Northern Missouri Research, Extension & Education Center

University of Missouri

Field Day Annual Report
July 31, 2025

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 2025

(Volume 4)

<u>Editors</u>

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Northern Missouri Research, Extension, and Education Center

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TABLE OF CONTENTS

WELCOME

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.

Jeff Case
Director, NMREEC

This year marks the 48th 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 "Drive to Distinction".

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SCAN TO RECEIVE THE NM-REEC MONTHLY NEWSLETTER

2025 NMREEC FIELD DAY PRESENTATIONS

Beef and Forage Management

Sorghum Sudangrass for Winter Grazing

- Dr. Carson Roberts

Grazing Grain Sorghum in Solar Corridor Cropping Systems

- William Lee

Reproductive Technologies in Beef Cattle

- Genevieve VanWye

Hair Shedding Scores: More than Heat Stress

- Dr. Jamie Courter

Integrated Pest Management

Balancing Productivity & Protection: EPA's Pesticide Mitigation Strategies

- Kaitlin Flick-Dinsmore

Weed Management Considerations for 2026 & Beyond

- Dr. Kevin Bradley

Rot, Spot, and Tiny Worms: Crop Pathogens of Concern

- Dr. Mandy Bish

Agronomic Management

Terrace Blind Inlet Demonstration

- Dr. Kelly Nelson

Soil Fertility Update

- Dr. Gurpreet Kaur

Can Strip-Tillage & Fertilizer Placement on Claypan Terraces Build Soil Fertility Bank

- Dr. Gurbir Singh

Lunch Program

Farm Production and Conservation

- Richard Fordyce, Under Secretary of Agriculture for Farm Production and Conservation (Nominated)

ADVISORY BOARDS

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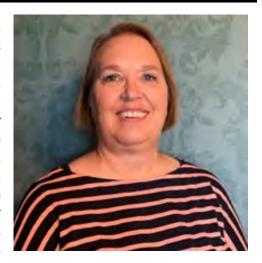
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IN MEMORY OF TERESA LYNN BRADLEY

As we gather and celebrate our progress, we also pause to reflect and honor the life of Lynn Bradley, longtime Office Administrator and Lab Technician at Greenley Research Farm, who recently passed away. Lynn was more than a colleague; she was the heartbeat of Greenley Research Farm for many years. Her passion for supporting successful field days was unmatched, and she played a vital role in making sure every detail, from logistics to hospitality, reflected the excellence we strive for. Perhaps most notably, Lynn had a deep care for the countless graduate students who passed through our programs. She welcomed them, guided them, and supported them like family. Her absence will be felt deeply, but her impact will live on in the lives she touched and the legacy she leaves behind.

Teresa Lynn Bradley, 66, of Knox City, Missouri, passed away Sunday morning, June 22, 2025, at Blessing Hospital in Quincy, Illinois.

Lynn was born on June 6, 1959, in Kirksville, Missouri, the daughter of William R. "Bill" and Rosalyn Gillaspy Eyman.

She attended Knox City Elementary and graduated from Knox County High School, Class of 1977. Lynn continued her education at William Woods College and the University of Missouri before going into banking in St. Louis.

On September 11, 1999, Lynn married Bryan Keith Bradley in St. Louis, Missouri. They later moved to Quincy, Illinois, and then to Knox City, Missouri, where they made their permanent home in 2007. She was employed at the MU Greenley Research Farm in Novelty, Missouri.

Lynn is survived by her husband of over twenty-five years, Bryan Bradley; her parents, Bill and Rosalyn Eyman of Knox City; a sister, Julie and her husband Bill Moore of Columbia, Missouri; niece, Rachel (Alex) Chacon; and a nephew, Chris (Melissa) Moore; along with cousins and a host of friends.

Lynn's commitment to the environment was noted as she hung everything on the outside clothesline to dry. Her love for her pets followed her everywhere. Teaching her niece and nephew to sing "Goodness Gracious Great Balls of Fire" at the top of their lungs marked childhood joys. Swimming, sailing, skiing, and playing at the lake were many summer days of fun. She was an avid reader, taught step aerobics and water aerobics for the Community Center, loved Star Wars, and was a board member for the Knox County Nursing Home for nearly 10 years, serving as president in 2021/2022. She grew up attending Bee Ridge Methodist Church. She was indeed a child, girl, and woman of many talents and interests that she shared with Bryan and the community.

LEE GREENLEY Jr. MEMORIAL RESEARCH FARM

Donnie Hubble
Senior Farm Manager

Dr. Kelly Nelson
Professor

Dr. Gurpreet Kaur
Assistant Professor

Dr. Gurbir Singh
Assistant Professor

Cortney Hyman
Business Support
Specialist II

Jeana Curtis
Outreach Coordinator

Nichole Miller
Research Specialist II

Abby Welschmeyer
Technical Assistance
Coordinator

Rodney Freeman
Research Specialist I

Michael Kim Hall
Sr. Ag Associate

Steve McHenry
Ag Associate II

Lynn Bradley
Lab Technical
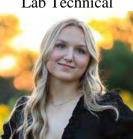
Renee Belknap
Technician

Rachel Case
Temporary Technical

Kaitlin Campbell
Temporary Technical

Malea Nelson
Temporary Technical

Dr. Mehtab M. Aslam
Postdoctoral Fellow

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Farm Manager

Dr. Carson Roberts
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Worker

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Research Specialist II

THOMPSON RESEARCH FARM

Stoney Coffman
Senior Farm Manager

Laramie Persell
Ag Associate II

Amanda Coffman
Ag Associate

Kyla Coffman
Temporary Technical

NMREEC GRADUATE STUDENTS

Anjeeta Nain
M.S. in Soil, Environmental, and Atmospheric Sciences (2024-2025)

Anjeeta received a B.S. in Agriculture Sciences from CCS Haryana Agricultural University, India, in 2023. She started her M.S. degree in spring 2024 in the School of Natural Resources with Dr. Gurpreet Kaur and will graduate in Fall 2025. Anjeeta is working on developing agronomic management practices for industrial hemp production in Missouri. She is conducting multilocation trials in Missouri for industrial hemp variety testing and nitrogen management.

Dustin Steinkamp
M.S. in Plant, Insect, and Microbial Sciences (2023-2025)

Dustin started his MS degree at Lee Greenley Jr. Memorial Farm in 2023 and plans to graduate in Summer 2025. He graduated from Western Illinois University with a B.S. in agriculture in 2023. His thesis research is on the field evaluation of dicyandiamide rates and enhanced efficiency urea treatments for corn. He is grateful for the opportunity to continue his education and work with Dr. Kelly A. Nelson, along with a very friendly and knowledgeable staff at Greenley Research Farm.

Pranay Kumar Kadari
M.S. in Plant, Insect, and Microbial Sciences (2023-2025)

Pranay graduated from Professor Jayashankar Telangana State Agricultural University in 2022 with a B.S. degree in Agricultural Sciences. He started his MS degree in Fall 2023 and graduated in Summer 2025. His research focuses on studying the effects of nitrogen application timings and rates, along with various nitrogen stabilizers at different topographic positions on crop production, gaseous emissions, soil, and water quality. He loves learning from the expert staff at the NMREEC.

Genevieve M. VanWye
Ph.D. Candidate in Animal Science (2023-2027)

Genna graduated from Iowa State University in the spring of 2020 with a bachelor's degree in animal science and started her graduate program at the University of Missouri in the fall of 2020. Her research has focused on the use of long-term progestin-based estrus synchronization protocols and optimal timing of AI with sex-sorted semen in beef heifers. She successfully defended her M.S. thesis in November of 2022 and recently started a Ph.D. In the future, Genna hopes to be an educator to both cattle producers and students in beef production and reproductive management.

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

This is Rose's fourth 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.

Charchit Bansal
M.S. in Plant, Insect, and Microbial Sciences (2024-2025)

Charchit received his B.S. in Agriculture from Punjab Agricultural University, India, in 2023. He started his M.S. in Plant Sciences in Spring 2024 and will graduate in Fall 2025. His research focuses on drainage water management on terraced fields with new tile inlet technologies to reduce nutrient sediment loss in water. He is very grateful for the opportunity to study and work with Dr. Gurbir Singh and the Lee Greenley Jr. Memorial Research Farm staff.

Tharindu Rambadagalla
M.S. in Soil, Environmental, and Atmospheric Sciences (2023-2025)

Tharindu is a second-year master's student in the School of Natural Resources, working under Dr. Morgan Davis, Dr. Ranjith Udawatta, and Dr. Gurbir Singh. He earned his B.S. in Agricultural Technology and Management with a major in Crop Sciences from the University of Peradeniya, Sri Lanka, in 2022. Tharindu is conducting field research at the Greenley Research Center focusing on evaluating the effects of winter cover crops on nitrogen dynamics in agricultural systems. His study also examines the overall performance of corn-soybean rotations when integrated with cover crops, which is particularly relevant to sustainable agriculture practices. Tharindu's goal is to integrate knowledge of agronomy with principles of sustainable agriculture and natural resource management, aiming to maximize agricultural system productivity while minimizing environmental impact.

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.

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.

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.

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.

INNOVATIVE TERRACED TILE INLET TECHNOLOGIES TO REDUCE NUTRIENT AND SEDIMENT LOSS IN RUNOFF

Charchit Bansal
Graduate Research Assistant

Gurbir Singh
Assistant Professor

Kelly A. Nelson
Professor

Gurpreet Kaur
Assistant Research Professor

INTRODUCTION

The cultivable terrain of Northern Missouri above the Missouri River is highly dominated by natural loess deposits that created elevations and slopes, hosting more than 60% of soybean and 70% of corn production in Missouri (Nelson et al., 2023). The rolling topography of the fields leads to runoff issues due to the flowing action of the runoff water. It leads to an increase in nutrient, sediment, and herbicide losses, which impairs the water quality downstream (Kladivko et al., 2004; Smith & Livingston, 2013; Smith et al., 2015). Terraces equipped with underground tile drainage systems are regarded as effective land improvements for minimizing runoff, nutrient, and sediment removal from crop fields (Skaggs et al., 1994; Wei et al., 2016; Stops et al., 2022). An underground tile drainage system collectively consists of surface inlets or tile risers, underground tile lines, and tile outlets (Gupta et al., 2019). HickenBottom (HB) is a standard perforated tile riser, which is installed at the lowest point in the channel area of the terrace (Smith & Livingston, 2013; Kaur et al., 2023). The major concern with HB is the removal of sediments from the field compared to other new inlets, such as the water quality inlet (WQI). Therefore, HB can be used as the best option to remove water at a high rate, where sediment removal from the field is not of much concern (Li et al., 2017; Smith et al., 2015). Results of Li et al (2017) showed that the WQI was the most effective in reducing sediment loss compared to the HB, with a 66% reduction in sediment concentration and 23% reduction in sediment load.

Recently, blind inlets (BI), which have different layers of limestone gravel, have been evaluated as an alternative to traditional tile risers. They are efficient in reducing the nutrient and sediment loads from effluent water, which includes phosphorus, nitrates, and total soluble solids (TSS) (Smith & Livingston, 2013; Smith et al., 2015; Li et al., 2017). When comparing a BI and HB, Feyereisen et al. (2015) found reduced total P, TSS loads, and soluble reactive P in BI by 60, 66, and 50%, respectively. Moreover, some studies have reported the loss of herbicides and related chemicals from the terrace tile outlets, which were highest in the first event following herbicide application as compared to the next events (Franti et al., 1998; Kalita et al., 2006). However, Gonzalez et al., (2016) found 11 and 58% reduction in herbicide and pesticide contents involving atrazine, 2,4-D, metolachlor, and glyphosate in the discharge water from BI as compared to HB. Moreover, BI does not obstruct the path of farm equipment compared to a typical water inlet (USDA-NRCS, 2011).

OBJECTIVE

The overall objective of this study was to evaluate the efficiency of various terraced tile inlet technologies to remove runoff water from the field and improve downstream water quality.

PROCEDURES

The research site was set up at the Grace Greenley Research Farm near Leonard, Missouri. After eight terraces were constructed in 2022, each terrace was equipped with a grower-standard 15 cm

diameter HB riser, which was replaced in the summer of 2023 with new inlet technologies. HickenBottom with underground channel tile laterals (HBR+CL), WQI, BI, and HB were installed with two replications in a randomized complete block design (Figure 1).

Blind Inlets - BI were constructed by excavating a 10 x 10 x 2 ft (LWH) hole around the terrace tile inlet. The hole was lined using engineering cloth, which is a nonwoven geotextile made of 100% polypropylene staple fiber (Agri Drain, Adair, IA). Schedule 40 PVC pipes were installed for collecting the water, and the hole was filled with differential limestone layers (1.5 and 0.5 ft layers of 3" and 3/8" diameter rock, respectively). Large aggregate was on the bottom, and small aggregate was above.

Channel Tiling – Underground perforated pipes or channel tiles/laterals were installed at 5 ft downslope and 10 ft upslope from the channel region. These channel laterals were installed on one side of the HBR, whereas no channel laterals on the other side. This design removes both surface and subsurface water and delivers it to the outlet.

Water Quality Inlet - Water quality inlets were made of a bundle of wicks. Each wick was made of HDPE material with a 0.625" diameter and 0.070" slot openings.

Water samples were collected from each terrace tile outlet after every rain event starting from March 2023. MX2001 HOBO data loggers (Onset HOBO Company, Bourne, MA) were used to calculate the daily discharge values. The cumulative and daily discharge values, along with daily average sediment loads, were determined for each tile inlet technology from March 2023 to March 2025. The collected water samples were analyzed for pH, electrical conductivity (EC), TSS, and dissolved nutrients from Spring 2023 to Fall 2024. Statistical analysis was done with SAS v9.4 (SAS Institute, Cary, NC) using the GLIMMIX procedure, where treatments were considered as fixed factors and replications were random factors. All the analysis was done at the significance level of $p = 0.05$. Data transformation was done as and when required and backtransformed for reporting purposes.

RESULTS

Data from March 2023 to March 2025 indicated that HBR+CL had 9, 62, and 73% greater cumulative discharge compared to HB, WQI, and BI, respectively. Cumulative TSS loss was lower for WQI inlets (137 ± 3 lb ac^{-1}) when compared to BI (166 ± 33 lb ac^{-1}) and HB (284 ± 9 lb ac^{-1}). The higher TSS losses from BI and HB were attributed to soil disturbance caused during the inlet installations, since most of the runoff samples were generated following construction. However, there were no significant differences for cumulative discharge and cumulative TSS loads among different tile inlet technologies at $p<0.05$ (Figure 2).

Higher pH water in BI resulted from limestone, which released carbonates and hydroxides, forming bicarbonates in water. At a high pH, sulphate is soluble in water, giving higher SO_4-S values in BI (Table 1). Available nitrates and ammonia in soil may have dissolved in sub-surface drainage water flowing in HBR+CL, resulting in higher values of NO_3-N and NH_4-N. However, clay minerals, iron, and aluminium oxides may have adsorbed the phosphates from water, significantly lowering the values of o-P in HBR+CL at $p = 0.05$ (Table 1).

There were higher contents of Mn with the WQI, which can be attributed to the higher solubility of Mn in anaerobic conditions, as waterlogging was observed with the WQI (Table 1). Long-term monitoring is being continued for these tile inlet technologies to evaluate the shifts in water quality patterns over time.

Apart from that, some visual observations were also recorded. Visual drying was observed in the channel tiling (Figure 1D), where the drying front is clearly visible on the far side where channel laterals are present, helping in the early drying of the field in between two rain events. Whereas, the front side, where no channel laterals were installed, has wet soil. An unobstructed path of the field equipment and other field operations was present in BI, whereas obstruction was found in HB (Figure 3). Moreover, trapping of sediment was observed at the base of the water quality inlet and on the surface of the blind inlet, which helped in reducing the sediment loss from these innovative technologies (Figure 4).

RECOMMENDATIONS

A standard HBR can be replaced with a BI, as it does not obstruct the path of farm machinery, and there is no significant difference observed in the discharge values for BI when compared to HBR. Moreover, WQI can be used in areas where sediment loss is a major concern. It helps to reduce the TSS loss in the discharge when compared to HBR. Channel laterals help in early drying of the field in between the rain events, preventing waterlogging compared to HBR.

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Table 1. Daily average values of the water quality parameters. The underlined values were significantly different at alpha = 0.05.

Treatments	pH	EC	Discharge	TSS	NO$_3$-N	Cl	Fl
		µS cm^{-1}	gal ac^{-1}	------------------------------------ lb ac^{-1}--------------------------			
HB	7.72 ab	464.51	243.01	0.30	0.015 b	0.033	0.001
WQI	7.67 b	529.34	248.60	0.21	0.026 ab	0.054	0.002
BI	7.87 a	532.34	349.11	0.27	0.021 b	0.042	0.004
HBR+CL	7.51 b	524.42	281.80	0.31	0.038 a	0.041	0.002
p-values	0.0087	0.4937	0.6481	0.6889	0.0115	0.3414	0.3549

	Br	NO$_2$-N	SO$_4$-S	NH$_4$-N	o-P	Zn	Mn
	-- lb ac^{-1}--						
HB	0.009	0.0004	0.013 b	0.0013 b	0.0011	0.000087 a	0.000053 b
WQI	0.011	0.0003	0.017 b	0.0010 b	0.0008	0.000053 b	0.000223 a
BI	0.008	0.0003	0.060 a	0.0012 b	0.0009	0.000051 b	0.000038 b
HBR+CL	0.011	0.0004	0.015 b	0.0037 a	0.0007	0.000100 a	0.000070 b
p-values	0.5228	0.4656	<0.0001	0.0004	0.7963	0.0056	<0.0001

	Fe	Mg	Ca	Cu	Al	Na	K
	-- lb ac^{-1}--						
HB	0.000039	0.013 b	0.06 b	0.00007	0.00002	0.012 b	0.023
WQI	0.000038	0.019 b	0.10 b	0.00011	0.00004	0.017 b	0.023
BI	0.000064	0.031 a	0.15 a	0.00013	0.00004	0.018 b	0.026
HBR+CL	0.000034	0.019 b	0.09 b	0.00014	0.00004	0.030 a	0.018
p-values	0.6626	0.0148	0.0233	0.5269	0.8056	0.0037	0.8115

Abbreviations: HB – HickenBottom Riser; WQI – Water Quality Inlet; BI – Blind Inlet;
HBR+CL – HickenBottom Riser + Channel Laterals
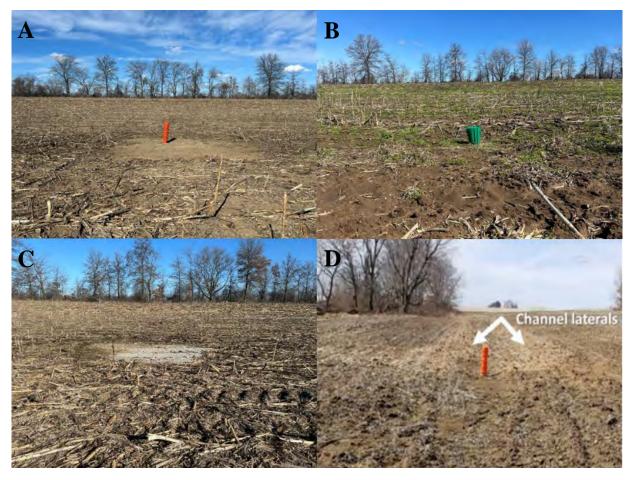
Figure 1. A) HickenBottom Riser (HB), B) Water Quality Inlet (WQI), C) Blind Inlet (BI), and D) HickenBottom with Channel Laterals (HBR+CL) at the Grace Greenley Farm site.
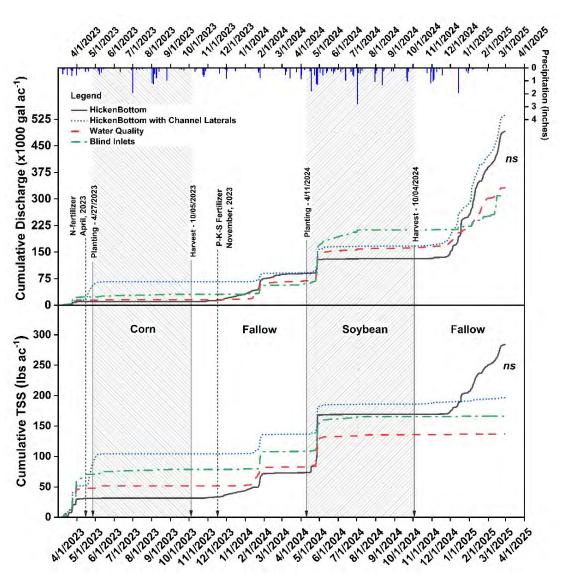
Figure 2. Cumulative daily discharge (1000 gal ac^{-1}) and total suspended solids (TSS) loads (lbs ac^{-1}) from March 2023 to March 2025. Vertical bars represent the daily precipitation in inches.

Figure 3. Unobstructed path observed in A) Blind Inlet, but obstruction in B) HickenBottom.
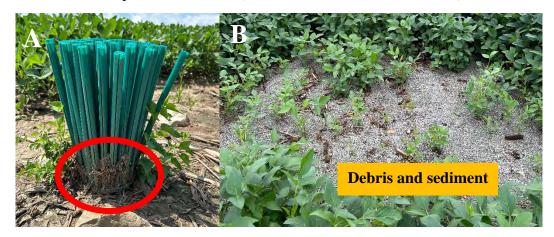
Figure 4. Sediment buildup at the Water Quality Inlet (A) and Blind Inlet (B).

DICYANDIAMIDE (DCD) RATES INFLUENCE UREA MANAGEMENT

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INTRODUCTION

Nitrogen (N) conundrum:
Corn soil fertility begins with a nitrogen (N) management plan. N is the mineral element most absorbed by corn plants under normal growing conditions and is typically the most limiting nutrient. However, finding the right balance between meeting agronomic (maximum yields) and environmental (minimal N loss) goals is challenging. The complexity of N management is primarily due to unpredictable weather (Tremblay et al., 2012; Tao et al., 2018), field variability (Scharf et al., 2005), and N loss mechanisms like leaching, volatilization, and denitrification (Robertson, 1997; Sawyer, 2004). All of these processes can reduce plant N uptake and N use efficiency.

N cycle:
Nitrogen is abundant in the atmosphere (Stein and Klotz, 2016) and in many soils (Stevenson, 1982), but much of it can't be utilized by corn because it is not in a readily available form as nitrate (NO_3^-) or ammonium (NH_4^+) (Young and Aldag, 1982). Corn utilizes fertilizer N, mineralized N from soil organic matter, and residual N in the soil profile. Typically, soils provide most of the necessary N needs with corn utilizing 30-40% of N from synthetic fertilizer (Reddy and Reddy, 1993; Stevens et al., 2005; Griesheim et al., 2019). Once fertilizer is applied, there are many different ways in which N can be lost in the environment. Volatilization is common with urea-based N sources where soil enzymes convert urea-N into ammonia which can be released into the atmosphere during dry conditions (Ernst and Massey, 1960; Meyer et al., 1961). Nitrification in the soil, which is the process by which bacteria convert NH_4^+ to NO_3^- (Schmidt, 1982), leaves NO_3^- susceptible to leaching beyond the root zone. Denitrification results in gaseous N loss, which is promoted by warm, saturated soils (Aulakh et al., 1992). Finally, N can also be lost to a lesser degree through erosion and surface water runoff.

Addressing the issue:
Urea is the most widely used N source in the world (Peterkova, 2023). To partially overcome the N conundrum, the use of 4R management strategies has been recommended, which consist of using the right rate, time, place, and source (Reetz et al., 2015). This study focused on using dicyandiamide (DCD), a nitrification inhibitor rates in a claypan soil. DCD temporarily inhibits the first stage of nitrification, which maintains N in the NH_4^+ form for a longer period of time (Amberger, 1989). Maintaining N in the NH_4^+ form should result in more corn N uptake and lower loss potential, which can increase production. This is because NH_4^+ has a positive charge, which binds negatively charged soil particles and reduces leaching. In addition, when N is in the NH_4^+ form, it is not susceptible to denitrification.

OBJECTIVES

The objectives of this study were to evaluate the impact of DCD rates on 1) corn response (plant population, SPAD, biomass, N uptake, and grain yield, 2) gaseous N emissions [nitrous oxide (N_2O) and ammonia (NH_3)], and 3) soil test and solution NO_3^{-1} and NH_4^{+1}.

PROCEDURES

Field research was conducted in 2023 and 2024 at the University of Missouri Lee Greenley Jr. Research Farm near Novelty. Field management information is reported in Steinkamp et al. (2025). Experiments were arranged in a randomized complete block design with four replications. Plots were 10 by 40 ft. Pioneer (P1359AM) corn was planted in 30-inch-wide rows at 35,000 seeds ac^{-1}. All N fertilizers were broadcast applied to the soil surface using a hand spreader and incorporated before planting.

DCD treatments included 0 (non-treated urea), 0.4, 0.75, 1, and 1.4% DCD formulated with urea at four N application rates (60, 120, 180, and 240 lbs N ac^{-1}). A non-treated control that received no fertilizer was also included. To convert g DCD kg^{-1} to % DCD move the decimal point to the left one spot. For example, 4 g DCD kg^{-1} is the same as 0.4% DCD formulated with urea. Crop response and soil data were subjected to ANOVA, and means were separated using Fisher's Protected LSD (P=0.05) for crop response and soil solution data, while P=0.10 was used for soil data. A quadratic grain yield response to DCD rates indicated an optimal DCD rate when data were combined over years and N rates. Emissions data were subjected to ANOVA and means separated using Fisher's Protected LSD (*P*=0.10).

1. *Corn response.* All DCD and N application rates were evaluated for the corn response (Figure 1). Plant population before harvest was determined from the entire length of the two middle rows. Leaf greenness was determined at VT (tasseling) using a SPAD chlorophyll meter (Konica Minolta, Tokyo, Japan) at all N rates. Biomass and N uptake were taken 8 weeks after treatment (WAT) at 180 lbs N ac^{-1} and just prior to harvest at 180 and 240 lbs N ac^{-1}. Biomass was collected from 3 ft of row on one of the two outer corn rows, dried, ground using a Thomas-Wiley mill® (Swedesboro, NJ) with a 0.8-inch sieve, and analyzed for total N (Brookside Labs, New Bremin, OH). Corn grain yields were determined by harvesting the middle two rows with a small plot combine (Wintersteiger Delta, Salt Lake City, UT) and adjusting moisture to 15% prior to statistical analysis. Corn grain samples from each plot were collected and analyzed for protein, oil, and starch concentration using near-infrared (NIR) spectroscopy (Foss Infratec, Eden Prairie, MN) (Data not presented).

2. *Gaseous N emissions.* Selected treatments, including the non-treated control and 180 lbs N ac^{-1}, were utilized to evaluate gaseous N loss. Nitrous oxide (N_2O) and ammonia (NH_3) emissions were measured weekly throughout the growing season using a GT5000 Gasmet FTIR analyzer (Vantaa, Finland) and static chambers. Static chambers were placed in the middle two rows of each plot. The Gasmet FTIR analyzer measures N_2O and NH_3 simultaneously at twenty-second intervals for five minutes. Emissions from each sampling day were linearly interpolated between each sampling date for each treatment and replication over the growing season. The sum of daily fluxes was used to calculate cumulative emissions. Soil temperature, air temperature, volumetric water content, and electrical conductivity measurements were recorded from each plot (data not presented). Yield-scaled emissions were calculated as the quotient of cumulative gas emissions and corn grain yield.

3. *Soil test N.* All DCD treatments were evaluated at 180 and 240 lbs N ac^{-1} along with the non-treated control. In-season soil samples were collected at three depths (0-6, 7-12, 13-18 inches)

before fertilizer application and 2, 4, 6, and 8 weeks after treatment (WAT). Post-harvest soil sampling was collected using a Giddings probe (Windsor, CO) at six depths (0-6, 7-12, 13-18, 19-24, 25-30, and 31-36 inches). In-season soil sampling occurred at 180 lbs of N ac^{-1}, while the post-harvest was evaluated at 180 and 240 lbs N ac^{-1}. All soil samples were dried and analyzed for NO_3-N and NH_4-N (Brookside Labs, New Bremin, OH). Soil solution NO_3-N concentrations were determined using suction cup lysimeters placed 18 inches deep between the middle two rows in the non-treated control and treatments with 180 lbs N ac^{-1}. Suction in the lysimeter was established at 60-70 psi before a predicted rainfall event. Samples were filtered and then analyzed using the Dionex Integrion HPIC (Thermo Fisher Scientific, Berkeley, CA) to determine the nitrate concentration.

RESULTS

1. *Environmental conditions affect the efficacy of technology*
   The 20-year (2005 to 2024) average cumulative rainfall during the growing season (April-October) was 25.2 inches (Figure 2). The 2023 growing season received 10.6 inches, which was 58% less than the 20-year average, and the 2024 growing season received 23.5 inches, which was 7% lower than the 20-year average. Throughout the 2023 growing season, it rained 22% of the time, with 6 days having precipitation events equal to or greater than 0.5 inches. For 2024, it rained 31% of the time and had 16 days where precipitation was 0.5 inches or greater. Due to dry conditions in 2023, yield potential and N loss mechanisms were significantly reduced. Dry conditions were a limiting factor, but a rate response to N was observed (data not shown). Conditions favoring denitrification early in the growing season and a restriction of water and N uptake during dry periods throughout the growing season are common for claypan soils (Jamison et al., 1968; Nelson and Motavalli, 2013), and they are important for farmers to make informed decisions on the utility of fertilizer technology. Steady precipitation through July and adequate moisture and lower overall temperatures during the early reproductive stages of development produced a much higher yield potential and more opportunities for environmental N loss in 2024.

2. *Direct and indirect measurements of N uptake by the plant showed minimal differences among DCD rates.*
   Ear leaf greenness (SPAD) was generally similar among DCD treatments at each N rate in 2023 and averaged over N rates in 2024 (data not presented). Plant biomass and N uptake 8 WAT and at harvest were similar between DCD rates (data not presented). Silage production was similar for the DCD rates evaluated in this research.

3. *The optimal rate of DCD for grain production was 0.89%.*
   Corn response to DCD rates varied based on the rate of N applied. When data were combined over years and N rates, the optimal DCD rate was 0.89% DCD (Figure 3). DCD rates were affected by precipitation amounts.

4. *Low rates of DCD are effective at reducing N_2O.*
   Cumulative N_2O emissions decreased (73, 78, 80, & 83%) with increasing DCD rates (0.4, 0.75, 1, and 1.4%), respectively, compared to the absence of DCD (Figure 4). Non-treated urea lost 6% of the applied fertilizer N as N_2O, while DCD rates from 0.4% to 1.4% had less than 1.3% loss. Cumulative NH_3 emissions were nearly zero for all treatments, which was due to the incorporation of urea shortly after application.

5. *DCD rates effectively shifted NH_4^+ to NO_3^- ratios in the soil.*

In-season soil sampling at a 0–6 inch depth showed that higher DCD rates increased soil test NH_4^+ to NO_3^- ratio (Figure 5). DCD formulated with urea at 1.4% had a significantly higher soil test NH_4^+ to NO_3^- ratio than non-treated urea 2, 4, and 6 WAT.

6. *Suction cup lysimeters indicated lower soil solution nitrate concentrations*.
   Due to dry conditions in 2023, minimal samples were collected, which resulted in all treatments having similar nitrate concentrations in the soil solution. With optimal temperatures and precipitation in 2024, low DCD rates (0.4%) had a reduction in soil solution nitrate concentrations (data not presented). The reduction in soil solution nitrate concentration compared to non-treated urea was 39, 51, 44, and 40% for 0.4, 0.75, 1, and 1.4% DCD, respectively (data not presented).

RECOMMENDATIONS

Based on gas emissions and lysimeter research, low rates of DCD are recommended for reducing environmental loss. While increasing DCD rates led to higher soil test NH_4 to NO_3 ratios, they did not significantly increase total plant N uptake. However, grain yields were optimized at 0.89% DCD, which may allow flexibility based on expected environmental conditions. The economics of DCD are yet to be determined based on the optimal DCD rate determined in this research.

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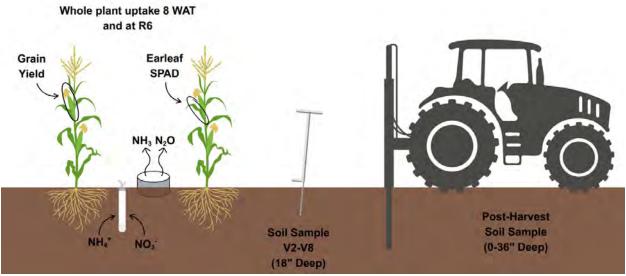
Figure 1. Field measurements of total N uptake, grain yield, gaseous emissions, soil N availability, and soil solution data. (Source: Kaitlin Campbell)
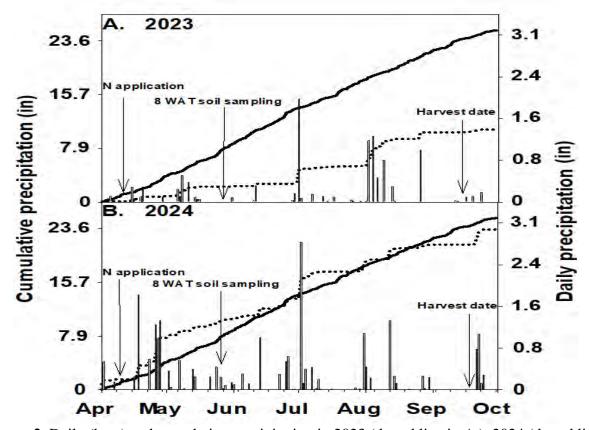
Figure 2. Daily (bars) and cumulative precipitation in 2023 (dotted line in A.), 2024 (dotted line in B.), and 20-year average (solid line).
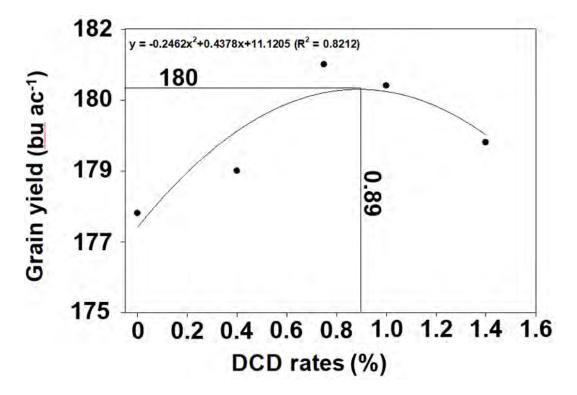
Figure 3. Grain yield response to dicyandiamide (DCD) rates. The 4 g DCD kg^{-1} rate is equivalent 0.4% DCD. Data was combined over years and N rates (60, 120, 180, 240 lbs ac^{-1}). The vertically aligned value represents the optimal DCD rate in this study. The horizontally aligned number represents the corresponding yield.
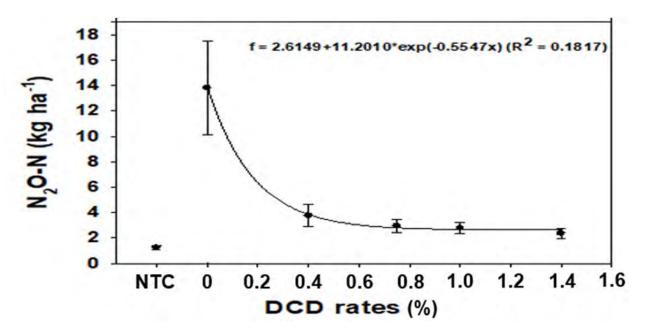
Figure 4. Cumulative N$_2$O for the non-treated control (NTC), and dicyandiamide (DCD) rates. Data were combined over the years. The equation fitted with point data and whiskers above and below the mean represents standard error values.
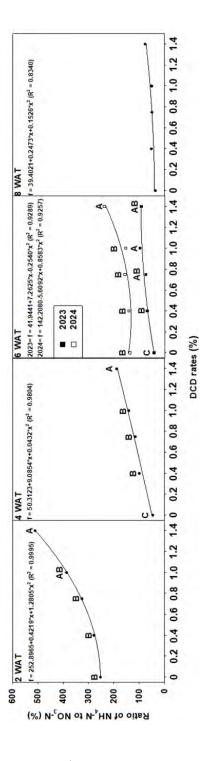
Figure 5. In-season soil test NH_4^+ to NO_3^- ratio at 2, 4, 6, and 8 weeks after treatment (WAT) for dicyandiamide (DCD) rates. Letters above points indicate significant differences between DCD rates within the sampling date using Fisher's Protected LSD (P=0.10).

EFFICACY OF ENHANCED EFFICIENCY UREA FERTILIZERS

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INTRODUCTION
Corn production on claypan soils
Farmers typically operate under tight margins; therefore, every agronomic decision is under intense scrutiny. One of the main challenges faced by farmers is how to keep N available throughout the growing season. Early season N loss is common in the Midwest due to wet springs that delay crop growth and result in N loss, since minimal N uptake occurs until after V6 (Bender et al., 2013). Claypan soils have a dense subsoil clay layer that is typically less than 24 inches deep which restricts root growth and water movement (Jamison et al., 1968). These soils favor denitrification because they are slow to dry out.

Enhanced efficiency fertilizer (EEF) modes of action
SuperU and Environmentally Smart Nitrogen (ESN) are EEF's that are commercially available. SuperU (Koch Agronomic Services, Wichita, Kansas) is granular urea with an analysis of 46-0-0 that contains 0.85% dicyandiamide (DCD) and 0.06% N-thiophosphoric triamide (NBPT) (Trenkel, 2010). The NBPT portion helps protect against volatilization by targeting the urease enzyme which converts urea-N into ammonia (NH_3) (Cantarella et al., 2018). The DCD portion helps protect against nitrate leaching by keeping N in the ammonium (NH_4^+) form longer (Amberger, 1989). DCD does this as a bacteriostatic nitrification inhibitor which means it temporarily inhibits bacteria that convert NH_4^+ into nitrite (NO_2^-) (Trenkel, 2010). ESN is a controlled-release nitrogen fertilizer with an analysis of 44-0-0 (Nutrien, Saskatoon, Canada). This technology is comprised of urea within a polymer coating that allows moisture to diffuse into the granule and release nitrogen 50-80 days after application (Azeem et al., 2014; Dowbenko 2007; Golden et al., 2011). Our research has focused on evaluating the efficacy of two different EEF modes of action that are designed to extend N availability later into the growing season.

OBJECTIVES
The objectives of this study were to evaluate the impact of optimal DCD rates, SuperU, and ESN on 1) corn response (plant population, SPAD, biomass, N uptake, and grain yield), 2) gaseous N emissions [nitrous oxide (N_2O) and ammonia (NH_3)], and 3) soil test and solution NO_3^- and NH_4^+.

PROCEDURES
Field research was conducted in 2023 and 2024 at the University of Missouri Lee Greenley Jr. Research Farm near Novelty. Field management information is reported in Steinkamp et al., 2025. Experiments were arranged in a randomized complete block design with four replications. Plots were 10 by 40 ft. Pioneer (P1359AM) corn was planted in 30-inch-wide rows at 35,000 seeds ac[-1]. All N fertilizers were broadcast applied to the soil surface using a hand spreader and incorporated before planting.

Treatments included non-treated urea (0 g DCD kg^{-1}), optimal DCD rates (0.75 and 1% DCD) as shown in (Steinkamp et al., 2025), SuperU, and ESN at four N application rates (60, 120, 180, and 240 lbs N ac^{-1}). A non-treated control that received no fertilizer was also included. To convert g DCD kg^{-1} into % DCD move the decimal point to the left one spot. For example, 7.5 g DCD kg^{-1} is the same as 0.75% DCD formulated with urea. Crop response and soil data were subjected to ANOVA and means separated using Fisher's protected LSD (P=0.05). Emissions data were subjected to ANOVA and means separated using Fisher's Protected LSD (P=0.10). Figure 1 summarizes the following evaluations.

1. *Corn response.* All selected DCD and EEF application rates were evaluated for the corn response. Plant populations before harvest were determined from the entire length of the two middle rows. Leaf greenness was determined at VT (tasseling) using a SPAD chlorophyll meter (Konica Minolta, Tokyo, Japan) at all N rates. Biomass and N uptake were determined 8 weeks after treatment (WAT) at 180 lbs N ac^{-1} and just prior to harvest at 180 and 240 lbs N ac^{-1}. Biomass was collected from 3 ft of row from one of the two outer corn rows, dried, ground using a Thomas-Wiley mill® (Swedesboro, NJ) with a 0.8-inch sieve, and analyzed for total N (Brookside Labs, New Bremen, OH). Corn grain yields were determined by harvesting the middle two rows with a small plot combine (Wintersteiger Delta, Salt Lake City, UT) and adjusting moisture to 15% prior to statistical analysis. Corn grain samples from each plot were collected and analyzed for protein, oil, and starch concentration using near-infrared (NIR) spectroscopy (Foss Infratec, Eden Prairie, MN) (Data not presented).

2. *Gaseous N emissions.* Selected treatments, including the non-treated control and 180 lbs N ac^{-1}, were utilized to evaluate gaseous N loss. Nitrous oxide (N$_2$O) and ammonia (NH$_3$) emissions were measured weekly throughout the growing season using a GT5000 Gasmet FTIR analyzer (Vantaa, Finland) and static chambers. Static chambers were placed in the middle two rows of each plot. The Gasmet FTIR analyzer measured N$_2$O and NH$_3$ simultaneously at twenty-second intervals for five minutes. Emissions from each sampling day were linearly interpolated between each sampling date for each treatment replication over the growing season. The sum of daily fluxes was used to calculate cumulative emissions. Soil temperature, air temperature, volumetric water content, and electrical conductivity measurements were also recorded from each plot (Data not presented). Yield-scaled emissions were calculated as the quotient of cumulative gas emissions and corn grain yield.

3. *Soil test N.* Selected DCD rates and EEF treatments were evaluated at 180 and 240 lbs N ac^{-1}, along with the non-treated control. In-season soil samples were collected at three depths (0-6, 7-12, 13-18 inches) before fertilizer application and 2, 4, 6, and 8 weeks after treatment (WAT). Post-harvest soil sampling was collected using a Giddings probe (Windsor, CO) and occurred at six depths (0-6, 7-12, 13-18, 19-24, 25-30, and 31-36 inches). In-season soil sampling occurred at 180 lbs of N ac^{-1} while the post-harvest soil sampling evaluated the non-treated control, 180 lbs N ac$^{-1,}$ and 240 lbs N ac^{-1}. All soil samples were dried and analyzed for NO$_3$-N and NH$_4$-N (Brookside Labs, New Bremen, OH). Soil solution NO$_3$-N was determined using suction cup lysimeters placed 18 inches deep between the middle two rows in the non-treated control and included treatments with 180 lbs N ac^{-1}. Suction in lysimeters was established at 60-70 psi before a predicted rainfall event. Samples were filtered and then ran through the Dionex Integrion HPIC (Thermo Fisher Scientific, Berkeley, CA), which determined the nitrate concentration. Data were subjected to ANOVA, and the means were separated using Fisher's Protected LSD at alpha P=0.05 for soil solution measurements and P=0.10 for soil sampling measurements.

RESULTS

1. *Environmental conditions affect the efficacy of technology*

   The 20-year (2005 to 2024) average cumulative precipitation during the growing season (April-October) was 25.2 inches (Figure 2). The 2023 growing season received 10.6 inches, which was 58% less than the 20-year average, and the 2024 growing season received 23.5 inches, which was 7% lower than the 20-year average. Throughout the 2023 growing season, it rained 22% of the time, with 6 days having precipitation events equal to or greater than 0.5 inches. For 2024, it rained 31% of the time and had 16 days where precipitation was 0.5 inches or greater. Due to dry conditions in 2023, yield potential and N loss mechanisms were significantly reduced, with dry conditions being a limiting factor, but a rate response to nitrogen was observed (data not shown). Conditions favoring denitrification early in the growing season and a restriction of water and N uptake during dry periods throughout the growing season are common for claypan soils (Jamison et al., 1968; Nelson and Motavalli, 2013), and they are important for farmers to make informed decisions on the utility of fertilizer technology. Steady precipitation through July and adequate moisture and lower overall temperatures during the early reproductive stages of development produced a much higher yield potential and more opportunities for environmental N loss in 2024.

2. *Direct and indirect measurements of N uptake by the plant showed minimal benefits associated with EEF's.*

   Ear leaf greenness (SPAD) showed similar values among EEF treatments (Data not shown). Biomass and N uptake 8 WAT and at harvest showed similar values among urea technology (Data not presented).

3. *ESN had a 10 bu yield advantage over non-treated urea.*

   There were no differences in yield among treatments in 2023 (Figure 3), which was probably due to dry conditions. However, 1% DCD and ESN had 5 to 10 bu ac^{-1} higher yields than non-treated urea in 2024, respectively. SuperU and 0.75% DCD had yields similar to non-treated urea, suggesting that a higher concentration of DCD may be needed for claypan soils.

4. *EEF's reduced N_2O emissions over 65%.*

   Cumulative N_2O emissions decreased (78, 80, 80, 65%) from non-treated urea for 0.75% DCD, 1% DCD, SuperU, and ESN, respectively (data not presented). Non-treated urea lost 6% of the applied fertilizer N as N_2O, while EEF treatments had less than 2% loss. Cumulative NH_3 emissions were nearly zero in all treatments.

5. *EEF's maintained high NH_4^+ to NO_3^- ratios in the soil.*

   In-season soil sampling at a depth of 0-6 inches showed that SuperU consistently had a higher soil test NH_4 to NO_3 ratio (Figure 4) 2, 4, and 6 WAT. The reason why ESN had low soil test NH_4 to NO_3 ratios 2 and 4 WAT may be a reflection of residual N instead of ESN-N because very little fertilizer had been released from ESN.

6. *Soil solution nitrate concentration was reduced over 40% using EEF technology.*

   Steady precipitation in 2024 showed that overall sampling dates showed sizeable reductions in soil solution nitrate concentrations occurred with all EEFs. The reduction compared to non-treated urea was 51, 44, 44, and 49% for 0.75% DCD, 1% DCD, SuperU, and ESN, respectively (Data not presented).

RECOMMENDATIONS

DCD had the greatest reduction in N_2O emissions, while ESN had similar N_2O emissions. Both modes of action (DCD-treated urea and polymer-coated urea) reduced nitrate concentration in the

soil solution. Both ESN and 1% DCD had higher yields than non-treated urea even though no differences in N uptake were detected among treatments which indicates a complex relationship between N availability and N uptake, N uptake, and harvested yield. When prices are available, this research will help farmers determine a positive ROI using enhanced efficiency urea technology.

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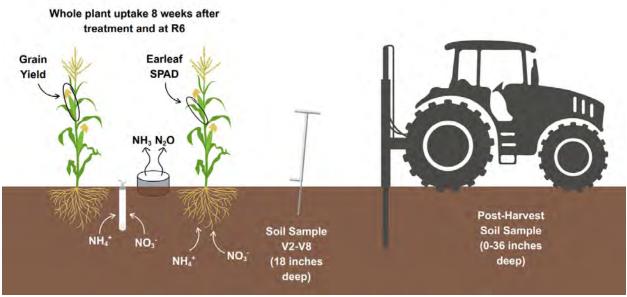
Figure 1. Field measurements of total N uptake, grain yield, gaseous emissions, soil N availability, and soil solution data. (Source: Kaitlin Campbell)
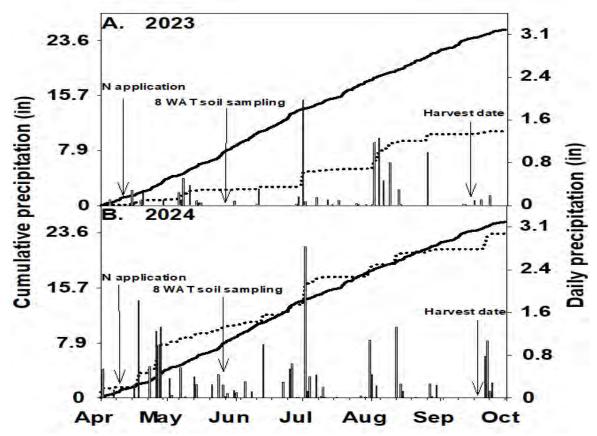
Figure 2. Daily (bars) precipitation in 2023 (A) and 2024 (B). Cumulative precipitation in 2023 (dotted line in A.), 2024 (dotted line in B.), and 20-year average (solid line).
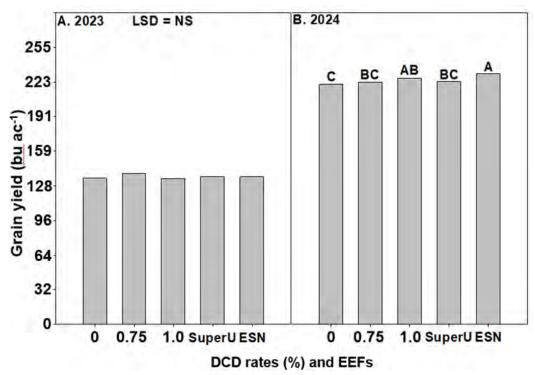
Figure 3. Grain yield response to non-treated urea (0), selected dicyandiamide (DCD) rates, SuperU, and ESN in 2023 (A), and 2024 (B). Data were combined over N rates. Letters above bars indicate significant differences among treatments within a given year using Fisher's Protected LSD (P=0.05).
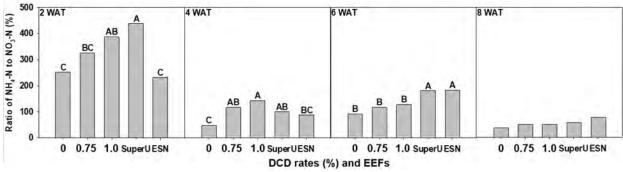
Figure 4. In-season soil test NH_4 to NO_3-N ratio 2, 4, 6, and 8 (WAT) for non-treated urea (0), selected DCD rates, SuperU, and ESN. Letters indicate significant differences between urea treatments within a sampling date using Fisher's Protected LSD (P=0.10).

ANHYDROUS AMMONIA WITH NITRAPYRIN INCREASES CORN YIELD AND PROFITABILITY ACROSS TOPOGRAPHIC POSITIONS

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INTRODUCTION

Nitrogen (N) fertilizer accounts for approximately 20-25% of total operational farm costs, yet its uptake efficiency in the field remains low. On average, only 35% of applied N is taken up by corn globally, with field-level efficiency in the U.S. estimated at around 41% (USDA ERS, 2021; Omara et al., 2019). The remaining N is often lost through leaching, denitrification, or volatilization. Gaseous loss is especially problematic in claypan soils. Claypan soils have a dense sub-surface clay layer that limits water movement and creates a perched water table in subsoil which causes waterlogging in the plant root zone and promotes N loss (Nash et al., 2012). Terrace construction has been widely adopted on highly erodible soils to reduce fertilizer losses associated with erosion and runoff, but the microtopographic variation that develops within these terraces can influence N loss pathways and affect nutrient availability and crop productivity (Adler et al., 2018). In general, upper slope positions tend to be well-drained and dry, while lower slopes often retain moisture and promote conditions for N loss (Singh et al., 2016; Kaur et al., 2024). Kaur et al. (2023) reported that soybean yields on a terraced field was ranked shoulder (75 bu ac^{-1}) > backslope (70 bu ac^{-1}) > footslope (63 bu ac^{-1}) > channel (52 bu ac^{-1}) and corn yields were ranked backslope (115 bu ac^{-1}) > shoulder (113 bu ac^{-1}) > footslope (78 bu ac^{-1}) > channel (61 bu ac^{-1}). This spatial variability in N losses and crop productivity suggests that a uniform N management strategy may not be appropriate across fields with such topographic variation. Instead, site-specific approaches that account for fixed topographic features are necessary to improve N use efficiency and crop productivity.

Nitrification inhibitors (NIs) such as nitrapyrin are recommended for reducing N losses, especially when applied with anhydrous ammonia (AA) in poorly drained soils (Kaur et al., 2020, 2024; Nash et al., 2012). Nitrapyrin delays the conversion of ammonium to nitrate, which helps retain N in the root zone longer and supports plant uptake. Studies have shown that nitrapyrin can reduce N losses and increase corn yields on claypan soils (Nelson & Motavalli, 2013; Singh & Nelson, 2024). However, little is known about NIs and their effectiveness based on topographic positions, especially in a terraced field.

OBJECTIVE

The objective of this study was to evaluate the effects of an AA application with or without nitrapyrin on corn productivity and economic returns across topographic positions (i.e., shoulder, backslope, and footslope) in a terraced field.

PROCEDURES

A field experiment was conducted from 2019 to 2022 on parallel terraces established in 1981 at the Lee Greenley Jr. Memorial Research Farm (40.02328° N, 92.19179° W) located near Novelty, Missouri. The soil series of the experimental field was classified as Kilwinning silt loam (fine, smectitic, mesic Vertic Epiaqualfs) and Putnam silt loam (fine, smectitic, mesic Vertic Albsaqualfs). The experiment was a randomized complete block design with two N treatments

established within each topographic position. These treatments included AA applied alone and AA co-injected with a NI, nitrapyrin (N-Serve, Dow AgroSciences, Indiana). Terraces were adjacent and managed under a dryland corn-soybean rotation. Treatment replications varied by year, with six replications in 2019 and 2021, and ten replications in 2020 and 2022.

Corn was no-till planted in all four years using a Case IH 1245 PT planter (Racine, Wisconsin). In 2019, 2020, and 2021, DKC 63-55 (Bayer, Leverkusen, Germany) was planted at 32,000 seeds per acre in 2019 and 34,000 seeds per acre in 2020 and 2021. In 2022, G12S75-5112 (Golden Harvest Seeds, Waterloo, Nebraska) was planted at 32,000 seeds per acre. Anhydrous ammonia was spring-applied using a Dalton toolbar (Lenox, Iowa) in 2019 through 2021, while a John Deere 2510 (Moline, IL) applicator was used in 2022. Nitrapyrin was co-injected downstream with AA using a Sidekick™ injection system (Sioux Falls, South Dakota) as described by Singh and Nelson (2019). The N rate was consistent between treatments within each year, with the only difference being the presence or absence of nitrapyrin. Total N applied was 203 lb N ac^{-1} in 2019, 173 lb N ac^{-1} in both 2020 and 2021, and 161 lb N ac^{-1} in 2022. The nitrapyrin rate was 1 qt ac^{-1} of N-serve (0.5 lb active ingredient ac^{-1}) each year. All agronomic and crop protection practices were implemented according to the best regional management practices for corn production in northern Missouri.

RESULTS
Grain yields
Grain yields were significantly influenced by either topographic position, N treatment, or their interaction, depending upon the site-year (Table 1). In 2019, the shoulder position had 24-29 bu ac^{-1} higher grain yields compared to the backslope and footslope. The addition of nitrapyrin to AA increased yields 11 bu ac^{-1} at the backslope and 21 bu ac^{-1} at the footslope landscape position in 2020. In 2021, the shoulder position produced 13 to 64 bu ac^{-1} higher yields than the backslope and footslope. Anhydrous ammonia + nitrapyrin increased yield 15 and 11 bu ac^{-1} compared to AA alone in 2021 and 2022, respectively. The footslope exhibited the highest yield (168 bu ac^{-1}) in 2022, which was 13 and 30 bu ac^{-1} more than the backslope (155 bu ac^{-1}) and shoulder (138 bu ac^{-1}), respectively. Averaged over four growing seasons (2019-2022), AA + nitrapyrin treatment showed a yield advantage ranging from 5 to 17 bu ac^{-1} over AA alone across all topographic positions.

Economic Analysis
Over the four-year study period, spring application of nitrapyrin with AA consistently resulted in positive expected net returns across all topographic positions, with the exception of the footslope position in 2021 (Table 2). The incremental yields or the yield advantage of applying AA+nitrapyrin over AA alone were negative at the backslope (-3 bu ac^{-1}) in 2019 and shoulder (-5 bu ac^{-1}) in 2020. All other treatments had an 8-21 bu ac^{-1} yield increase across the topographic positions, which resulted in a revenue gain of $22-97 across all slope positions. This economic impact was notably the highest at the footslope in 2020 and 2021. Net economic gain, the extra money a farmer earns after covering all production costs, including nitrapyrin application was within a range of $9-12 ac^{-1} in 2019, $38-35 ac^{-1} in 2020, $61-88 ac^{-1} in 2021, and $61-66 ac^{-1} in 2022. Overall, average net returns, incremental yield increase, net economic gains, and other economic parameters were positive and higher at the footslope followed by the backslope and the shoulder. This suggests that the nitrapyrin application could be more beneficial at the footslopes that are periodically waterlogged after a rainfall event.

RECOMMENDATIONS

1. Spring application of nitrapyrin with anhydrous ammonia improves corn productivity across all topographic positions.
2. Nitrapyrin (N-Serve) can provide economic benefits even after covering its application costs in terraced fields.
3. Farmers can realize the greatest incremental yields and economic returns from nitrapyrin in the footslope landscape position, followed by the backslope and shoulder positions of a terraced field.

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Table 1. Corn grain yields for the main effects of topographic positions (TPs), nitrogen treatments (NT), and their interaction effect in 2019, 2020, 2021, and 2022, as well as an average over years (2019 to 2022). Similar letters within a column are not significantly different at p<0.05 within a factor. Underlined p-values indicate significant type-3 fixed effects model values.

Topographic Positions (TPs)	Nitrogen Treatment (NT)	Corn Grain Yield (bu ac^{-1})				
		2019	2020	2021	2022	2019-2022
Shoulder		209 a	186 b	150 a	138 c	172 a
Backslope		185 b	202 a	137 b	155 b	173 a
Footslope		180 b	188 b	86 c	168 a	161 b
	AA+nitrapyrin	193	196 a	132 a	159 a	174 a
	AA	190	187 b	117 b	148 b	163 b
Shoulder	AA+nitrapyrin	213	184 c	156	144	174 b
	AA	205	189 c	145	133	169 c
Backslope	AA+nitrapyrin	186	207 a	145	161	178 a
	AA	184	196 b	129	149	168 c
Footslope	AA+nitrapyrin	183	198 b	94	173	170 c
	AA	177	177 d	78	163	153 d
Source of variation	*df*	--------------------------*p-value*----------------------------				
TP	2	<u><0.0001</u>	<u><0.0001</u>	<u><0.0001</u>	<u><0.0001</u>	<u><0.0001</u>
NT	1	0.846	<u><0.0001</u>	<u><0.0001</u>	<u><0.0001</u>	<u><0.0001</u>
TP x NT	2	0.6516	<u><0.0001</u>	0.0632	0.7083	<u><0.0001</u>

Abbreviations: AA+nitrapyrin, nitrogen applied as Anhydrous ammonia with nitrapyrin; AA, Anhydrous ammonia applied without nitrapyrin; *df*, numerator degrees of freedom.

Table 2. Estimated gross returns, production costs, expected net returns, profit difference, incremental yield gain, breakeven yield gain, economic yield gains, and net economic gains based on yields of the three topographic positions with nitrapyrin from 2019 to 2022.

Topographic positions	Gross returns	Expected net returns	Incremental Yield gain[†]	Incremental Revenue Gain[¥]	Economic Yield Difference[ᵻ]	Net Economic Gain[ϕ]	Breakeven Yield Gain[‡]
		$ ac⁻¹	bu ac⁻¹	$ ac⁻¹	bu ac⁻¹	$ ac⁻¹	bu ac⁻¹
2019							
Shoulder	791	284	8	29	5	19	3
Backslope	679	173	-3	-9	-5	-19	3
Footslope	659	153	6	22	3	12	3
2020							
Shoulder	895	358	-5	-21	-7	-30	2
Backslope	970	433	10	48	8	38	2
Footslope	919	382	21	94	18	85	2
2021							
Shoulder	978	367	11	70	10	61	2
Backslope	919	308	15	94	14	84	2
Footslope	605	-6	16	97	14	88	2
2022							
Shoulder	983	309	11	75	10	66	1
Backslope	1118	444	12	80	10	71	1
Footslope	1159	485	10	71	9	61	1
Average							
Shoulder	1060	387	7	41	5	30	2
Backslope	1062	389	12	73	10	62	2
Footslope	986	313	15	92	13	81	2

Note: [†]Incremental Yield Gain = Yield of the nitrapyrin treatment-Yield of control treatment (AA);

[¥] Incremental Revenue Gain = Incremental Yield Gain*Corn Price

[‡]Breakeven Yield Gain = Cost of NI / Corn Price;

[ᵻ]Economic Yield Difference = Incremental Yield Gain - Breakeven Yield Gain;

[ϕ]Net Economic Gain = Incremental Revenue Gain - Cost of NI

OPTIMIZING NITROGEN SOURCE, RATE, AND TIMING WITH A NITRIFICATION INHIBITOR TO IMPROVE CORN GRAIN YIELD

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INTRODUCTION

The 4R nutrient stewardship framework of applying the right fertilizer source at the right rate, right time, and in the right place is critical for effective fertilizer management (Reetz et al., 2015). In Missouri, where corn is grown on varied terrain with poorly drained soil and is subject to extreme weather events, crop production can be highly variable. The region typically receives excessive rainfall in the spring and early fall. When precipitation variability is combined with complex topography, the fate of applied nitrogen can be drastically influenced. Therefore, selecting the appropriate fertilizer source, application timing, and rate is especially important. To minimize nitrogen loss and maintain high crop yields, several management strategies have been developed. These include splitting nitrogen applications, using nitrification inhibitors (NIs), and applying nitrogen at rates that are agronomically and economically optimal. Nitrification inhibitors help reduce N losses due to denitrification by slowing the microbial conversion of ammonium to nitrate (Subbarao et al., 2012; Wang et al., 2020).

OBJECTIVE

The objective of the study was to evaluate the efficiency of nitrogen fertilizer sources in the presence or absence of a nitrification inhibitor at different application rates and timings in corn production systems in northern Missouri.

PROCEDURES

A three-year (2023, 2024, 2025 (ongoing)) field study was conducted at the University of Missouri Lee Greenley Jr. Memorial Research Farm near Novelty, MO. The soil series at the study site was a Putnam silt loam (fine, smectitic, mesic vertic albaqualfs) with a slope of 0 to 1 percent. The study was arranged as a randomized complete block design with six replications, each having a plot size of 10 by 40 ft. Treatments included applying nitrogen as anhydrous ammonia (AA) at different times (fall and spring) and rates (60, 120, 180, and 240 lb ac^{-1}) with or without a nitrification inhibitor at 20 qt ton^{-1} (pronitridine, Centuro^{TM}). Anhydrous ammonia was applied using a John Deere 2510 (Moline, IL) applicator for the fall and spring application and urea ammonium nitrate (UAN) was applied at V6 growth stage with and without a NI at 10 qt ton^{-1} in 2023 and 2024 at 6 qt ton^{-1} 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). Additionally, a non-treated control was added to the design. Corn was no-till planted at 35,000 seeds ac^{-1} using a Kinzie 4-row planter with a row spacing of 30 inches. The corn hybrid, DKC65-95, was planted each year. Maintenance fertilizer N-P-K-S was applied at 13-60-80-15 lb N-P-K-S ac^{-1}. The center two rows of each plot were harvested using a plot combine to determine corn grain yield. All grain yield data were adjusted to 15% moisture before statistical analysis.

Grain yield data were subjected to normality analysis using the UNIVARIATE procedure and were analyzed using the GLIMMIX procedure in SAS v.9.4 (SAS Institute, Cary, NC) at a significance level of $p = 0.05$. The independent variables for the study were treatments, and random variables were replications. The differences between treatment means were tested based on T-groupings at $p = 0.05$.

Agronomic Optimum Nitrogen Rate (AONR) and Economic Optimum Nitrogen Rate (EONR) were calculated using the Quadratic Plateau (QP) model in R v4.5.0 (RStudio, Vienna, Austria). AONR was defined as the N rate at the point where yield plateaued, while EONR was determined using economic parameters, including a corn price of $4.91 bu^{-1} (USDA, Quick Stats, 2024), AA price of $0.40 lb^{-1}, and pronitridine price of $15 ac^{-1}.

RESULTS

The response of corn grain yield to the different fertilizer sources, rates, and timings is reported in Figures 1-3 and Table 1. Corn grain yield was significantly affected by N treatments in both years ($p<0.0001$). Both years had different effects on grain yield due to precipitation differences between 2023 and 2024 (data not presented). Rainfall varied significantly between 2023 (623 mm) and 2024 (891 mm). Though rainfall during both site years was less than the 22-year average (978 mm), 2024 had evenly distributed rainfall. Due to dry conditions, corn grain yield was lower in 2023 compared to 2024. The highest yield recorded in 2023 was 175 bu ac^{-1} with UAN-240 + NI treatment, while the highest yield (268 bu ac^{-1}) was observed with the AA-240-S treatment in 2024. The addition of a NI to fall-applied AA did not affect yield compared to fall-applied AA alone, which was probably due to dry conditions over the winter months. A slight increase was observed when the NI was added to spring-applied AA compared to AA alone in 2024. This has been observed in other research in well- and poorly-drained soils (Kaur et al., 2024). UAN applied at the V6 growth stage yielded similar to spring-applied AA in 2023. A similar trend was observed in 2024, where V6-applied UAN without NI had grain yields that were 4 to 9 bu ac^{-1} more than fall-applied AA without NI.

The addition of a NI with AA at different timings showed that spring-applied AA with a NI had similar yields at the AONR with a reduced N rate compared to the absence of NI (Figure 2). With spring applied AA, the addition of a NI had 7 bu ac^{-1} lower yield while decreasing the N rates by 34% at AONR. With fall AA, the addition of a NI had a 3 bu ac^{-1} yield increase with an increase of 46 lb N ac^{-1} at AONR. For UAN treatments, the presence or absence of an NI did not significantly affect either AONR or the yield at that rate (Figure 3). For fall AA with NI, increasing the N rate by 36 lb N ac^{-1} resulted in only a 3 bu ac^{-1} yield gain at the EONR. Pronitridine produced similar yields at the EONR, whether applied in the fall or spring with AA, but when used in the spring it reduced the nitrogen requirement by 18% when used in the spring. For UAN treatments, both the grain yield and nitrogen rate at the EONR were comparable with and without pronitridine.

RECOMMENDATIONS

Based on the study findings, it is recommended to prioritize spring applications of AA and V6-stage applications of UAN, as these timings generally resulted in higher corn grain yields compared to fall applications. The use of an NI such as pronitridine should be considered when aiming to enhance nitrogen use efficiency; however, their impact on yield was inconsistent and dependent on application timing and yearly environmental conditions.

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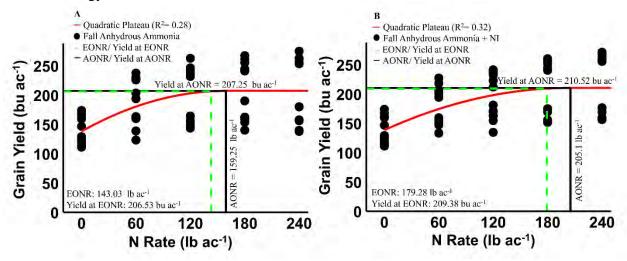
Figure 1. Corn grain yield response to fall-applied anhydrous ammonia alone (A) and with a nitrification inhibitor (B).
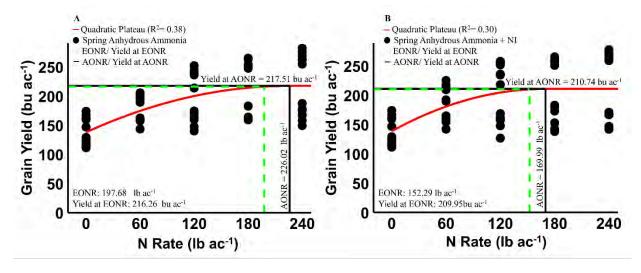

Figure 2. Corn grain yield response to spring-applied anhydrous ammonia alone (A) and with a nitrification inhibitor (B).
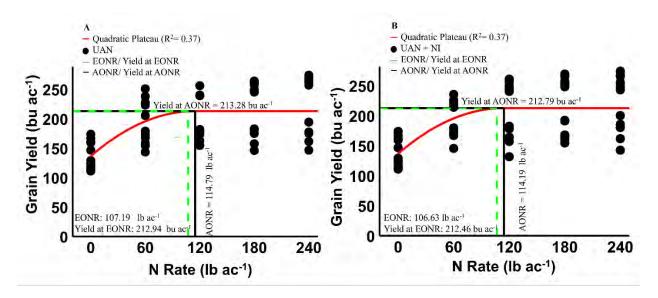
Figure 3. Corn grain yield response to UAN alone (A) and with a nitrification inhibitor (B).

Table 1. Corn grain yield response to different nitrogen sources, rates, and timing with and without nitrification inhibitors in 2023 and 2024. Means followed by different letters showed significant differences among treatments within a column.

Treatments	Corn Grain Yield	
	2023	2024
	---------------------------- bu ac^{-1} ----------------------------	
0 NTC[†]	119 i	154 l
AA-60-F	151 gh	219 h-j
AA-120-F	152 f-h	242 ef
AA-180-F	161 b-g	252 c-e
AA-240-F	159 d-h	262 a-c
AA-60 + NI-F	149 h	209 jk
AA-120 + NI-F	161 b-g	231 gh
AA-180 + NI-F	160 d-h	252 c-e
AA-240 + NI-F	163 b-f	265 ab
AA-60-S	157 e-h	198 k
AA-120-S	159 d-h	238 fg
AA-180-S	168 a-e	258 a-d
AA-240-S	169 a-d	268 a
AA-60 + NI-S	162 b-g	211 ij
AA-120 + NI-S	154 f-h	242 ef
AA-180 + NI-S	162 b-g	259 a-d
AA-240 + NI-S	160 c-h	267 ab
UAN-60 at V6	163 b-f	229 gh
UAN-120 at V6	172 ab	243 ef
UAN-180 at V6	171 a-c	256 b-d
UAN-240 at V6	172 ab	266 ab
UAN-60 + NI at V6	169 a-d	222 hi
UAN-120 + NI at V6	163 b-f	249 df
UAN-180 + NI at V6	172 ab	258 a-d
UAN-240 + NI at V6	175 a	259 ad
p-value	$\leq$0.0001	$\leq$0.0001

[†]Abbreviations: NTC, non-treated control; AA, anhydrous ammonia; F, fall applied; NI, nitrification inhibitor centuro; S, spring applied; UAN, urea ammonium nitrate.

PHOSPHORUS APPLICATION RATES AFFECT SOYBEAN PRODUCTION IN NORTHEASTERN MISSOURI

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INTRODUCTION

Phosphorus (P) is one of the three primary macronutrients required by plants and serves as a key structural component of nucleic acids, phospholipids, and adenosine triphosphate. It constitutes around 0.2% of the crop's dry weight (Schachtman et al., 1998). The other basic roles that P plays in plants are root and shoot development, crop quality and maturity, and resistance against disease. In soybeans, P affects nodulation, biomass, and yield production. Nitrogen fixation by soybean is directly related to P content in the plant stem (Pang et al., 2011). Out of the total P applied, 80% is immediately fixed by soil components like clay, organic matter, and oxides and hydroxides of iron, aluminum, and calcium. Phosphorus fertilization exceeding the crop requirement leads to P accumulation in soils. Motavalli & Miles (2002) documented increased P reserves in Sanborn field soil due to overapplication in the desire to get higher yields out of each cropping system. The current P recommendation in the Midwestern United States has not been updated for several decades. Therefore, it is important to evaluate the crop responses to P applications in soils having different P availability.

OBJECTIVES

The objective of this study was to evaluate the impact of different P rates on the development and yield of soybean in Northeast Missouri.

PROCEDURES

The experiments were conducted for two consecutive years, 2023 and 2024, at two different sites in Northeast Missouri – Ross Jones Farm near Bethel (Shelby County) and a grower's farm near Millard (Adair County). The experimental design was a randomized complete block replicated four times. Five different P rate treatments were 0, 22, 44, 66, and 87 lbs P ac^{-1}. The source of P was triple superphosphate, which supplies 46% P_2O_5. It was broadcast on 4/21/2023 and 5/3/2023 at the Millard and Bethel locations, respectively. In 2024, the fertilizer application dates were 5/1/2024 for Millard and 4/15/2024 for Bethel. The soil series at the Bethel location was a Putnam silt loam characterized by claypan subsoil with poor hydraulic conductivity. The soil at the Millard location was an Armstrong silt loam. The plot size was 10 by 40 ft. Row spacing was 15 inches and each plot had seven rows.

Soybean was harvested with a plot combine mounted with a yield monitor to determine weight, moisture, and test weight. The soybean yield data were adjusted to 13% moisture content prior to data analysis. Pre-plant and post-harvest soil samples were taken at 0-6 and 7-12 inches. The soil was analyzed for pH, organic matter, Bray I-P, Mehlich III-P, potassium, calcium, magnesium, and zinc. In addition to yield and phosphorus uptake measurements, partial factor productivity of P (PFP-P) and agronomic efficiency of P (AE-P) were calculated to assess the efficiency of P use. PFP-P was determined as the ratio of grain yield to the amount of P applied,

and AE-P was calculated as the increase in yield per unit of P fertilizer applied relative to the control.

The data were statistically analyzed using SAS statistical software version 9.4 (SAS Institute, Cary, NC) through the GLIMMIX procedure at a significance level of 0.05. Rate response plots were created using SigmaPlot, which gave agronomic optimum nutrient rate (AONR) and yield at AONR (YAONR) values. Where AONR is the optimum nutrient rate that gives the highest yield, and YAONR is the yield achieved at that optimal nutrient rate.

RESULTS

In both years, phosphorus application rates had significant effects on grain yield, grain phosphorus removal and uptake, PFP-P, and AE-P at both the Millard and Bethel locations. The highest grain yield (61.1 bu ac^{-1}) was achieved with 22 lb P ac^{-1}, while the lowest yield was reported in the control with no P application. Increasing rates beyond 22 lb P ac^{-1} (i.e., 44, 66, and 87 lb P ac^{-1}) did not result in significant yield improvements (Table 1).

Grain P removal increased progressively with an increase in P application rates. Application of 87 lb P ac^{-1} led to the highest grain P removal (24.71 lb ac^{-1}). Whereas no-P application led to 5.4 lb ac^{-1} less P removal as compared to application of 87 lb P ac^{-1} (Table 1).

In 2023, the P agronomic optimum nutrient rate (AONR) was 19.2 lb ac^{-1} at the Bethel location which produced a yield at AONR (YAONR) of 58.3 bu ac^{-1}, while the Millard location field showed a slightly higher AONR of 24.3 lb ac^{-1} with a similar yield of 58.2 bu ac^{-1} (Figure 1). In 2024, the AONR at Bethel increased substantially to 40.9 lb ac^{-1} which resulted in a higher YAONR of 68.5 bu ac^{-1}. In contrast, the Millard location showed no significant yield response to phosphorus application that year.

Higher application rates also led to greater residual P buildup in the soil. Bray-1 P content increased with application rate, reaching a maximum of 26.2 lb ac^{-1} at the 87 lb P ac^{-1} rate, compared to 11.2 lb ac^{-1} in the control treatment (Table 1).

RECOMMENDATIONS

Based on the AONR findings, a phosphorus application rate in the range of 20-40 lb P ac^{-1} is recommended to optimize the soybean yield while maintaining the nutrient use efficiency. This reflects the variation observed across the sites and years, where lower application rates were sufficient under some conditions, but higher rates were needed to achieve maximum yield under others. Although higher application rates increased the grain P removal and Bray-1 P levels, they did not contribute much to yield. This suggests diminishing returns and potential environmental concerns. Therefore, P application rate in the range of 20-40 lb P ac^{-1} supports efficient phosphorus use, maximizing partial factor productivity, and minimizing unnecessary buildup of residual soil P.

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Table 1. Average soybean grain yields, grain P removal, partial factor productivity, agronomic efficiency, Bray-1 P, and Mehlich-III P as affected by the phosphorus application rates. Data is averaged over two locations and years. Similar letters within a column indicate no significant difference at α=0.05

P Application Rates	Soybean Grain Yield	Soybean Grain P Removal	Soybean Grain P Content	PFP-P	AE-P[†]	Bray-1 P	Mehlich-III P
lb ac^{-1}	bu ac^{-1}	lb ac^{-1}	%	%	bu lb^{-1}	lb ac^{-1}	ppm
0	55.4 b	19.27 d	0.58 d	0	0	11.8 d	10.86 d
22	61.1 a	22.84 c	0.62 c	2.78 a	0.26 a	13.4 cd	12.51 cd
44	60.2 a	23.46 bc	0.65 b	1.37 b	0.11 b	17.7 bc	14.93 bc
66	60.5 a	24.27 ba	0.67 a	0.92 c	0.08 b	22.2 ab	17.43 ab
87	60.8 a	24.71 a	0.68 a	0.70 d	0.06 b	26.2 a	19.56 a

[†]Abbreviations: P, Phosphorus; PFP-P, Partial Factor Productivity of Phosphorus; AE-P, Agronomic Efficiency of Phosphorus
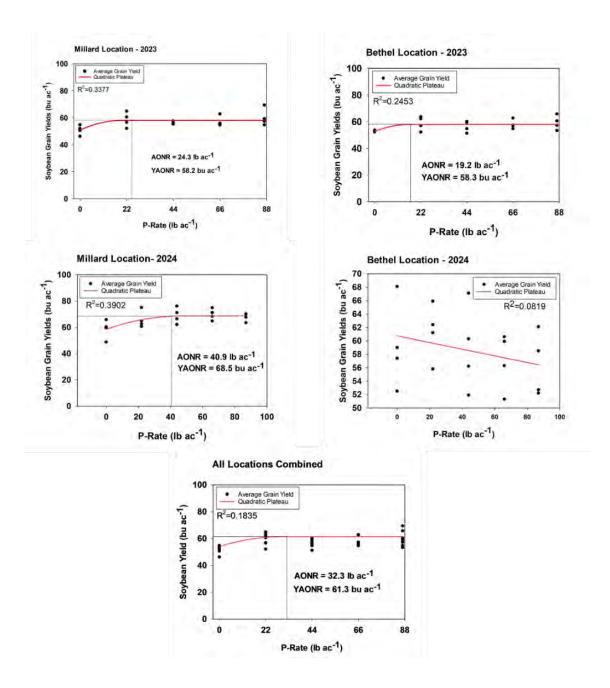
Figure 1. Yield response graphs to different phosphorus application rates depicting AONR and YAONR values at the four site-years and combined over locations.

SOYBEAN RESPONSE TO POLY4 RATES AND DIFFERENT SOURCES OF SULFUR AND POTASSIUM IN NORTHEASTERN MISSOURI

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INTRODUCTION

Sulfur (S) and potassium (K) are two essential nutrients required by soybean for nodulation, protein synthesis, and yield. Sulfur enhances the oil content in soybean and improves grain quality. There are different sources of sulfur available, including elemental sulfur, ammonium sulfate (AS), and POLY4. Ammonium sulfate is the most widely used fertilizer source of sulfur, containing both sulfur and nitrogen. It is readily available and cost-effective (Powlson & Dawson, 2022). POLY4 is a balanced nutrition fertilizer source for long-term supply due to its slow-release properties. POLY4 is a multi-nutrient fertilizer containing 19% S, 14% K_2O, 17% CaO, and 6% MgO derived from a naturally occurring polyhalite mineral in the north-eastern coast of the United Kingdom (Singh et al., 2023). It's a slow-releasing fertilizer without chlorine, which could be beneficial for chlorine-sensitive crops like soybean with higher use efficiency (Gopinath et al., 2024). Its gradual nutrient release and low leaching potential make it particularly useful under the high rainfall conditions of northeastern Missouri (Tan et al., 2022).

Potassium can be applied through different sources, including muriate of potash (MOP; 60% K_2O), potassium sulfate, K-Mag, and POLY4. Muriate of potash is a cost-effective source of K (Gautam et al., 2022). K-Mag is a balanced fertilizer that supplies 21% K_2O, 21% S, and 10% Mg. Supplying K_2O through POLY4 may help farmers reduce the extra cost of sulfur and other essential nutrient fertilizers. However, little information is available on soybean response to these sulfur and potassium sources in northern Missouri.

OBJECTIVES

The objective of this study was to evaluate the soybean grain response to different rates of POLY4 and K fertilizer sources.

PROCEDURES

Field experiments were conducted at Millard in 2023 and at Bethel in 2024. The experiment was a randomized complete block design replicated four times. The plot size was 10 by 40 ft with soybeans planted in 15-inch rows, and each plot had seven rows. Table 1 presents the key information about the trials conducted across different years. The treatments included different sources of K (control, MOP, MOP + AS, Poly4, and K-Mag + MOP) and S (control, AS, MOP + AS, Poly4, and K-Mag + MOP). Different S rates were supplied with POLY4, including 0, 9.5, 19, 27.5, and 38 lb ac^{-1}. The fertilizer was broadcast applied before planting.

Soybean was harvested with a plot combine equipped with yield monitors that can collect data related to test weight, grain moisture, and yield. Soybean yield was adjusted to 13% moisture content before data analysis. Statistical analysis was performed using SAS Statistical Software version 9.4 (SAS Institute, Cary, NC) through the GLIMIX procedure, and the means were separated at a significance level of 0.05. SigmaPlot software was used to generate the S rate response curves and obtain the AONR and corresponding YAONR values. The AONR is the

optimum nutrient rate that maximizes grain yield, and YAONR is the yield achieved at that optimal nutrient rate.

RESULTS

Based on the S rate response curve for all the site years, soybean grain yield increased with increasing S rates up to 19 lb ac^{-1} (Figure 1). The AONR for S was 17.1 lb ac^{-1}, which produced a soybean YAONR of 67.8 bu ac^{-1} (Figure 1).

When data were averaged over all site-years, K sources significantly increased soybean grain yield as compared to the control (Table 2). However, no statistically significant difference was observed among the different K sources.

In 2023, S sources did not affect soybean grain yield (Table 3). In 2024, both early and late planting showed significant differences among the sources in terms of grain yield. Among the S sources, application of AS with MOP produced 11.3 bu ac^{-1} and 7.9 bu ac^{-1} higher yields as compared to AS without MOP at Bethel for EP and LP soybeans, respectively. AS alone had lower grain yields than the Poly-4 and K-Mag + MOP, which was probably due to the K concentration.

RECOMMENDATIONS

Based on the AONR findings, an S application rate of 17.1 lb ac^{-1} in soybeans is recommended to meet the crop requirement and maximize grain yield. Potassium sources do not affect the grain yield significantly when applied at the same rate. However, the application of K along with S is strongly recommended to ensure balanced nutrition.

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Table 1. Crop management dates and information related to the field experiments conducted in 2023 and 2024 at Millard and Bethel.

Field operations	2023 Millard	2024 Bethel-EP[†]	2024 Bethel-LP[†]
Planting date	04/18	04/15	05/13
Cultivar	AG38XF0	GH3994E3	GH3994E3
Seeding rate (seeds ac^{-1})	180,000	180,000	180,000
Fertilizer application	05/11	04/8	04/8
Harvest	10/06	09/29	09/29
Soil sampling	11/02	11/22	11/22

[†]EP, Early planting; LP, Late planting

Table 2. Soybean grain yields as affected by the potassium fertilizer treatments in 2023 and 2024. Means followed by similar letters within a column are not significantly different at α= 0.05.

Treatments	S	K	Ca	Mg	2023 Millard	2024 Bethel-EP[†]	2024 Bethel-LP	Average over all site years
	----lb a.i. ac^{-1}------				-------Soybean grain yields (bu ac^{-1}) ------			
Control	0	0	0	0	62.8	63.0	62.8	62.8 b
MOP	0	62	0	0	-	68.7	68.9	68.8 a
MOP + AS	19	62	0	0	65.8	71.7	68.8	68.8 a
Poly-4	102	62	65	19	65.0	70.6	69.0	68.2 a
K-Mag + MOP	19	62	0	10	-	67.6	67.0	67.3 a
Source of Variation								
df					2	4	4	5
p-values					0.1985	0.1146	0.078	0.0019

[†]EP, Early Planting; LP, Late Planting; MOP, muriate of potash; AS, ammonium sulfate

Table 3. Average grain yields for individual site years and all site years combined under the main effect of different sulfur sources. Means followed by similar letters within a column are not significantly different at α= 0.05

Treatments	S	K	Ca	Mg	2023 Millard	2024 Bethel EP[†]	2024 Bethel LP	Average Overall Site-years
	-------lb a.i. ac^{-1}----				----------------------------bu ac^{-1}----------------------------			
Control	0	0	0	0	62.8	63.0 bc	62.8 b	62.9 b
AS	19	0	0	0	65.6	60.4 c	60.9 b	62.3 b
MOP+ AS	19	62	0	0	65.8	71.7 a	68.8 a	68.8 a
Poly-4	19	12	12	4	64.3	69.9 a	68.3 a	67.5 a
K-Mag+ MOP	19	62	0	10	-	67.6 ab	67.0 a	67.3 a
Source of Variation								
df					3	4	4	4
p-values					0.5091	0.0068	0.0044	<0.0001

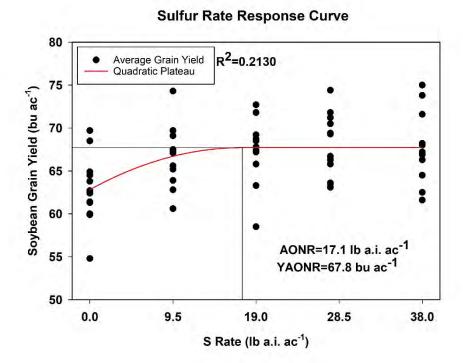[†]EP, Early Planting; LP, Late Planting; MOP, muriate of potash; AS, ammonium sulfate

Figure 1. Soybean grain yield response curves to different sulfur application rates depicting AONR and YAONR values. Data were combined over the early and late planting dates at Bethel and Millard.

SCREENING SOYBEAN VARIETIES TO FLOODING STRESS IN NORTHERN MISSOURI

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INTRODUCTION

In Missouri, soybean is the number one crop both in production and value (USDA-NASS, 2024). Due to undulating topography, river bottom fields, and the presence of claypan soil in northern Missouri, soybeans are particularly susceptible to waterlogging stress after excessive rainfall events (Hammer et al., 1995). Waterlogging creates hypoxic (oxygen-deficient) conditions. These conditions get worse with the passage of time and lead to an anoxic (absence of oxygen) state, which subsequently inhibits aerobic respiration (Wegner, 2010). Anoxic conditions affect soybean seed viability and germination (Wu et al., 2017) and cause chlorosis, necrosis, defoliation, stunted growth, reduced nitrogen (N) fixation, yield loss, and even plant death (Hasanuzzaman et al., 2016). Moreover, the growth stage at which flooding occurs also influences the degree of yield loss. For instance, losses have ranged from 17 to 43% when flooding occurred during the vegetative stage of development and 50 to 56% during the reproductive stage of development (Oosterhuis et al., 1990). Therefore, it is essential to identify commercially available soybean varieties that can withstand flooding stress while maintaining optimal yield potential for farmers.

OBJECTIVE

The objective of this study was to evaluate the effects of flood duration on commercially available soybean varieties during their early growth stages.

PROCEDURES

Experiments were conducted at the University of Missouri Lee Greenley Jr. Memorial Research Farm near Novelty, MO in 2023 and 2024. The study was designed as a randomized complete block with a split-plot arrangement and three replications. Main plots were flooding duration [0 (non-flooded control), 3, and 7 days], and sub-plots were commercial soybean varieties of different maturity groups. Some varieties were with or without seed treatment. Twenty commercial soybean varieties were evaluated in 2023, while twenty-two commercial soybean varieties were tested in 2024. Soybean was planted on 24 May 2023 in a row spacing 15 inches (Table 1). In 2024, soybean was planted on 30 May 2024 with a row spacing of 30 inches (Table 1). The seeding rate was 140,000 seeds acre^{-1}. The soil was a Putnam silt loam.

Flooding started on 12 July 2023 and 3 July 2024 when soybeans were at the V3-V5 growth stage of development. Data, including various parameters such as plant height, plant population, and pods per plant, were collected at the R7-R8 growth stage. Soybean was harvested using a plot combine from the center four rows in 2023 and two rows in 2024 of each sub-plot to determine seed yield. Seed yield was adjusted to 13% moisture content before statistical analysis. Data were 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 α < 0.05.

RESULTS

Soybean plant height, plant population, pods per plant, and seed yield were significantly affected by the main effect of flooding duration in 2023 (Table 2). Soybean plant height varied significantly among the varieties in 2023 (Table 3). In 2024, soybean seed yield and plant population were affected by the main effects of flooding duration. Plant population, pods per plant, and soybean seed yield were affected by the main effects of variety in 2024 (Table 4). Three and 7-days of flooding reduced soybean plant height by 4 and 21%, respectively, compared to non-flooded soybean in 2023 (Table 2). The flooding duration of 3 and 7 days decreased the plant population 23 to 38% compared to the non-flooded treatment in 2023 (Table 2). In 2024, 7 days of flood reduced the plant population compared to non-flooded conditions (Table 2). Pods per plant decreased 21% when soybean was flooded for 7 days compared to non-flooded soybean in 2023 (Table 2). Three days of flooding did not cause a significant reduction in pods per plant in 2023. Reduced plant population due to 7 days of flooding resulted in an 11 to 31% reduction in soybean seed yield compared to the non-flooded treatment (Table 2). Each day of flooding resulted in soybean yield loss of 2.8 bu ac^{-1} and 1.03 bu ac^{-1} per day in 2023 and 2024, respectively (Figure 1).

CONCLUSIONS

The results showed that flooding duration impacts soybean production by affecting overall plant growth and development. However, the yield reduction due to flooding varies by year and variety.

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Table 1. Field operations and crop management in 2023 and 2024.

Field operations/Crop management	2023	2024
Tillage	Vertical tilled - Twice Culti-packed - Once	Vertical tilled - Once Cult-packed - Once
Planting Date	05/24/2023	05/30/2024
Sub-Plot Size	10 × 30 feet	10 × 20 feet
Row Spacing	15 inches	30 inches
Herbicides/ Pesticides	Pre-Emergence 05/25/2023 - 20 oz. ac^{-1} Reflex, 20.8 oz. ac^{-1} Metolachlor, 0.25% v/v NIS, 17 lbs. per 100 gal AMS, 1 qt. ac^{-1} Roundup PowerMax	Pre-Emergence 04/10/2024 - 32 oz. ac^{-1} Verdict, 12 oz. ac^{-1} MSO, 8 oz. ac^{-1} UAN.
	Post-Emergence: 06/14/2023 1 qt. ac^{-1} Roundup PowerMax, 1 qt. ac^{-1} Liberty, 17 lbs. per 100 gal AMS	Post-Emergence: 06/11/2024 24 oz. ac^{-1} UltraBlazer, 1 qt. ac^{-1} UAN, NIS 0.25% v/v, FirstRate 0.3 oz. ac^{-1}, Select 8 oz. ac^{-1} 07/19- Dual II Magnum 20.8 oz. ac^{-1}
Maintenance fertilizer	12/07/2023 - 0-60-80-15S lbs. ac^{-1}	03/05/2024 - 12.6-60-80-15S lbs. ac^{-1}
Between-row cultivation	None	Twice after flooding
Flooding Initiation	07/12/2023	07/03/2024
Harvest	10/11/2023	10/04/2024

Table 2. Impact of flooding duration on soybean plant height, plant population, pods per plant, and seed yield in 2023 and 2024. Means followed by the same letter within a column are not significantly different at α=0.05.

Flooding duration	Plant Height		Plant Population		Pods/plant		Seed Yield	
	2023	2024	2023	2024	2023	2024	2023	2024
Days	----inches---		---Plants ac^{-1}----				----bu ac^{-1}------	
0	33.86a	47.24a	61158a	118520a	87a	49a	67a	68a
3	32.28b	33.46a	47180b	117464a	81a	48a	64a	62b
7	26.77c	32.28a	38042c	112248b	68b	48a	46b	61c

Table 3. Soybean plant height as affected by soybean variety and seed treatment (ST) in 2023. Means followed by similar letters within a column are not significantly different at α = 0.05.

Soybean Variety	Plant Height (inches)
AG36XF	29.78efgh
AG37XF1	34.44ab
AG38XF1	32bcde
AG40XF1	34.22ab
B359EE	30efgh
B371EE-NoST	28.67gh
B371EE-ST	30.78defg
B389EE-NoST	28.56gh
B389EE-ST	29.78efgh
B402EE	29.11fgh
B423EE	33.44abc
GH3582E3	29fgh
GH3922E3-NoST	31.33cdef
GH3922E3-ST	32bcde
P38A54E	30.56defgh
P42A84E	35.11a
P44A91E	32.56bcd
P46A84E	30.11defgh
XO3651E	28.22h
XO3752E	29.22fgh

Table 4. Soybean plant population, pods per plant, and yield as affected by soybean variety in 2024. Means followed by similar letters within a column are not significantly different at α = 0.05.

| Soybean Variety	Plant population	Pods	Soybean Seed Yield
	Plants ac^{-1}	No. plant^{-1}	bu ac^{-1}
AG36XF4	126862ab	46bcde	70a
AG37XF1	113788cd	48abcde	65bcd
AG38XF1	113788cd	48abcde	65bc
AG39XF3	116209abcd	49abcde	68ab
AG40XF1	115725bcd	52ab	65bc
AG41XF2	121536abc	49abcde	57g
B359EE	96841e	50abcd	61defg
B363EE	115725bcd	47bcde	60efg
B373EE	113304cd	48abcde	64cde
B384EE	120083abc	44de	65abc
B384EE-ST	116209abcd	43e	65bc
B394EE	113788cd	55a	67abc
B402EE	100230e	50abcd	62cdef
B423EE	112820cd	52ab	60efg
GH3582E3	112820cd	51ab	64cde
GH3994E3	125409ab	45bcde	67abc
GH3994E3-ST	127346a	45bcde	67abc
P42A84E	123472abc	51abc	58g
P44A91E	107494de	50abcd	58fg
P46A09E	122988abc	44de	60efg
XO3483E	120567abc	52ab	65bc
XO3752E	116694abcd	44cde	67abc
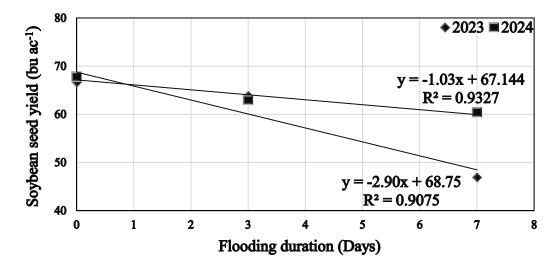
Figure 1. Linear regression analysis of soybean seed yield as affected by flooding duration at early growth stages in 2023 and 2024.

58

MULTILOCATION INDUSTRIAL HEMP CULTIVAR TESTING IN MISSOURI

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INTRODUCTION

Industrial hemp (*Cannabis sativa* L.) is gaining attention in Missouri as a valuable specialty crop that is grown for fiber, seed, and/or cannabidiol content (Adesina et al., 2020). After a 45-year gap, the Agricultural Act of 2014 (Public Law 113-79) reinstated the production of industrial hemp in the USA through state pilot programs (Mark et al., 2020). The 2018 Farm Bill stipulates that cultivated hemp must contain no more than 0.3% THC (Delta-9 tetrahydrocannabinol). The U.S. Drug Enforcement Administration (DEA) strictly regulates its production, ensuring compliance with cultivation conditions (Yano & Fu, 2023). In Missouri, Senate Bill 133 was signed into law on 24 June 2019, which permitted higher education institutions to research and study the growth, cultivation, or marketing of industrial hemp (Falkner et al., 2023). Although Missouri's history of hemp cultivation dates back to 1835 (USDA 1914), the long hiatus has resulted in a significant knowledge gap regarding industrial hemp varieties and production techniques. Thus, it is crucial to evaluate new industrial hemp cultivars across Missouri to identify those best suited to local conditions and provide recommendations to growers.

OBJECTIVES

The objective of this experiment 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 2024 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.

The experiment was a randomized complete block design with four replications. The plot size was 10 by 20/30 ft 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 except in Portageville, MO, where rows were 38 inches wide to accommodate flood irrigation. 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 per 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 the means were separated by least square difference (LSD) at alpha =0.05.

RESULTS

Establishment of industrial hemp was challenging due to waterlogged conditions at the time of planting or later in the season. The plants did not emerge at Spickard and Columbia because of soil saturation due to rainfall events (Figure 1), which resulted in crop failure. The Columbia and Spickard sites were abandoned due to poor stands that resulted from waterlogged conditions (Table 1). Therefore, no biomass or grain yield data were collected at the Spickard and Columbia locations in 2024.

The Portageville and Albany sites were replanted. Among all varieties, Puma (0.35%) had a THC content higher than 0.3% at the Albany site (data not presented). The highest overall biomass for most of the cultivars was at Albany, while the lowest was at Portageville (Figure 2). The Puma variety resulted in the highest biomass production at Albany, while Puma and Yuma had similar biomass yields at Novelty and Portageville (Figure 2). No significant differences were found for biomass production between varieties at Portageville, except Puma and Yuma. The favorable climatic conditions and soils at Albany resulted in higher biomass production.

Grain yield production among locations varied by variety. The highest grain yields were observed at Novelty for all varieties except Trichomo, followed by Albany and Portageville (Figure 3). At Novelty, Vega had the highest yielding variety, whereas Fibror 79 and Futura 83 had the lowest grain yield. The replanted hemp at Portageville probably affected overall biomass and seed yields. We have observed that later planting dates can affect hemp growth and yields. Environmental and soil conditions affect the performance of different cultivars in Missouri. The study will be repeated in 2025 to provide recommendations about the suitable industrial hemp varieties for production in Missouri.

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Yano, H., & Fu, W. (2023). Hemp: A Sustainable Plant with High Industrial Value in Food Processing. Foods, 1(3), 651. https://doi.org/10.3390/foods12030651

Table 1. Planting, re-planting, and harvesting dates in 2024.

Location	Planting date	Re-planting date	Harvesting date
Albany	5/30/2024	6/18/2024	9/17/2024
Columbia	6/18/2024[†]	----------	----------
Novelty	5/22/2024		8/29/2024, 9/12/2024
Portageville	5/30/2024	6/25/2024	10/7/2024
Spickard	5/30/2024[†]	----------	----------

[†]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 2024.

Location	Date	Rate	Source
Albany	6/3/2024	60 lbs N ac^{-1}	SuperU®
Columbia		60 lbs N ac^{-1}	SuperU®
Novelty	3/5/2024	18 lbs N ac^{-1}; 60 lbs P ac^{-1}; 80 lbs K ac^{-1}; 15 lbs S ac^{-1}	MES-10 in combination with KCl
	3/19/2024	178 lbs N ac^{-1}	Anhydrous ammonia
Portageville		60 lbs N ac^{-1}	SuperU®
Spickard	6/12/2024:	60 lbs N ac^{-1}	SuperU®

Note: SuperU: 45.5% Urea Nitrogen and 0.5% Other Water Soluble Nitrogen; MES-10: MicroEssentials S10: 12-40-0-10S; Anhydrous Ammonia: 82% N (82-0-0); KCl: 50-52% K

Table 3. Weed management for the industrial hemp field trials in 2024.

Timing	Albany	Columbia	Novelty	Portageville	Spickard
PPI (Preplant incorporated)	5/30/24: Trifluralin @1 lb ai ac^{-1}	Trifluralin @ 1 lb ai ac^{-1}	5/21/24: Trifluralin @ 1 lb ai ac^{-1} (Applied twice)	Trifluralin @1 lb ai ac^{-1}	5/30/24: Trifluralin @1 lb ai ac^{-1}
Post-emergence	7/3/24: Cultivated 7/11/24: Manual weeding	None	06/4/24: S-Metolachlor @ 1.51 lbs ai ac^{-1} 6/10/24: Cultivated 6/6/24 and 6/25/24: Hand weeding	None	None

Note: Trifluralin: α, α, α-trifluoro-2,6-dinitro-N, N-dipropyl-p-toluidine; S-Metolachlor: 2-chloro-N-(2-ethyl-6-methylphenyl)-N-[(1S)-2-methoxy-1-methylethyl] acetamide

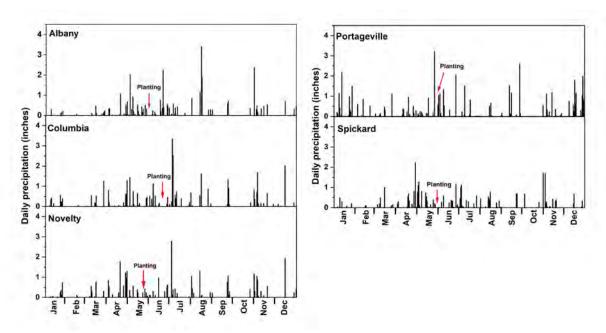**Figure 1.** Daily precipitation in 2024 at all five locations. Planting dates are denoted by red arrows.
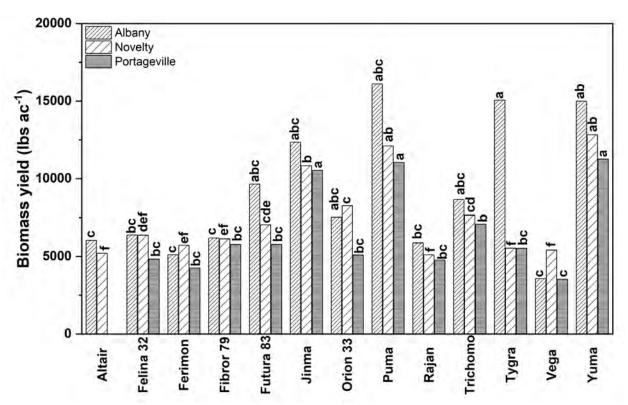
Figure 2. Biomass production by different industrial hemp varieties at three locations in 2024. Mean separation was evaluated separately at each location. Within a location, bars with similar letters indicate no significant differences between means at p <0.05.
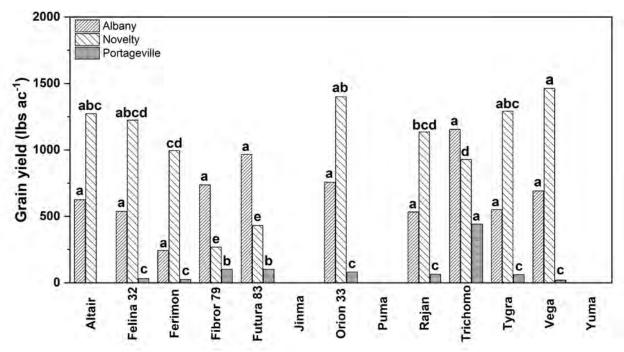

Figure 3. Grain yield production by different industrial hemp varieties at three locations iin 2024. Mean separation was evaluated separately at each location. Within a location, bars with similar letters indicate no significant differences between means at p <0.05.

INDUSTRIAL HEMP RESPONSE TO NITROGEN APPLICATIONS IN MISSOURI

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INTRODUCTION

Industrial hemp (*Cannabis sativa L.*) is gaining renewed interest in Missouri as a high-value specialty crop cultivated for fiber, grain, and/or cannabidiol (CBD) production (Adesina et al., 2020). 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 industrial hemp from the list of controlled substances and defined legal industrial hemp as containing no more than 0.3% delta-9 tetrahydrocannabinol (THC). Despite this progress, hemp cultivation remains closely regulated by the U.S. Drug Enforcement Administration (DEA) to ensure compliance with federal standards (Yano, 2023).

In Missouri, the passage of Senate Bill 133 on June 24, 2019, allowed institutions of higher education to conduct research on the growth, management, and marketing of industrial hemp (Falkner et al., 2023). Although Missouri has a long history of industrial hemp production dating back to 1835 (USDA, 1914), decades of inactivity have led to major gaps in agronomic knowledge, particularly regarding soil fertility and nutrient management.

Nitrogen (N) is a critical nutrient influencing plant growth, biomass production, and grain yield (Kakabouki et al., 2021; Papastylianou et al., 2018). However, limited data exist on the nitrogen requirements of industrial hemp under Missouri's diverse soil and climatic conditions. Therefore, research was needed to evaluate cultivar performance and determine optimal nitrogen application rates across different regions of the state. This will help in developing recommendations for growers, improving crop productivity, and promoting efficiency as well as sustainable nutrient use.

OBJECTIVES

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

PROCEDURES

Field experiments were conducted in 2024 at two locations in Missouri, including the Lee Greenley Jr. Memorial Research Farm near Novelty and the 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 ft at each location. SuperU$^{®}$ was used as an 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 Albany and 20 lbs ac^{-1} at Novelty. The planting and harvesting dates are provided in Table 1. The weed management details are provided in Table 2.

Soil samples were collected from 0-6- and 7-12-inch soil depths before planting and post-harvest and analyzed for soil fertility parameters. 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 the means were separated by least square difference (LSD) at alpha = 0.05.

RESULTS

The initial soil properties at two different depths for both locations are provided in Table 3. At Novelty, stem diameter was significantly influenced by variety (Figure 1A) and nitrogen fertilization (Figure 1B). There was significant interaction between the two factors. This indicates that the stem diameter varies across nitrogen levels within different varieties. The largest stem diameter was recorded in Yuma at 160 lbs N ac^{-1} which was statistically similar to Yuma at 120 lbs and Puma at 160 lbs N ac^{-1}. Plant height at Novelty was also significantly affected by both variety (Figure 2A) and nitrogen amounts (Figure 2A). Taller plants were observed at higher nitrogen rates (120 and 160 lbs ac^{-1}). Biomass production at Novelty responded to both variety and nitrogen treatments. The maximum yield observed was at 120 lbs N ac^{-1} which was significantly higher than the yields from other nitrogen levels (Figures 3 A&B). Puma produced the highest biomass among all varieties. The response curve for biomass yield of dual-purpose varieties is shown in Figure 4. An agronomically optimum nitrogen rate (AONR) of 94 lbs N ac^{-1} was observed for the dual-purpose varieties producing a biomass yield of 7051 lbs ac^{-1} (Figure 4A). For the fiber varieties, an AONR of 38 lbs N ac^{-1} produced 10,640 lbs ac^{-1} of biomass (Figure 4B). Grain yield at Novelty was significantly influenced by nitrogen, with a notable variety by nitrogen interaction. The highest grain yield was recorded with Futura 83 at 120 lbs N ac^{-1} (Figure 5A).

At Albany, stem diameter showed significant variation across varieties, but it was not clearly associated with nitrogen application, suggesting that variety played a stronger role at that site (Figure 1A). Plant height at Albany varied among varieties, with Puma consistently producing taller plants (Figure 2A). At Albany, biomass also varied by variety, with Puma having the greatest yield (Figure 3A). Grain yield at Albany was primarily affected by variety, with Futura 83 achieving the highest yield (1928 lbs ac^{-1}) (Figure 5A). The response curve for grain yield of dual-purpose varieties is shown in Figure 6. At an AONR of 147.5 lbs N ac^{-1}, the dual-purpose varieties produced 28 bu ac^{-1} of grain yield (Figure 6).

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Yano, H., & Fu, W. (2023). Hemp: A Sustainable Plant with High Industrial Value in Food Processing. Foods, 12(3), 651. https://doi.org/10.3390/foods12030651

Table 1. Planting, re-planting, and harvesting dates in 2024.

Location	Planting date	Re-plant date	Harvest date(s)
Albany	5/30/2024	6/18/2024	9/17/2024
Novelty	5/23/2024	------------	9/5/2024; 9/12/2024

Table 2. Weed management for nitrogen trials at Albany and Novelty in 2024.

Timing	Albany	Novelty
Preplant Incorporated	5/30/2024: Trifluralin @ 1 lb ai ac^{-1}	5/21/2024: Trifluralin @ 1 lbs ai ac^{-1}
Post-emergence	7/1/2024, 7/11/2024, 7/22/2024, 8/8/2024: Hand weeding	6/4/2024: *S*-metolachlor @ 1.51 lbs ai ac^{-1} 6/20/2024: Cultivated 6/26/2024: Hand weeding

Note: Trifluralin: α, α, α-trifluoro-2,6-dinitro-N, N-dipropyl-p-toluidine; *S*-metolachlor: 2-chloro-N-(2-ethyl-6-methylphenyl)-N-[(1S)-2-methoxy-1-methylethyl] acetamide.

Table 3. Initial soil parameters at Novelty and Albany in 2024.

| Soil Parameter	Novelty		Albany	
	0-6 in	6-12 in	0-6 in	6-12 in
Total Exchange Capacity (meq/100g)	20.8 ± 2.8	25.0 ± 6.3	23.4 ± 1.8	24.3 ± 2.4
pH	6.0 ± 0.2	5.5 ± 0.3	6.5 ± 0.3	6.2 ± 0.3
Organic Matter (%)	3.7 ± 0.4	3.1 ± 0.4	4.2 ± 0.3	3.3 ± 0.3
Estimated N Release (lbs N ac^{-1})	87.3 ± 4.1	79.3 ± 6.8	92.7 ± 3	83.03 ± 3.3
S (ppm)	12.2 ± 1.3	14.9 ± 2.5	10.3 ± 0.7	10.0 ± 0.8
P (ppm)	31.5 ± 10.2	11.5 ± 3.5	102 ± 37	73.5 ± 31
Ca (ppm)	2754.8 ± 292	2538.7 ±506	3284.1± 261	3101.2 ± 242
Mg (ppm)	214.8 ±39	255.7 ± 76	333.5 ± 29	430.7 ± 69
K (ppm)	188.9 ± 37	104.6 ± 23	438.1 ± 121	241.8 ± 83
Bray I P (ppm)	20.7 ± 8	4.1 ± 2.8	75.1 ± 30.2	52.9 ± 24
Na (ppm)	24.3 ±4.5	36.5 ± 8	11.5 ± 1.7	13.7 ± 3.9
Fe (ppm)	206.4 ± 42	133.1 ± 38	307.6 ± 40	275.4 ± 44
Mn (ppm)	57.5 ± 15	24.1 ± 11	52.2 ± 5.8	31.8 ± 6.6
Cu (ppm)	1.5 ± 0.8	1.18 ± 0.4	2.3 ± 0.3	2.4 ± 0.6
Al (ppm)	812.8 ± 108	1170.7 ± 129	548.0 ± 68	701.2 ± 106
B (ppm)	0.4 ± 0.1	0.3 ± 0.2	0.7 ± 0.1	0.7 ± 0.1
Zn (ppm)	1.7 ± 0.4	0.7 ± 0.2	9.7 ± 2.9	4.7 ± 2.3
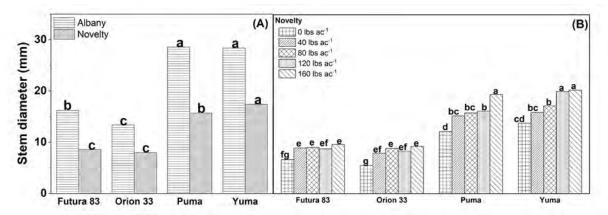
Figure 1. Stem diameter as affected by industrial hemp varieties at Albany and Novelty (A), and N application rates at Novelty (B) in 2024. Within a location, bars with similar letters indicate no significant differences between means at $p < 0.05$.
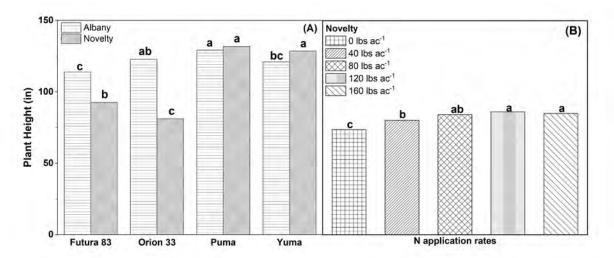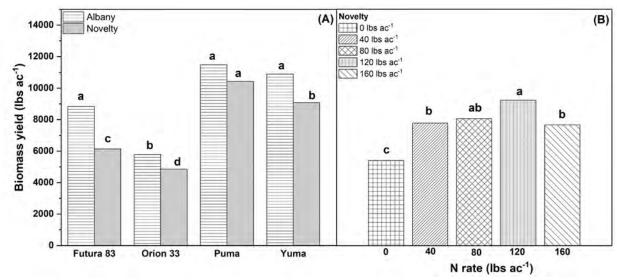

Figure 2. Plant height as affected by industrial hemp varieties at Albany and Novelty (A), and N application rates at Novelty (B) in 2024. Within a location, bars with similar letters indicate no significant differences between means at $p < 0.05$.

Figure 3. Aboveground biomass yield as affected by industrial hemp varieties at Albany and Novelty (A), and N application rates at Novelty (B) in 2024. Within a location, bars with similar letters indicate no significant differences between means at p <0.05.
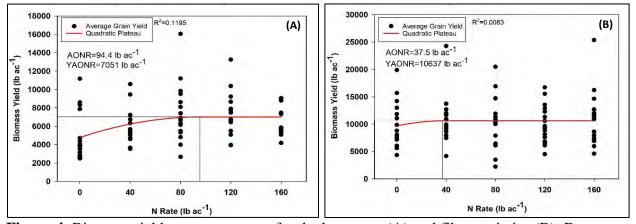

Figure 4. Biomass yield response curves for dual-purpose (A) and fiber varieties (B). Data were averaged over the locations in 2024.
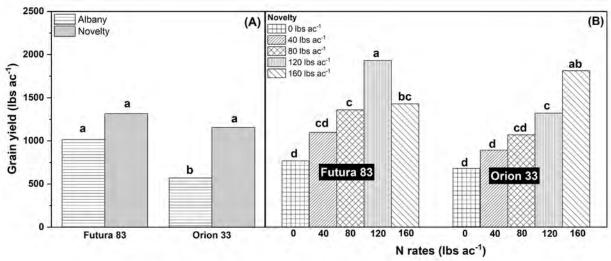
Figure 5. Grain yield as affected by industrial hemp varieties at Albany and Novelty (A), and N application rates at Novelty (B) in 2024. Within a location, bars with similar letters indicate no significant differences between means at p <0.05.
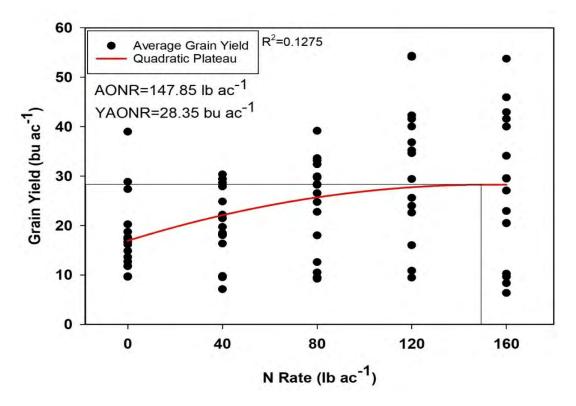

Figure 6. Grain yield response curve for dual-purpose varieties. Data were averaged over both locations.

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

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INTRODUCTION

Grain sorghum (*Sorghum bicolor*) 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. A substantial portion of the cost associated with conventional grain production is mechanical harvest, trucking, and storage costs. Utilizing livestock to harvest grain sorghum has the potential to reduce expenses and increase the 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 lower plant leaves with solar radiation energy (Deichman et al., 2014; Nelson, 2014). This lower plant leaf saturation potentially allows increased individual plant performance at lower seeding rates. By transitioning to an SCCS, grain sorghum was grown in 60-inch rows to allow planting using 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 this cropping system. 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).

OBJECTIVE

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

PROCEDURES

Field trials were conducted in 2024 and 2025 to evaluate the SCCS effectiveness using grain sorghum and legume intercrops (Figures 1 & 2). This research was conducted at the University of Missouri's Bradford Research Farm near Columbia, Missouri (38.9° N, 92.2° W). The study design was a randomized complete block with four replications. Grain sorghum, Pioneer 85P75',

was planted no-till at 60,000 seeds ac^{-1} in 60-inch wide-row plots and at 120,000 seeds ac^{-1} in 30-inch row plots on 7 June 2024, and 22 May 2025. The legume intercrop cultivars for cowpea and forage soybean were 'California' and 'Laredo', respectively. The cowpea and forage soybean were no-till planted at 139,000 seeds ac^{-1}. The replicated design is summarized in Figure 1. Soil samples were collected and analyzed at the University of Missouri soil testing lab (Columbia, MO). Fertilizer recommendations for phosphorus and potassium were based on a 120 bu ac^{-1} yield goal. Nitrogen was broadcast applied at 100 lbs N ac^{-1} as SuperU (Koch Agronomic Services, Wichita, KS).

Weed control included a preemergent herbicide application of S-metolachlor (Dual II Magnum, Syngenta, Greensboro, NC) at 1.3 pt ac^{-1}, which was followed by a postemergence application of bentazon (Basagran, Winfield, St. Paul, MN) at 1.5 pt ac^{-1}. Sorghum, intercrops, and annual weeds were harvested from 3 by 5 ft quadrats, and dry weights were determined. Plots were harvested monthly from early fall through winter. Annual weeds were collected to determine weed control differences among treatments and biomass contribution toward grazing.

RESULTS

Grain sorghum planted in 30-inch-wide rows yielded 29 to 50 bu ac^{-1} higher than all other treatments (Figure 3). The addition of a cowpea or soybean intercrop in 60-inch rows reduced grain sorghum yield (P=0.10) 18 and 21 bu ac^{-1}, respectively, due to interference with the sorghum crop. Increased weed interference occurred in plots utilizing wide rows and/or intercrops. This contributed to the inability to use standard weed management practices such as atrazine in an intercropping situation with grain sorghum, along with the lack of canopy closure with wide-row (60-inch) sorghum (visual observation).

The highest biomass yields were observed in September and October, with a steady decline of 112 to 11,706 lbs ac^{-1} as the year progressed (Figure 4). Recoverable biomass in the absence of grazing was reduced to 60% from September to February harvest. A significant loss of grain sorghum biomass occurred in plots from seed predation by birds in later months (visual observation). The wide-row (60-inch) SCCS sorghum biomass yield was 25 to 36% less than 30-inch-wide rows from September to December. All treatments with sorghum generally had biomass yields greater than the legume monoculture. Weeds contributed a minimal amount of total biomass to 30-inch wide-row grain sorghum, while weed biomass totaled 10 to 71% of the biomass in the other cropping systems. The primary weed species present were fall panicum and large crabgrass.

RECOMMENDATIONS

After one year of research, grain sorghum in a 30-inch row spacing had the highest grain and biomass yield with the lowest weed interference. The use of intercrops with grain sorghum limits available herbicide options to control weeds. Wide (60-inch row spacing) rows allowed more sunlight to reach the soil surface, which resulted in greater weed growth compared to narrow (30-inch) row spacing. If farmers are grazing these cropping systems, consider grazing earlier than later to capture more available feed biomass, which would allow greater recovery of biomass production. This research is ongoing, and more conclusive recommendations will be made when the second year (2025-2026) and an economic analysis is completed.

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Treat 1   Treat 2   Treat 3   Treat 4   Treat 5   Treat 6

Figure 1. Plant arrangement of grain sorghum (l) in 30- and 60-inch rows, solar corridor (X), and intercrop monoculture (Y = cowpea or soybean) rows in one replication of the field trial. Treatment 2 is wide-row (60-inch) sorghum with no intercrop. Treatments 3 and 4 are wide-row (60-inch) sorghum with cowpea and soybean intercrop.

Figure 2. Grain sorghum in September (University of Missouri Bradford Research Farm) with a 60-inch row spacing and soybean intercrop.
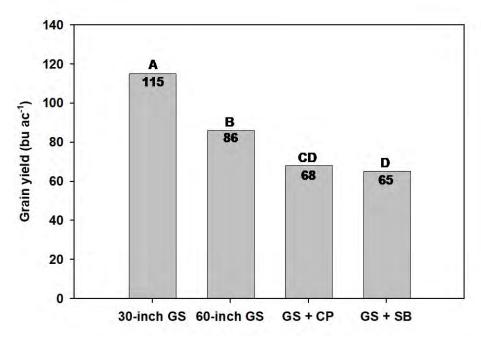
Figure 3. Grain sorghum (GS) grain yield by row spacing (30-inch, 60-inch). Grain sorghum was planted in 60-inch wide rows with a cowpea (+ CP) or soybean (+ SB) intercrop in 2024. Letters above bars represent significant differences among treatments using Fisher's protected LSD (*P*=0.10).
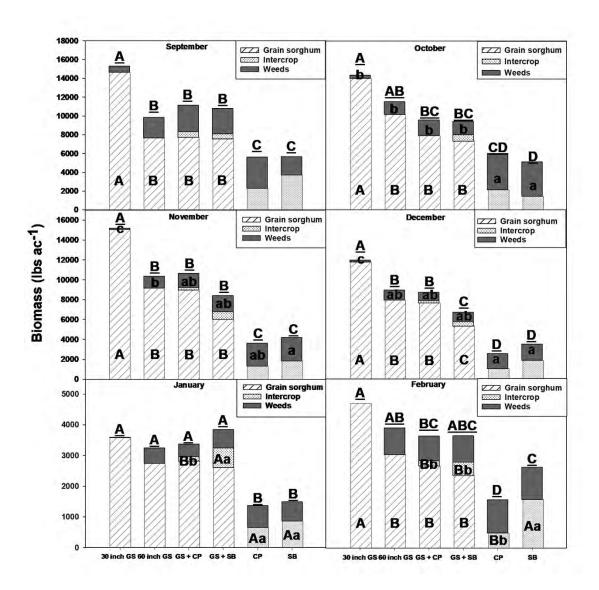
Figure 4. Grain sorghum (GS), intercrop [cowpea (CP) or soybean (SB)], and weed biomass from September 2024 to February 2025. Comparisons within a biomass type are valid within each sampling date. Letters [upper case (grain sorghum), lower case (weeds), or a combination of upper and lower case (intercrop)] within the bars indicate significant differences for individual forage biomass values within each sampling period. Underlined letters represent significant differences in total biomass, and comparisons within a sampling date are valid. Statistical differences were calculated using Fisher's Protected LSD (*P*=0.05).

SORGHUM SUDANGRASS FOR WINTER GRAZING

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INTRODUCTION

Warm-season annual grasses are very productive and are suitable for stored forage and summertime grazing. Sorghum x sudangrass is the most common warm-season annual. These grasses grow quickly, usually 1-2 inches per day, and can produce as much as 8 tons of good-quality forage in a single year. They are also more tolerant to drought and lower soil fertility compared to corn, and sorghum x sudangrass is very responsive to good management practices and improved fertility.

Conventional hybrids are characterized by upright growth, narrow leaves, and lignified stems. Maturity is typically reached early in the growing season (~50 days after emergence), limiting harvest flexibility. Yield production on these varieties is typically high, but quality can suffer, especially if harvest is delayed. Increasing seeding rates is usually recommended to improve the quality by reducing stem size.

The brown midrib (BMR) trait is a mutant gene that reduces the lignin in the plant. The different strains of this mutation are BMR -2, -6, -12, and -18. BMR-6 is the most prevalent and generally exhibits the greatest reduction in lignin, improving dry matter digestibility. Hybrids with this trait have a distinct brown color along the midrib of the leaves and in the stems.

The brachytic dwarf trait shortens the internodes of the plant. This substantially improves the leaf-to-stem ratio and reduces lodging. Brachytic dwarf hybrids are typically higher in quality but may have lower yields due to reduced stem mass.

Traditionally, these grasses have been grown for hay, baleage, or summer grazing. However, there is a growing interest in these grasses as a stockpiled forage. Lack of fall rains for fescue stockpile growth in the past few years has made stockpiling difficult. The shift to warm-season stockpile that depends on spring and summer rains could be an effective alternative to stockpiling cool-season grasses. There is little information available to aid in understanding the implications of this practice. Furthermore, the genetic differences of improved varieties may perform differently in a stockpiled situation.

OBJECTIVE

Our objective was to determine the effectiveness of sorghum x sudangrass as a stockpiled forage.

PROCEDURES

A study is being conducted at the Cornett farm in 2024-2025 near Linneus, MO, to assess the different stockpiling abilities of sorghum x sudangrass hybrids. The predominant soil type was Armstrong Loam (Fine, smectitic, mesic Aquertic Hapludalfs). Treatments were arranged in a randomized complete block design with four replications. Plots were 20 by 100 ft. Treatments were sown into a disked seedbed following cereal rye on June 12, 2024, with a 10-ft no-till drill. The treatments were nine different hybrids and varieties of SxS. Mid-summer forage was harvested for hay.

Forage quality and yield measurements were collected on 21 November 2024, 23 December 2024, and 22 January 2025. Plots were harvested at a 4-inch stubble height using a self-propelled forage harvester (HEGE 212, Wintersteiger AG). Grab samples were collected after each

plot was harvested for forage quality analysis. Dried samples were ground to ultimately pass through a 1 mm screen. Forage quality was estimated using a near-infrared reflectance spectrophotometer (Pheonix 5000 NIR Forage Analyzer, Blue Sun Scientific, Jessup, MD) at the Cornett Farm forage lab. The samples were analyzed using equations developed by the NIRS Consortium. The samples were analyzed using grass hay calibrations (24GH50.eqa) developed by the NIRS Consortium (Hillsboro, WI, February 2020) for alfalfa, oat, and weed components, respectively. Constituents evaluated for each component were crude protein (CP), and vitro true dry matter digestibility at 30 h (IVTDMD30).

Data were analyzed using the lmer function in the lme4-R package (Bates et al., 2015) of R (R Core Team, 2025). The dependent variables were yield, CP, and IVDMD30. The three harvest dates were considered repeated measures, and the block was considered random.

RESULTS

Forage yield varied by hybrid and harvest date but not by their interaction. The lack of interaction shows that all hybrids declined in yield throughout the winter at about the same rate. Yields were reduced by 50% between the December and January harvest dates (Figure 1). Yield also fell by 12% between November and December. Because of this, it would be recommended to graze stockpiled SxS earlier in the winter rather than later to capture the most yield. The brachytic dwarf trait was the main predictor of yield among the hybrids (Figure 2). Hybrids with this trait produced less yield than the others. However, this may not always be true. The hybrid 1531 (Croplan) was among the highest-yielding hybrids.

Crude protein varied by hybrid and harvest date but not by their interaction. Crude protein of the harvested forage increased throughout the winter (Figure 3). This is likely due to lodging such that the harvester was not able to pick up the stems. Crude protein varied among the hybrids, with the brachytic dwarf hybrids containing substantially more CP (7.8%) than the other BMR hybrids (6.2%; Figure 4). The conventional hybrid contained the lowest CP (4.7%).

IVTDMD30 varied by hybrid, harvest date, and their interaction. In general, the brachytic dwarf hybrids had higher IVTDMD30 and maintained it better throughout the season (Figure 5). All hybrids declined in digestibility between November and December, but only certain hybrids declined in digestibility between December and January.

The quality of the plant parts is a contributing factor in the variation in quality. A brachytic dwarf hybrid had a higher percentage of leaves (43%) than a conventional hybrid (19%; Figure 6). Crude protein was substantially higher in both CP and IVTDMD30 in both hybrids (Figures 7&8).

CONCLUSIONS

Sorghum-sudangrass can be effectively stockpiled for winter grazing. When utilizing SxS for stockpile, it is best to graze it early in the winter season, saving other stockpile forages like tall fescue for late winter grazing. Supplemental protein or energy may not be necessary if the hybrid has the brachytic dwarf trait. Forage sampling is necessary to determine if a protein supplement is needed. Hybrid selection is important for maximum production and quality; improved hybrids consistently outperform conventional types. Hybrids should be tried at the farm level to identify specific hybrids that perform best in each context.
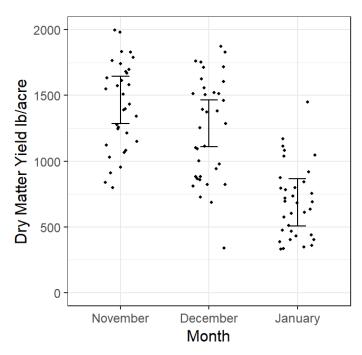
Figure 1. Dry matter yield of sorghum-sudangrass with a 95% confidence interval around the mean during the three winter months at the Cornett Farm near Linneus, MO.
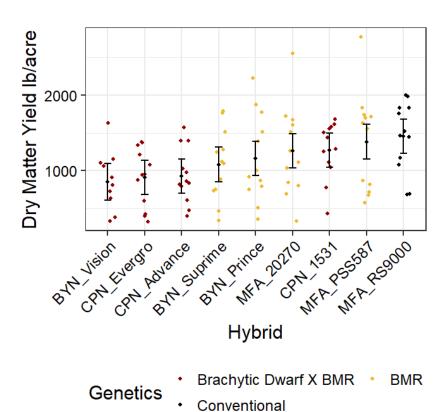

Figure 2. Dry matter yield of stockpiled sorghum-sudangrass hybrids with a 95% confidence interval around the mean at the Cornett Farm near Linneus, MO.
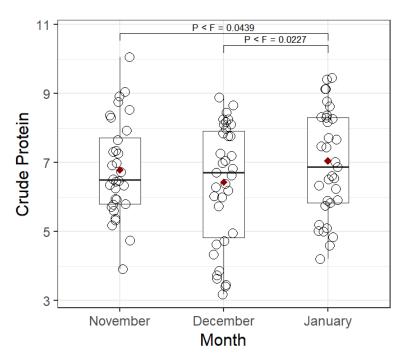
Figure 3. Crude protein of stockpiled sorghum-sudangrass hybrids for three winter months at the Cornett Farm near Linneus, MO.
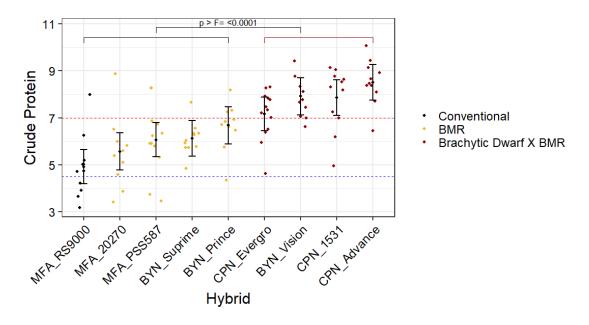

Figure 4. Crude protein of stockpiled sorghum-sudangrass hybrids with a 95% confidence interval around the mean at the Cornett Farm near Linneus, MO. The red line represents the requirement for dry, pregnant cattle, and the blue line represents the average for corn stalks.

Figure 5. In-vitro true dry matter digestibility at 30 hours (IVTDMD30) of stockpiled sorghum-sudangrass hybrids at the Cornett Farm near Linneus, MO. The blue line represents the average for corn stalks.

Figure 6. Dry matter percentage of leaves and stems of stockpiled sorghum-sudangrass Cornett Farm near Linneus, MO.

Figure 7. Crude protein of leaves and stems of stockpiled sorghum-sudangrass at the Cornett Farm near Linneus, MO.
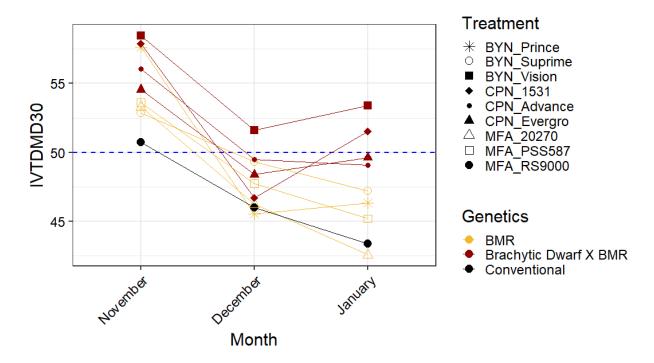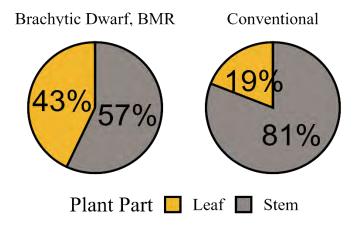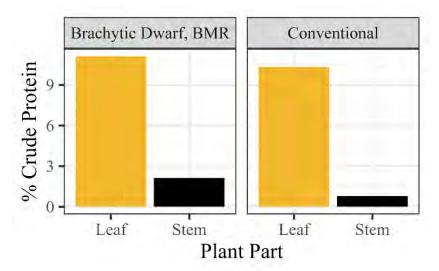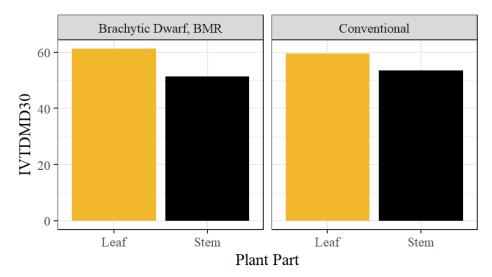

Figure 8. In-vitro true dry matter digestibility at 30 hours (IVTDMD30) of leaves and stems of stockpiled sorghum-sudangrass at the Cornett Farm near Linneus, MO.

EVALUATING THE OPTIMAL TIMEPOINT FOR ARTIFICIAL INSEMINATION RELATIVE TO ESTRUS ONSET WHEN USING SEX-SORTED SEMEN

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INTRODUCTION

Many factors influence pregnancy rate to artificial insemination (P/AI), including the time at which AI is performed relative to the time at which ovulation occurs (or as a proxy, the time at which expression of estrus occurred). Early research in this area, conducted by Trimberger & Davis (1943) and Trimberger (1948), determined that P/AI in dairy cattle is maximized when AI is performed during midstrus or a few hours after the end of behavioral estrus. This work led to the development of the AM-PM rule, in which cattle are bred 12-18 h following observed estrus (Trimberger & Davis, 1943; Trimberger, 1948). More recently, research has indicated that timing of AI impacts both fertilization rate and embryo quality (Dransfield et al., 1998; Saacke et al., 2000; Dalton et al., 2001a; Dalton et al., 2001b; Saacke, 2008). This research indicates that insemination too early relative to the time of ovulation results in high embryo quality but may reduce fertilization rates due to lower numbers of viable sperm present at the time of ovulation. Conversely, insemination too late relative to the time of ovulation results in a high fertilization rate by ensuring sufficient numbers of available sperm cells, but may lead to reduced embryo quality as the oocyte ages before fertilization.

The optimal timing of insemination with sex-sorted semen may differ from conventional recommendations due to the reduced lifespan of sex-sorted sperm cells in the female reproductive tract (Maxwell et al., 2004), fewer sperm cells per insemination (DeJarnette et al., 2008), and increased incidence of precapacitation (Lu & Seidel, 2004). These factors may narrow the window of fertility with regard to the timing of insemination relative to ovulation (Sales et al., 2011; Bombardelli et al., 2016). Research in this area has explored this concept with regard to timing of ovulation and within FTAI protocols. The data obtained from these studies suggest that pregnancy rates to AI with sex-sorted semen are improved when animals are inseminated closer to the time of ovulation (Sales et al., 2011; Bombardelli et al., 2016). However, results have been mixed when delaying timing of FTAI with sex-sorted semen until later than typically recommended when using conventional semen. Some experiments have suggested modest improvements in P/AI with sex-sorted semen when timed AI is delayed (Sales et al., 2011; Oosthuizen et al., 2021) whereas others have observed no improvement (Hall et al., 2017; Drake et al., 2020; Ketchum et al., 2021; Oosthuizen et al., 2021). The following experiments were developed with these considerations in mind, to evaluate optimal timing of AI relative to estrus onset when using sex-sorted semen, using the CowManager system to determine onset of estrus expression.

OBJECTIVES

Objective 1: Determine the optimal timing of artificial insemination (AI) relative to estrus onset when using sex-sorted semen following the 14 d CIDR-PG protocol in heifers and 7 & 7 Synch in cows.

Objective 2: Use data collected from this experiment to create a model to predict anticipated conception rates to AI at various fixed-time AI timepoints when using sex-sorted semen following a 14 d CIDR-PG in heifers and 7 & 7 Synch in cows.

PROCEDURES

Experiment 1: Among beef heifers, estrus was synchronized using the 14 d CIDR-PG protocol (Figure 1): insertion of an intravaginal progesterone-releasing insert (CIDR; 1.38 g progesterone) on Day -34 and removal on Day -20, and administration of prostaglandin F$_{2\alpha}$ (PG; 25 mg dinoprost) on Day -4. CowManager tags were inserted and the system activated on Day -27 of the protocol to ensure adequate data collection when heifers were not in estrus. The CowManager System was used to determine if and when heifers expressed estrus following CIDR removal on Day -20 and PG administration on Day -4. Heifers were inseminated based on a split-time AI schedule, with all heifers having expressed estrus by 44 h inseminated at that time and all remaining heifers inseminated at 76 h. Heifers that failed to express estrus by 76 h were administered gonadotropin-releasing hormone (GnRH; 100 µg gonadorelin). This schedule allowed for variation in timing of AI relative to estrus onset. All heifers that expressed estrus received sex-sorted semen, and the remaining received conventional semen collected from the same sire. Heifers were introduced to natural service sires starting 14 days after AI, and pregnancy diagnosis was performed via transrectal ultrasonography 75 days following AI.

Data collected regarding onset of estrus relative to timing of AI will be used to evaluate how the interval from estrus onset to AI affects conception rates to AI when using sex-sorted semen following the 14 d CIDR-PG protocol. This data will further be used to develop a model to predict conception rates to AI with sex-sorted semen based on when fixed-time or split-time AI is performed.

Experiment 2: Among beef cows, estrus was synchronized using 7 & 7 Synch (Figure 2): administration of PG (PG; 500 µg cloprostenol sodium) coincident with CIDR insertion on Day -17, gonadotropin-releasing hormone (GnRH; 100 µg gonadorelin) on Day -10, and PG coincident with CIDR removal on Day -3. CowManager tags were inserted and the system activated on Day -17 of the protocol to ensure adequate data collection when cows are not in estrus. The CowManager System was used to determine if and when cows expressed estrus following CIDR removal and PG administration on Day -3. Cow cyclicity status was determined on D -17 by transrectal ovarian ultrasonography and based on ovarian structures present, cows were characterized as deep anestrous (no corpus luteum; CL, follicles present are less than 10 mm in diameter), superficial anestrous (no CL, follicle present that is greater than or equal to 10 mm in diameter) or cycling (CL present). Cows were blocked by cyclicity status and preassigned to receive sex-sorted or conventional semen. On Day -3, transrectal ovarian ultrasonography was performed to determine CL status and measure the largest follicle diameter (LFD). This data will be used to determine if cows that do not have a CL present at the time of PG administration express estrus earlier following PG administration and/or have reduced fertility compared to cows that have a CL present at the time of PG administration.

Data collected regarding the onset of estrus relative to the timing of AI will be used to

determine an optimal time point for AI when using sex-sorted semen in cows following a 7 & 7 Synch. This will further be used to develop a model to predict conception rates to AI with sex-sorted semen based on when fixed-time AI is performed.

RESULTS
Experiment 1: Estrous response of heifers treated with the 14 d CIDR-PG estrus synchronization protocol was 86% [55/64] by 76 h after PG administration. Overall pregnancy rate to AI among heifers was 64% [41/64]. Pregnancy rates to AI among heifers that received sex-sorted semen and conventional semen were 64% [34/53] and 64% [7/11], respectively. Pregnancy rates from an additional location will be collected this summer, with further evaluation of pregnancy rate to AI based on the interval from estrus onset to AI when using both sex-sorted and conventional semen.

Experiment 2: Overall estrous response of cows treated with 7 & 7 Synch was 94% [203/216] by 90 h after CIDR removal. Pregnancy rate to AI (Figure 3) among cows receiving sex-sorted and conventional semen was 75% [111/149] and 61% [131/216], respectively. Pregnancy rates from an additional location will be collected this summer, with further evaluation of pregnancy rate to AI based on the interval from estrus onset to AI when using both sex-sorted and conventional semen.

RECOMMENDATIONS
Until pregnancy checks are completed and data are analyzed, a recommendation on optimal timing of AI based on estrus expression when using sex-sorted semen cannot be made from this research. Recommendations can be made based on previous research conducted in our lab regarding the use of sex-sorted semen.

Generally, the use of sex-sorted semen is not recommended for use in fixed-time AI protocols due to reduced pregnancy rates, especially among females that fail to express estrus. A management method used to address this challenge while maintaining the use of FTAI is limiting the use of sex-sorted semen to only cattle that express estrus by timed AI. This requires a means of determining estrous response so that all females that fail to express estrus are inseminated with conventional semen. This remains one of the most effective ways of managing the reduced P/AI associated with the use of sex-sorted semen.

Another way to improve pregnancy rate to FTAI is to increase the proportion of females that express estrus prior to AI. Split-time artificial insemination (STAI) was developed to increase the proportion of cattle expressing estrus prior to insemination following an estrus synchronization protocol. Cattle that express estrus by the standard FTAI timepoint are serviced at that time, and insemination of non-estrous females is delayed by 20 to 24 hours. This method increases the total proportion of females expressing estrus by the time of insemination and can improve the overall pregnancy rate to synchronized estrus when using sex-sorted or conventional semen.

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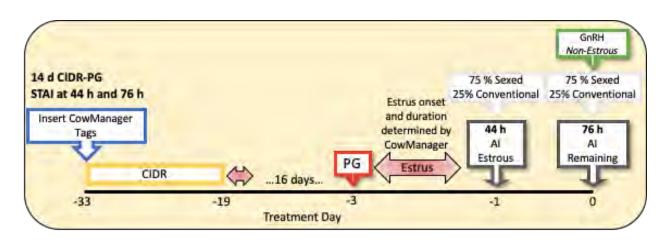
Figure 1. Experimental design for Experiment 1. Heifers were treated with the 14 d CIDR-PG estrus synchronization protocol and inseminated at 44 h or 76 h following PG administration based on timing of expression of estrus, determined by CowManager.

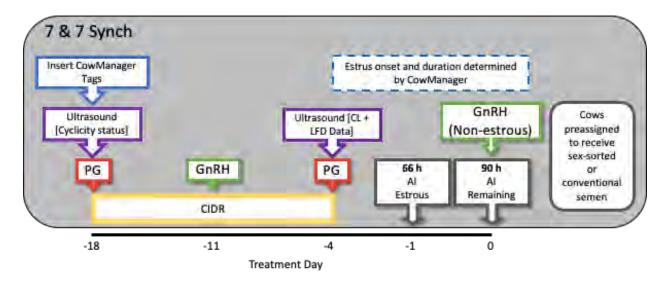**Figure 2.** Experimental design for Experiment 2. Cows were treated with 7 & 7 Synch and inseminated with sex-sorted or conventional semen at 66 h or 90 h based on the timing of expression of estrus, determined by CowManager.
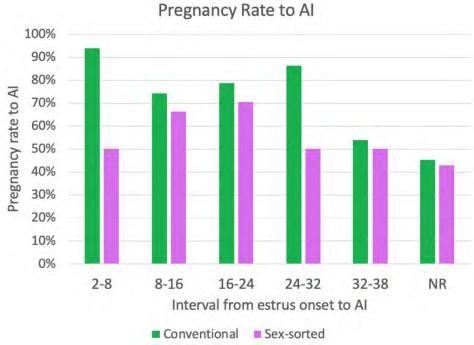

Figure 3. Pregnancy rate to AI among cows (n = 365) receiving conventional or sex-sorted semen by interval from estrus onset to AI, following 7 & 7 Synch.

MISSOURI MESONET

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Assistant Professor

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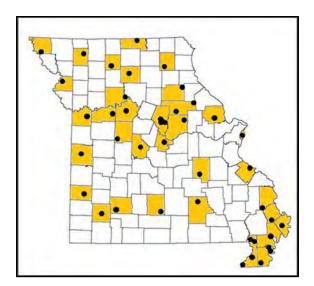
In 2010, the National Oceanic and Atmospheric Administration (NOAA) implemented a multi-state project in which metadata and near-real-time data were collected from various state mesonets, including the Missouri Mesonet, and used by NOAA to assess the quality of the network and improve forecasting ability.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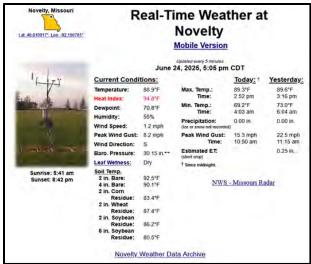
For access to the Missouri Mesonet, please visit:

mesonet.missouri.edu
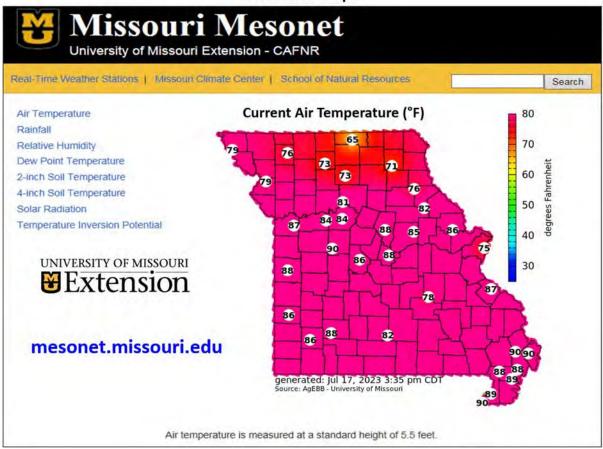
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Novelty, Missouri
Lat. 40.018917° Lon. -92.190781°

Mobile Version

Updated every 5 minutes
June 24, 2025, 5:05 pm CDT

Current Conditions:		Today: †	Yesterday:
Temperature:	88.9°F		
Heat Index:	94.0°F		
Dewpoint:	70.8°F		
Humidity:	58%		
Wind Speed:	1.2 mph		
Peak Wind Gust:	8.2 mph		
Wind Direction:	S		
Baro. Pressure:	30.15 in.↔		
Leaf Wetness:	Dry		

|	Today: †	Yesterday:
Max. Temp.:	89.3°F	89.6°F
Time:	2:52 pm	3:16 pm
Min. Temp.:	69.2°F	73.0°F
Time:	4:03 am	6:04 am
Precipitation: (ice or snow not recorded)	0.00 in.	0.00 in.
Peak Wind Gust:	15.3 mph	22.5 mph
Time:	10:50 am	11:15 am
Estimated ET: (short crop)		0.25 in.
† Since midnight.		

Sunrise: 5:41 am
Sunset: 8:42 pm

Soil Temp.
2 in. Bare: 92.5°F
4 in. Bare: 90.1°F
2 in. Corn Residue: 83.4°F
2 in. Wheat Residue: 87.4°F
2 in. Soybean Residue: 86.2°F
6 in. Soybean Residue: 80.5°F

NWS - Missouri Radar

Novelty Weather Data Archive

Real-time maps

Missouri Mesonet
University of Missouri Extension - CAFNR

Real-Time Weather Stations | Missouri Climate Center | School of Natural Resources | Search

Air Temperature
Rainfall
Relative Humidity
Dew Point Temperature
2-inch Soil Temperature
4-inch Soil Temperature
Solar Radiation
Temperature Inversion Potential

UNIVERSITY OF MISSOURI
Extension

mesonet.missouri.edu

Current Air Temperature (°F)

generated: Jul 17, 2023 3:35 pm CDT
Source: AgEBB - University of Missouri

Air temperature is measured at a standard height of 5.5 feet.

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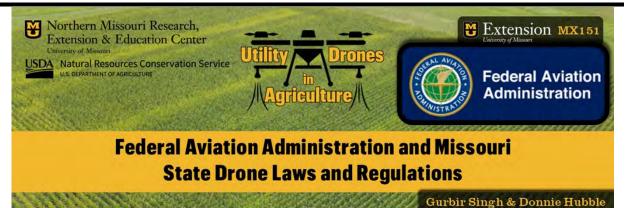- Planting Depth Soil Temperature
- Weed Scouting Aid
- Stored Grain Management Moisture Table
- Design Storm Report
- PRF Rainfall Index Monitor
- Insect Scouting Aids
- Fall Nitrogen Application Chart
- Rainfall Runoff Estimator
- Animal Comfort Indices

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

Northern Missouri Research, Extension & Education Center — University of Missouri

USDA Natural Resources Conservation Service — U.S. DEPARTMENT OF AGRICULTURE

Utility Drones in Agriculture

Extension MX151 — University of Missouri

Federal Aviation Administration

Federal Aviation Administration and Missouri State Drone Laws and Regulations

Gurbir Singh & Donnie Hubble

The use of unmanned aerial vehicles (UAVs) continues to rise on the farm and in commercial operations. Drone operators must understand the federal laws and regulations that govern their use.

FEDERAL AVIATION ADMINISTRATION (FAA) REGULATIONS

To obtain FAA compliance, every drone operator must obtain a remote pilot certification (Part 107).

Part 107 Certification Process:

- Be at least 16 years old
- Learn the rules
- Register your drone with the FAA
- Pass the knowledge test with at least 70%

For further information, study materials, and testing facilities visit faa.gov/uas/commercial_operators.

PART 137 EXEMPTION RULE

If an operator plans to spray or dispense a substance from a drone which falls within the definitions in Section 137.3 of the 14 CFR, you must receive an exemption by completing FAA Form 8710-3.

Part 137 Exemption Process (Refer to Certification Process for Agricultural Aircraft Operators):

- Petition for an exemption
- Submit basic operational information
- Complete FAA Form 8710-3
- Submit form to UAS137certificates@faa.gov

DRONE REGISTRATION

All UAVs over 0.55 lbs. must be registered by the owner (or owner's parent/guardian) with the FAA. Registration is $5/drone and is valid for 3 years. The registration number must be written on the drone.

- Registration information: faa.gov/uas/getting_started/register_drone
- Registration: faadronezone-access.faa.gov/#/register

DRONE OPERATING HOURS, ALTITUDE, AND SPEED

- No agricultural spraying or spreading at night
- Pilots can fly during daylight or in twilight
- Weather visibility: minimum of 3 miles
- Altitude: 400 feet above ground maximum
- Can fly higher if within 400 feet of a structure
- Speed: 100 mph maximum

AIRSPACE AUTHORIZATION

A drone operator must request authorization if flying within 5 miles of a controlled airport (Figure 1).

To request airspace authorization, a request can be submitted to:
faa.gov/uas/commercial_operators/part_107_airspace_authorizations

Figure 1. Airspace classification by the FAA and for a controlled airport (FAA's Pilot's Handbook of Aeronautical Knowledge).

MISSOURI STATE DRONE LAWS

UAV operators in Missouri are subject to FAA regulations and flight controls established by local city and state government authorities. Check with local authorities for city and county drone codes.

House Bill 1204

- UAVs cannot be used to gather evidence or other information pertaining to criminal conduct except to the extent authorized in a warrant.
- UAVs cannot be used to conduct surveillance or observation of an individual or property without the permission of that individual or property owner.

House Bill 1963

- Section 217.850 prohibits the use of drones near correctional and penal institutes.
- Section 577.800 prohibits the use of drones within 400 feet of altitude and property of an open-air facility including sports, theater, performing arts, or other entertainment facility with a capacity of five thousand people or more and not completely enclosed by a roof or other structure.

Drone remote pilot compliance requires:

- Remote pilot (part 107) certification
- Valid exemption part 137 if flying over 55 lbs.
- Airspace Certificate of Waiver or Authorization
- Agricultural Aircraft Operator Certificate
- State Pesticide Applicator License if applicable
- Insurance coverage per state's requirements

ACKNOWLEDGEMENTS

For further questions about utility drones in agriculture please contact
Dr. Gurbir Singh at gurbirsingh@missouri.edu.

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93

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USDA Natural Resources Conservation Service
U.S. DEPARTMENT OF AGRICULTURE

Utility Drones in Agriculture

Extension MX150
University of Missouri

Procedures for Drone Calibration and Worksheet for Evaluating Spreading Patterns

Gurbir Singh

WHAT'S NEEDED TO CALIBRATE A DRONE?

- Drone with calibration curve for selected seed
- Computer to plot spreading patterns
- Basic knowledge of Microsoft Excel
- Spread pattern test kit

- 200 lbs. of seed (Wheat in this example)
- Marking flags
- Measuring tape
- Weighing scale

WHAT'S THE DRONE CALIBRATION PROCESS?

1. Drone Set Up

- Set the flight height and speed constant (height to 10 ft above canopy, speed to 20 ft/sec).
- Set the spinner disk rotations to 1200 rpm.
- Set the drone to RTK mode.
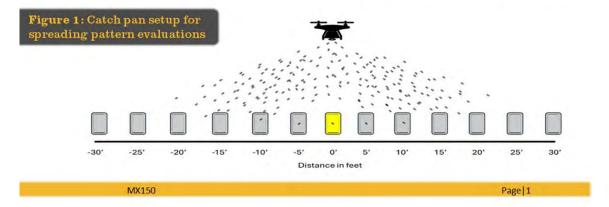
2. Set Catch Pans (Figure 1)

- Determine the zero-point (middle of the swath).
- Place pans at 5-foot distances extending 30 feet in both directions (60 foot swath).
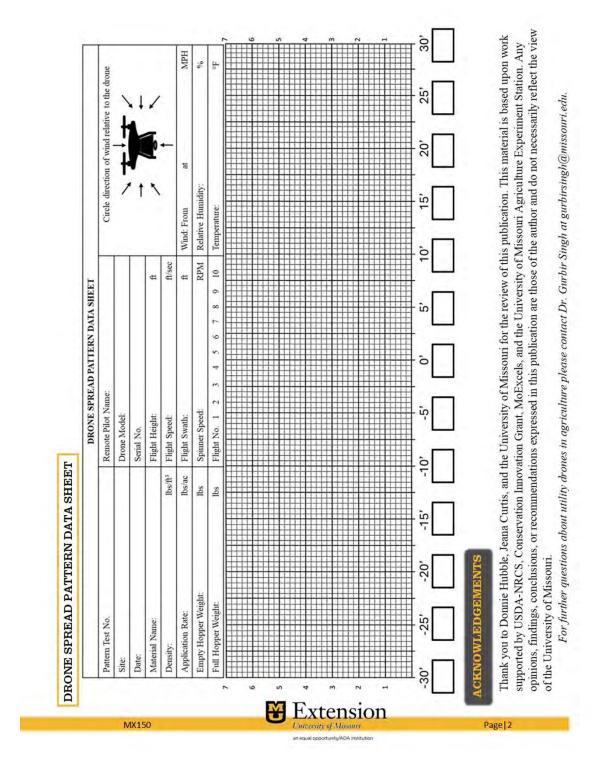- Secure the catch pans with anchors (long wire flags were used in this example).

3. Flight

- Fly the drone 10 times over the zero-point line (Yellow pan in Figure 1).

4. Collection and Analysis

- Gather seeds in the provided tubes and label them properly.
- On the attached worksheet, record the weight of each tube in the boxes provided.
- Plot on the graph to determine spreading pattern shape.
- Use the total number or weight of seeds captured to develop a distribution curve in Microsoft Excel.

Figure 1: Catch pan setup for spreading pattern evaluations

-30' -25' -20' -15' -10' -5' 0' 5' 10' 15' 20' 25' 30'

Distance in feet

DRONE SPREAD PATTERN DATA SHEET

DRONE SPREAD PATTERN DATA SHEET

Pattern Test No.		Remote Pilot Name:		Circle direction of wind relative to the drone
Site:		Drone Model:		
Date:		Serial No.		
Material Name:		Flight Height:	ft	
Density:	lbs/ft³	Flight Speed:	ft/sec	
Application Rate:	lbs/ac	Flight Swath:	ft	Wind: From ___ at ___ MPH
Empty Hopper Weight:	lbs	Spinner Speed:	RPM	Relative Humidity: ___ %
Full Hopper Weight:	lbs	Flight No. 1 2 3 4 5 6 7 8 9 10		Temperature: ___ °F

-30' -25' -20' -15' -10' -5' 0' -5' 0' 5' 10' 15' 20' 25' 30'

MX150

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Economics of Drone Ownership for Agricultural Spray Applications

The rapid development of drone technology offers significant potential for precision agriculture, allowing farmers to monitor crops and livestock; apply seed, fertilizers and pesticides; and assess land conditions with increased accuracy and efficiency. Though drones can provide substantial benefits in farm management, the question of whether owning drones is cost-effective compared to traditional methods — such as hiring airplanes, machinery or human labor — remains crucial for many farmers. This analysis estimates the costs of owning and operating an Agras T40 drone for spraying applications (Figure 1). This model can carry up to 10.6 gallons of spray and 110 pounds of spread load, a total of 18.5 gallons, allowing for spraying, spreading, surveying and mapping.

This guide focuses on determining whether the investment in drone technology offers a competitive edge in terms of cost and operational efficiency, and it introduces two tools developed to estimate the cost per acre of using drones for agricultural spray applications by farmers and custom operations. These tools identify the key cost components and analyze how they vary with drone usage (based on the number of acres treated annually) and interest rates.

Initial investment cost

Costs per acre for an application include ownership and operating costs. Ownership costs occur regardless of machine use and include depreciation, interest, taxes, insurance, and housing for the drone and additional equipment required. Operating costs vary directly with the use intensity, or acres applied per year, and include repair and maintenance, fuel, lubrication and labor costs.

To estimate all these cost components, assumptions must be made. Investment costs for the drone enterprise

Figure 1. T40 drones equipped with sprayers.

include the drone, batteries, a charger, a generator, and equipment to transport the mix to the field and load it into the drone. The ownership costs per acre include the costs of buying and owning these items, which include interest and depreciation. To estimate that, we assume the equipment prices, lifespan, maintenance and salvage value presented in Table 1.

Table 2 describes the additional assumptions adopted for the estimates of cost per acre presented in this guide.

Cost of owning drones for spray applications

The estimated costs per acre for the hypothetical farming and custom operations are presented in Table 3. The results show that the total cost per acre for drone applications, based on the assumptions in Tables 1 and 2, is $12.27 per acre for farmers and $7.39 per acre for custom operators. For comparison, custom hire rates for drone spray applications are typically around $16 per acre, and fungicide applications using crop dusters are about $12.50 per acre. These estimates suggest that, under the outlined assumptions, owning a drone may be a cost-effective option for a farm operation using drone application for at least 980 acres, and there is a competitive margin for custom operators interested in providing drone spraying services.

Another key finding from Table 3 is that ownership costs represent the largest component of total costs per

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Table 1. Equipment required for drone use for farmers and custom operations.

	Price of new unit (dollars)	Lifespan	Salvage value (dollars)	Annual maintenance costs (dollars)	Percentage use for drone application
Drone package (includes a charger)	23,000	8,000 acres	6,900	Farmer's: 1,000.00[1] Custom: 4,000.00[1]	100
Generator	7,500	10 years	2,625	253.13	100
Trailer (farmer's operation)	9,000	10 years	3,150	303.75	50
Trailer (custom operator)	14,500	10 years	5,075	489.38	100
Truck	50,000	10 years	15,000	406.25	25
Tank, pump and transfer system (farmer's operation)	1,000	10 years	300	97.50	100
Tank, pump and transfer system (custom operator)	1,500	10 years	450	146.25	100
Batteries (for drone, each)	2,500	5 years[2]	500		100
Total for a farm[3] (1 drone + equipment + 3 batteries)	56,000				
Total for a custom operation[3] (2 drones + equipment + 5 batteries)	94,500				

1. Drone maintenance costs are estimated as $1 per acre applied.
2. Drone batteries have a lifespan of 1,000 charge cycles. This analysis assumes a lifespan of 1,000 charge cycles or 5 years of use, whatever comes first.
3. Totals consider equipment-use percentage allocated to the drone enterprise.

Recommendations and functionalities of the farmer and custom operator tools

Scale of operations: The cost-effectiveness of owning a drone for spray applications is closely tied to the scale of the operation. Based on the assumptions in this study, farm operations spraying at least 980 acres per year are more cost-effective owning their own drones compared to custom hiring at the current rate of $16 per acre. Custom operators reach a target cost of $7.50 per acre if at least 3,900 acres are applied annually.

Battery management: A cost-effective strategy is to minimize the purchase of extra batteries. However, it is advisable to have at least one backup battery to avoid delays in operations due to unforeseen issues. In the tools, users are notified if batteries will be replaced due to degradation rather than completion of lifespan.

Drone use intensity: Scaling up drone use intensity can be an effective way to reduce ownership costs per acre. The tool's analysis in the "Cost by acreage and interest" tab can help determine these costs for varied drone use intensities and interest rates.

Interest rate impact for farmers: The U.S. prime rate is projected to decrease from 8.5% in 2024 to 6% in 2026, which could reduce the costs of drone ownership, assuming all other factors remain constant. Historically, custom hire rates have not fluctuated with interest rates, making the cost of capital a crucial factor in the viability of farmers financing a drone investment for agricultural applications. A decrease in the interest rate from 9% to 7% under the assumptions used in this guide decreases farmers' ownership costs by $0.97 per acre and custom operators' costs by $0.43 per acre.

Breakeven analysis for target costs: The tools include a table in the "Inputs and summary of results" tab that shows the annual applied acreage and time of application required to achieve indicated target costs. Use this table to appropriately equip, staff and market the drone business according to the desired drone use costs.

Additional uses: In addition to spraying, the drone model analyzed can also be used for spreading, surveying and mapping, potentially adding further value to the operation. For most applications, similar operating costs are applicable.

Table 2. Additional assumptions of this analysis.

Item	Value for farmers' tool	Value for custom operators' tool
Acres applied per charge cycle	6.5	6.5
Acres applied per flight	6.5	6.5
Acres of drone lifespan	8,000	8,000
Applied acres per year	1,000	4,000
Charges of battery lifespan	1,000	1,000
Daily miles driven	20	60
Diesel price (dollars per gallon)	3.31	3.31
Diesel use (gallons per hour)	1.10	1.10
Dish soap price (dollars per 2.64 liter)	25.30	25.30
Dish soap quantity (liters per day)	0.10	0.10
Drone cleaning (hours per day)	0.50	1.00
Drone crew members	1	2
Hours per day applying	6	6.5
Hours per day driving to and from fields	1	2
Interest rate (percent)	8	8
Labor cost (dollars per hour)	21	30
Loads per day	24	52
Number of batteries	3	5
Number of drones	1	2
Nonoperating field hours	0.83	1.72
Pickup fuel economy (miles per gallon)	12.50	12.50
Pumping in and mixing (hours per load)	0.08	0.08
Time recharging battery (hours per load)	0.17	0.17

acre. This indicates that the number of acres sprayed annually and the interest rate on capital significantly influence the economic feasibility of using drones in farming operations.

An analysis of the acreage applied per year (Figure 2) reveals that, under our assumptions, the cost of drone applications will drop below $12.50 per acre for farm operations applying 980 acres or more annually. For custom operators, the cost will drop below a target cost of $7.50 per acre if at least 3,900 acres are applied annually (Figure 3).

The high ownership costs associated with drone use for spray applications can be spread with greater use intensity, which decreases total costs per acre. However, the potential to reduce application costs by increasing acreage may be constrained by the time required to complete the spraying. For instance, a drone application for farmers spraying 980 acres per year would require 37.69 flight hours to be completed at a cost of $12.43 per acre. For farmers covering 2,000 acres annually, the cost could drop to $8.32 per acre but would require 76.92 hours of flight time. These time constraints could pose a challenge for operations with only one drone and a limited application window.
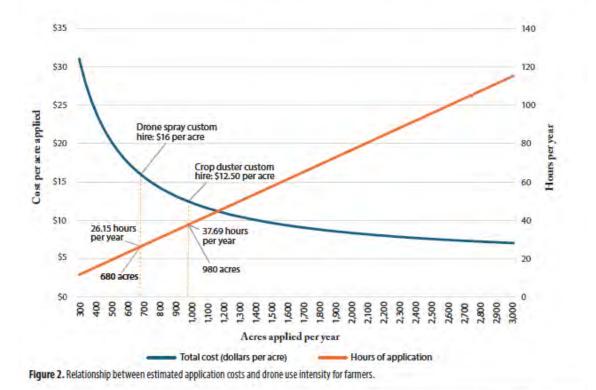
The relationship between the number of acres applied per year and the number of batteries also significantly impacts the cost of drone applications. In this guide, it is assumed that farmers purchase three batteries, two for use and one for backup, and one drone, and that custom operators purchase five batteries, four for use and one for backup, and two drones.

Each battery has a lifespan of 1,000 charge cycles, but its ability to store energy begins to degrade after five years. A battery can be fully charged in 10 minutes, which provides sufficient time to recharge between flights and while refilling the drone with the spray mix. Considering these factors, the most cost-effective strategy is to limit the purchase of extra batteries so that each battery can reach its full charge cycle potential before degradation.

Additionally, the interest rate on capital significantly affects application costs. For an operation using their drone over 1,000 acres, reducing the interest rate from 8% to 6.5% lowers the cost of drone applications from $12.27 to $11.55 per acre.

Table 3. Estimated costs of using the T-40 drone for agricultural spray applications.

Costs	Cost per acre applied (dollars per acre)		Cost per year for the operation (dollars)	
	Farmer	**Custom operator**	**Farmer (1,000 acres per year)**	**Custom operator (4,000 acres per year)**
Fuel	0.15	0.15	145.26	589.08
Labor	1.05	1.06	1,054.49	4,240.63
Other materials	0.02	0.01	16.22	29.94
Maintenance/Repairs	2.06	1.32	2,060.63	5,295.00
Interest over operating capital	0.10	0.10	97.28	388.77
Total operating costs (dollars per acre)	3.37	2.64	3,373.87	10,543.42
Depreciation + interest over capital (excluding batteries)	6.58	3.84	6,584.40	15,369.46
Batteries	1.72	0.72	1,720.93	2,868.22
Taxes + insurance + housing	0.59	0.20	592.38	782.25
Total ownership costs (dollars per acre)	8.90	4.75	8,897.70	19,019.93
Total costs (dollars per acre)	12.27	7.39	12,271.57	29,563.35

Figure 2. Relationship between estimated application costs and drone use intensity for farmers.
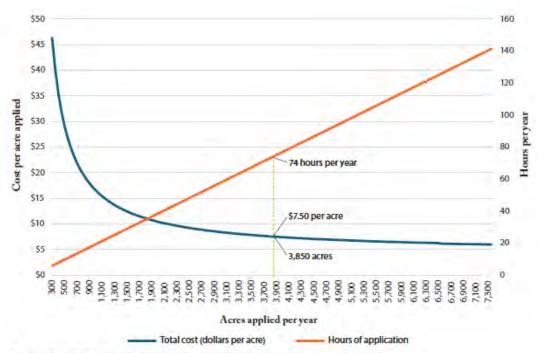
Figure 3. Relationship between estimated application costs and drone use intensity for custom operators.

Download the tools

- Drone Spray Cost Estimator: Custom Operation Version (XLSX) (extension.missouri.edu /media/wysiwyg/Extensiondata/Pro /AgBusinessPolicyExtension/Docs/drone -spray-cost-custom.xlsx)
- Drone Spray Cost Estimate: Farmer Version (XLSX) (extension.missouri.edu/media/wysiwyg / Extensiondata/Pro/AgBusinessPolicyExtension / Docs/drone-spray-cost-farmer.xlsx)

The University of Missouri intends neither endorsement of products named in this guide nor criticism of similar products that are not mentioned.

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NOTES

107

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