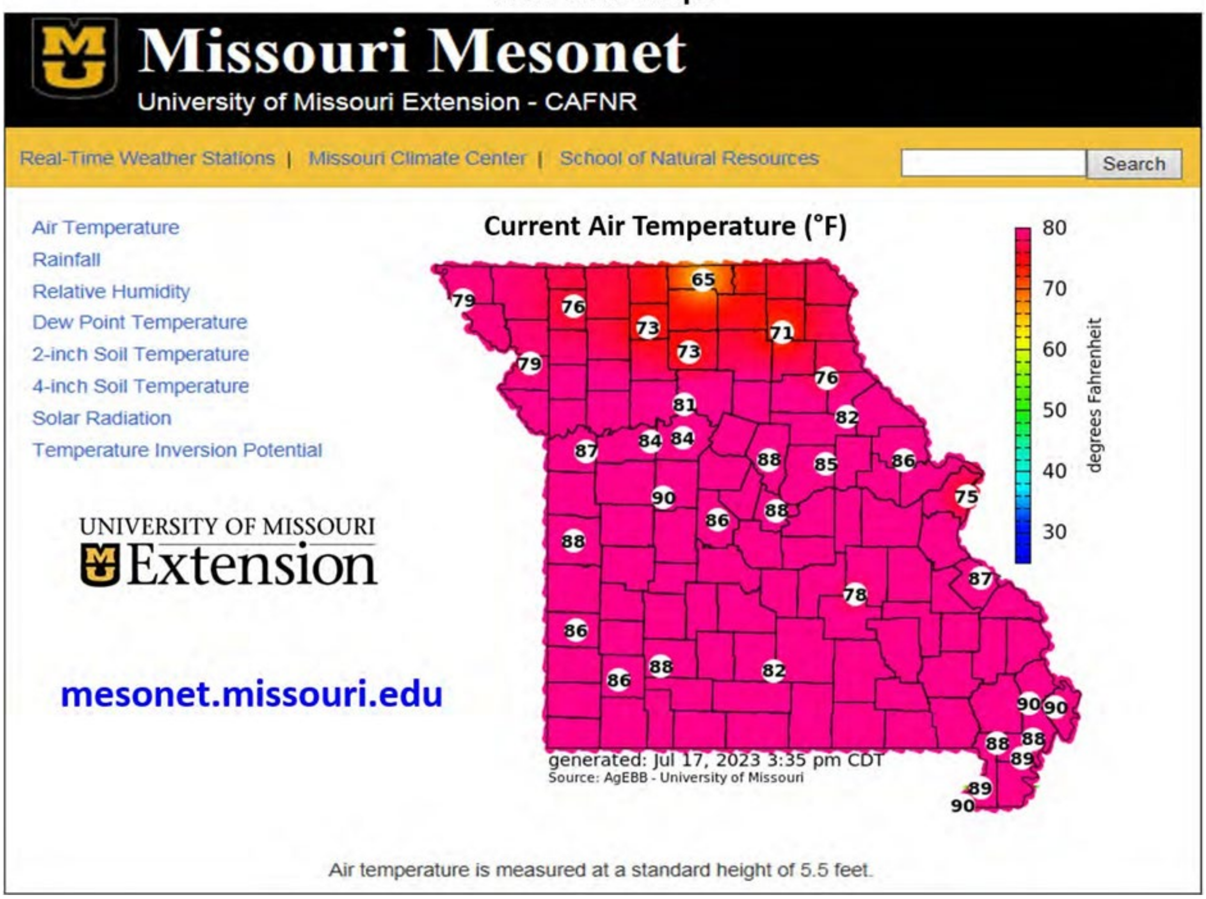




Real-time maps



WOULD YOU LIKE TO BE A VOLUNTEER WEATHER OBSERVER FOR MISSOURI? THE COCORAHS WEATHER NETWORK

Zachary Leasor
Assistant Professor

INTRODUCTION

Because of Missouri's size and topography, there is significant climatic variation within the state. Precipitation can be highly variable over short distances, especially during the summer when thunderstorm activity tends to be spotty. The hit-and-miss nature of rainfall during the growing season requires an extensive monitoring network to accurately capture precipitation patterns in the state. A large network of rain gauges across the state also provides valuable information about drought assessment, flood monitoring, prediction, research, and education.

In 2006, Missouri joined a national precipitation observation program called the Community Collaborative Rain, Hail, and Snow Network, or CoCoRaHS. CoCoRaHS was started in 1998 and is a grassroots volunteer network of observers who measure precipitation for their local communities. The program has been well-received in Colorado and has expanded to all 50 states. As stated in their mission statement, the only requirements to join are an enthusiasm for watching and reporting weather conditions and a desire to learn more about how weather can affect and impact our lives. Additionally, to provide consistent and accurate precipitation data, all observers are required to use a particular rain gauge model, which costs approximately $45.

Once enrolled, the weather observer is assigned a station ID and uses an interactive website to submit their observation. The website allows the observer to see their observation mapped in real-time and provides valuable information for all data users. Currently, Missouri has more than 350 regular observers participating in CoCoRaHS and data users include the National Weather Service, River Forecast Centers, Regional Climate Centers, and other stakeholders.

Participation in northeastern Missouri is not as robust as other parts of the state, and we would like to increase the volume of observers for the region. If you would like to be a CoCoRaHS volunteer weather observer in northeast Missouri, please go to www.cocorahs.org for more information or contact Dr. Zack Leasor (leasorz@missouri.edu) for Missouri CoCoRaHS information.

HORIZON POINT SITE SPECIFIC WEATHER SYSTEM

University of Missouri Extension and AgEbb

INTRODUCTION

Horizon Point is an educational program of the University of Missouri Commercial Agriculture Program that is designed to make precise weather information available to Missouri farmers in a way that assists them in managing their business. Site-specific weather reports and advisories are sent to participating farmers via quickly downloaded emails.

When farmers subscribe to Horizon Point, they provide an email address where reports are periodically sent and the precise location of their farm. The farmers also choose what advisories they want to receive and the frequency of their emailed reports.

Horizon Point is a custom weather analysis system for Missouri farmers. The weather information comes either from the National Weather Service or the Missouri Commercial Agriculture Automated Weather Station Network. The advisories process this weather information through research-based models to provide the best available, site-specific management information to farmers.

Site-specific weather information contained in Horizon Point reports includes:

- Precipitation
  - Historical and Forecasted
  - Probability and Quantity
- Temperature
  - Historical and Forecasted
  - Minimum and Maximum
- Wind Forecast
  - Speed and Direction
  - 3-hour Increments

Advisories use research-based information provided by plant and animal scientists and agricultural engineers. Chosen advisories are sent only in the seasons when they are appropriate. For example, soil temperatures are important in the spring for planting and in the fall for fall-applied fertilizer management. Soil temperature advisories are not sent during the summer when they are not critical to any management decision. Current advisories available include:

- Planting Depth Soil Temperature
- Weed Scouting Aid
- Stored Grain Management Moisture Table
- Design Storm Report
- PRF Rainfall Index Monitor
- Insect Scouting Aids
- Fall Nitrogen Application Chart
- Rainfall Runoff Estimator
- Animal Comfort Indices

The emailed reports contain hyperlinks to management information such as weed seedling pictures and how to use equilibrium moisture content to maintain stored grain quality.

Horizon Point subscribers are given a secure account page where they can manage such selections as email frequency and which advisories are received. Farmers can also access archives of site-specific daily reports for the last month.

For more information about the Horizon Point system, contact us at 573-882-4827 or email us at HorizonPoint@missouri.edu

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The peer-reviewed journal articles published before 2022 can be found in the NMREEC field day annual report 2022 at:
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