Northern Missouri Research, Extension & Education Center

University of Missouri

TM

Field Day Annual Report
August 3, 2023

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 2023

(Volume 2)

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Acknowledgement: We would like to thank Lynn Bradley, Racheal Neal, Northern Missouri Research, Extension and Education Center staff, and all authors for their contribution to this field day annual report.

SR605 New 8/2023

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WELCOME

Welcome to the Northern Missouri Research, Extension and Education Center's (NMREEC) annual field day. The NMREEC's focus is to conduct non-biased research that is beneficial to producers. 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 (Figure 1) demonstrating a sampling 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 46th 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 1,390 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 over 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) program 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 a 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 to superior sires. We practice rotational grazing and continue to strive to reduce the input costs and produce quality beef. This year was the 24th year that we have sold heifers in the Show Me Select Replacement Heifer program.

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 for the purpose of conducting 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 the farm consists of approximately 1,200 acres. The primary goal of the Cornett Research Farm is development and evaluation of forage/beef systems for all classes of beef cattle. For the past 57 years, we have conducted research and delivered the findings to our stakeholders. Educational activities are utilized throughout the year to deliver cutting edge technologies to farmers and agency personnel by conducting field days, grazing schools, focused workshops, and technical training sessions. 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. Focusing on efficient and profitable beef production systems, research is designed to investigate the interactions of cattle, plants, and soil (the systems approach), thus allowing a better understanding of cause-and-effect relationships in forage/beef systems. The center is an advocate for developing and implementing best management practices including reproductive technologies (estrous synchronization, AI, cross breeding), promoting liveweight gains on pasture including season long grazing and forage finishing beef, soil fertility management, development/adoption of smart farm technologies, and protecting and promoting our environment and natural resources. Our goal at the Cornett Research Farm is to help farmers become more profitable by producing a healthier and more nutritious product while improving the environment.

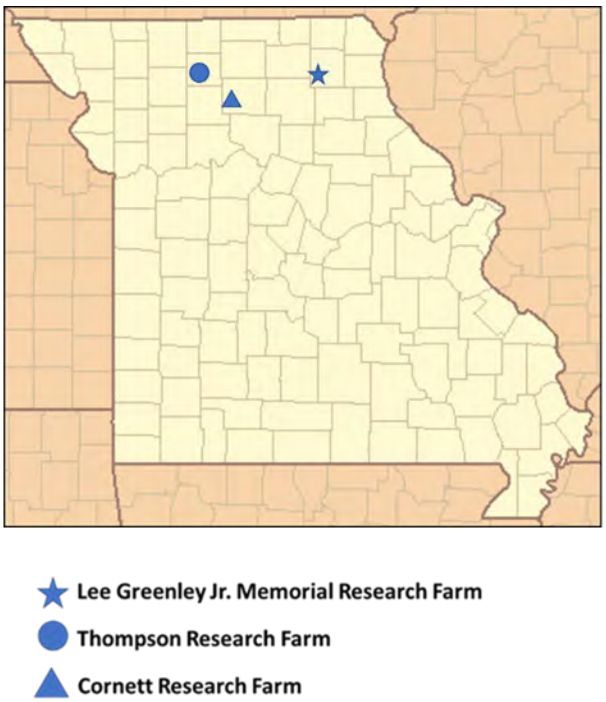

Figure 1. University of Missouri Northern Missouri Research, Extension and Education Center farms.

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 later was 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 soils 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 at 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 the Thompson Farm focuses on beef cattle production systems and forest management. The Thompson Research Farm has been instrumental in development and testing of estrous synchronization protocols in beef cattle and 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 Facebook page at https://www.facebook.com/MUNorthernMOREEC where you can watch for frequent center updates and see some of our day-to-day activities. We are also on Twitter at @cafnr.

We are grateful to the many sponsors that make this event possible, and they are mentioned on the back cover of this book. Lastly but importantly, we also thank the members of our Advisory Boards for their continued support and guidance.

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

2023 NMREEC FIELD DAY LIST OF TOURS AND PRESENTATIONS

Beef and Forage Management

Ticks on Missouri Cattle Pastures

- Dr. Rosalie Ierardi

Grazing Native Grasses

- Dr. Harley Naumann

Managing Through Tight Forage Supplies

- Zac Erwin

Integrated Pest Management

Agras T-20 & T-40 Drone Evaluation for Spray Applications

- Dr. Gurbir Singh and Donnie Hubble

Update on Nitrification Inhibitors for Anhydrous Ammonia

- Dr. Harpreet Kaur

Non-Convention Weed Management Techniques in our Conventionally Minded Ag Systems

- Dr. Kevin Bradley

Disease and Drought - What We Are Learning in 2023

- Dr. Mandy Bish

Agronomic Management

Biological N-Fixing for Corn

- Dustin Steinkamp

Mole Plow Field Demonstration

- Dr. Kelly A. Nelson

Industrial Hemp - Disease Management & New Varieties

- Dr. Peng Tian and Dr. Gurpreet Kaur

Growing Short Stature Corn

- Blake Barlow

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Steve McHenry
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Nichole Miller
Research Specialist II

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Ryan Hall
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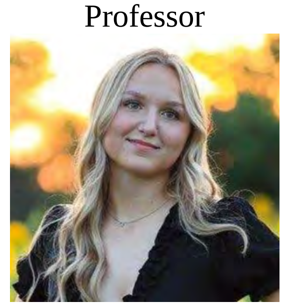

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Laramie Persell
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Amanda Coffman
Farm Worker II

NMREEC GRADUATE STUDENTS

Dean Frossard
M.S. in Soil, Environmental, and Atmospheric Sciences (2022-2024)

Dean graduated from Columbia College with a BS in environmental science and a minor in biology. He is studying the effects of different nitrogen fertilizer rates and nitrogen inhibitors on greenhouse gas emissions and corn production at the Lee Greenley Jr. Memorial Research Farm. Dean has enjoyed his time working at the Greenley Farm and learning from the helpful and knowledgeable staff.

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

This is Dustin’s first year at the Lee Greenley Jr. Memorial Farm. He graduated in the spring of 2023 with his BS in agriculture from Western Illinois University. He is studying the effects of nitrogen loss in corn fields through leaching and gaseous emissions as well as evaluating nitrification inhibitors use with urea. 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 the Greenley Research Farm.

Genna 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.

Harpreet Kaur
Ph.D. in Plant, Insect and Microbial Sciences (2020-2023)

Harpreet graduated in spring of 2023 with her Ph.D. and just completed her Master's in statistics. She studied the impact of cover crops on nutrient loss on a terraced tiled field as well as soil health and drainage water management. Her focus is learning the best management practices to reduce nutrient loss in water. She is very grateful for the opportunity to study and work with Dr. Kelly A. Nelson and the rest of the Greenley Research Farm staff.

Lucas Palcheff
M.S. in Animal Science (2022-2024)

Lucas received his B.S. in animal science from the University of Kentucky in 2021 and started a graduate program at the University of Missouri in the fall of 2022. His research focuses on evaluating estrus synchronization protocols to improve pregnancy rates among beef heifers and cows. Other research interests include whole-system breeding management, estrus synchronization protocols in exotic ungulates, and gamete & embryo cryopreservation. After completing his M.S. degree program, Luke hopes to work directly with beef producers and utilize reproductive technologies.

Megan Berry
Ph.D. candidate in Animal Science (2023-2027)

Megan Berry is a native from South Carolina and is a PhD student at the University of Tennessee in School of Natural Resources. She earned her Bachelor of Science in biology, with a concentration in environmental remediation and restoration from the University of South Carolina Aiken, where her research was on plant interactions within the rhizosphere. She then went on to earn her Master of Science in biology at Clemson University and taught secondary education science for several years before pursuing her doctorate. Megan is working with Dr. Harley Naumann and collecting data from the Cornett farm.

Miguel Salceda
Ph.D. in Natural Resources (2019-2023)

Miguel earned a Ph.D. in natural resources in summer 2023. His doctoral research consisted of determining the effects of watershed conservation practices such as agroforestry and cover crops on water quality. Moreover, he studied nutrient and sediment reductions in groundwater as a result of the implementation of agroforestry buffers in a grazed hillslope and surface water in agricultural watersheds with cover crops and agroforestry buffers. His research interests are watershed and groundwater modeling, field experiments with conservation practices, and watershed monitoring.

Nolan Monaghan
M.S. in Agroforestry (2022-2024)

Nolan is a second-year master's student in the University of Missouri Agroforestry program. He graduated with his bachelor's degree in horticulture and global resource systems from Iowa State University in 2022. He is studying the interactions and productivity of perennial crops in polyculture systems under different fertility treatments. The goal of his research is to improve land productivity and environmental quality while minimizing soil disturbance. His work is supervised by Dr. Ron Revord and Dr. Ranjith Udawatta.

AGRAS T-20 AND T-40 DRONE SWATH AND HEIGHT EVALUATIONS FOR SPRAY APPLICATIONS

Gurbir Singh
Assistant Professor
Kelly A. Nelson
Professor
Donnie Hubble
Senior Farm Manager

Harpreet Kaur
Graduate Research Assistant
Gurpreet Kaur
Assistant Research Professor

Introduction:

Drones consisting of spraying systems for crop protection applications are often called Unmanned Aerial Spraying Systems (UASS). Drone adoption in farming operations has exploded in East and Southeast Asia due to smaller farm holdings which require lower payload capacity for performing field operations. The average farm holding of 90% of the farms in East Asia is less than 2.5 acres whereas the average farm size in the US is greater than 445 acres. Ground spray rigs or manned fixed-winged aircraft are primarily used for pesticide applications in the US. Spray drone use has increased rapidly in recent years as technology has improved and payload capacity has doubled from 44 lbs. (5.3 gal.) for the Agras T-20 drone to 88 lbs. (10.6 gal) for the Agras T-40 drone. Spray drones have several merits as they allow for the timely application of pesticides, can be used on fields with rolling hills and terraces, and cause no physical damage to crop. The pesticide applicator is isolated from the drone during its operation which allows improved safety from chemical hazard, and crop protection applications can be performed when the ground spray rigs cannot enter fields due to wet soil conditions (Chen et al., 2022). In row crop production systems, spray drones are increasingly used to prevent and control crop diseases and pests by spraying insecticides or fungicides (Li et al., 2021a; Li et al., 2021b).

The efficiency of spraying drones has been evaluated earlier and has increased from 5 to 7 acres hr^{-1} to 37 to 50 acres hr^{-1} in recent years (Chen et al., 2021). However, efficiency in covering more acres comes with increasing swath width, increasing flying altitude (10 to 15 ft), reducing spray volume (gallons ac^{-1}), and increasing flight speed of the spray drone. This increased efficiency results in the creation of fine droplets in the air that are susceptible to off-target movement or spray drift causing potential environmental hazards. The environmental risks due to increased efficiency needs to be assessed so that spray application regulations can be developed for drones similar to manned aircraft (crop dusters). Spray drift due to wind has been evaluated for drones in wind tunnels (Wang et al., 2020). The results indicate that low-altitude flying from 3 to 9 ft with a lower spraying speed such as 3.5 mph significantly reduced spray drift (Wang et al., 2021). Slower flying speeds result in reduced spraying efficiency to cover more acres. Therefore, sprayer nozzle configuration, nozzle placement, drone rotor placement, downwash airflow, flying speed, flying height, flight direction, crosswind, and chemical/adjuvant combinations need to be evaluated before they can be fully incorporated into row crop production systems.

Objectives:

The goal of this study was to evaluate the effects of sprayer height and swath for two commercially available drones, Agras T-20 and T-40, using paraquat at 3 pt ac^{-1} plus crop oil concentrate at 1% v v^{-1} on plant greenness following application. This study also presents a new method to estimate in-field spray drift using remote sensing imagery to estimate an area weighted green index, and quantitatively evaluate weed control following a herbicide application.

Procedures:

This study was conducted on-farm at the Lee Greenley Jr. Memorial Research farm, Novelty, MO. The field selected for the study was in a no-till, corn-soybean rotation with winter wheat as a cover crop that was broadcast seeded with a dry fertilizer application following corn harvest. Treatments for this research included two drones (T-20 and T-40, DJI, Shenzhen, China), three flight heights (5, 10, and 15 ft) and three swath distances (15, 22, and 30 ft). The study was designed as a randomized complete block with three replications. The study also included a non-treated control where no herbicide was applied, and a treatment sprayed with a ground sprayer equipped with Teejet (Glendale Heights, IL) XR 8002 VS nozzles traveling at 2.9 mph and delivering 15 gpa with a 15-inch spacing between nozzles. The spray boom was maintained at 18 inches above the plant canopy. The T-20 drone was equipped with Teejet XR 11001 VS nozzles. The T-40 drone was equipped with dual atomized centrifugal driven nozzles (Figure 1). Detailed specifications on the design of centrifugal nozzles for the T-40 are not available in published research. To minimize the spray drift to neighboring treatments, plots were 90 ft wide by 200 ft long. The flight path was 150 ft long (Figure 2).

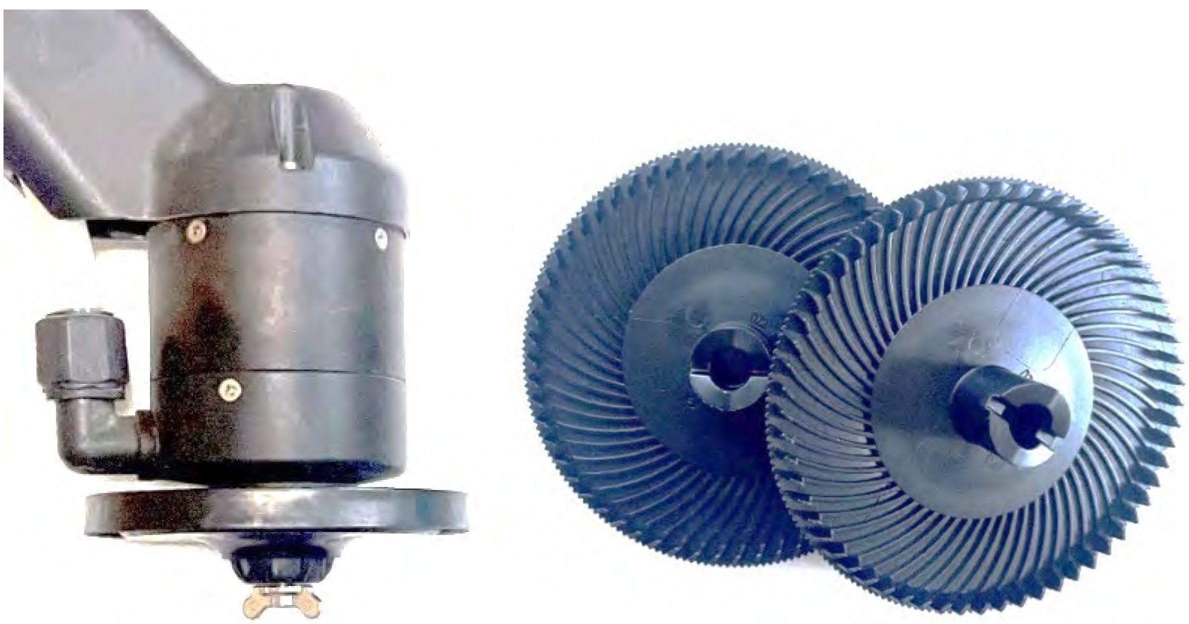

Figure 1. Dual atomized centrifugal nozzles with replaceable spinning disks.

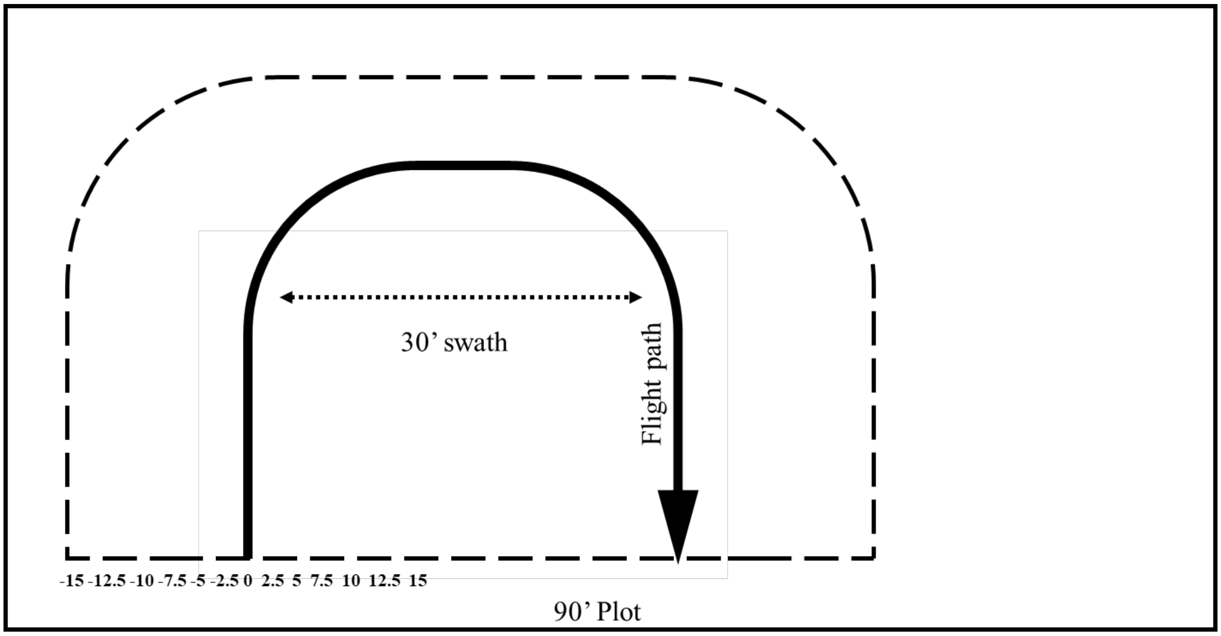

Figure 2. Spray distribution distance under the flight path is indicated by ±0 to ±15 ft. The flight path is indicated by a solid line with an arrow, flight swath is indicated by the dotted line with two arrows and the outer solid line represents the plot area.

Prior to the herbicide application, a survey of each plot was conducted on 10 April 2023. The selected field was surveyed using a DJI Mavic Air 2s drone equipped with a 1-inch CMOS 20 MP 2.4 µm pixel camera for estimating winter wheat and annual weed greenness. The camera lens had 88° field of view (FOV) with f/2.8 aperture. The image data was collected at 80% forward and side overlaps with a ground resolution of 1-inch pixel^{-1}. The RGB image was stitched using Agisoft Metashape Pro (v. 2.0.1) and processed for area-weighted Green Leaf Index, GLI (Louchaichi et al., 2001). The calculated GLI from each plot was analyzed in SAS (SAS Institute Inc., Cary, NC) to quantify spatial differences in greenness since corn stalk residue and bare ground was present. The image collected on 10 April 2023 served as a pre-herbicide application check for the cover crop and annual weed greenness. This confirmed that there was no significant difference ($P>0.05$) in the spatial greenness distribution among plots. This indicated uniformity between plots prior to the herbicide application.

The drone and ground herbicide application treatments were applied on 11 April 2023. Wind speed and direction at the time of application are provided in Table 1. Paraquat at 3 pt ac^{-1} plus crop oil concentrate at 1% v v^{-1} was applied at 2-gal ac^{-1}. The flying speed of the drones was maintained at 10 mph while the swath width and height of the drone was changed to evaluate coverage based on a greenness assessment. The T-40 centrifugal nozzle droplet size was set to medium. To evaluate the spray drone height and swath response to the postemergence herbicide application, remote sensing imagery data was collected using a DJI Mavic Air 2s drone on 18 April 2023 using the same settings as the pre-herbicide application image. The post-herbicide application imagery was stitched with Agisoft Metashape Pro (v. 2.0.1) and processed for area-weighted GLI. A positive value of the GLI means plants were in the green spectrum whereas a negative value means plants were in the brown color spectrum. All the raster and vector data were extracted in ArcGIS Pro (v 3.1.0, ESRI). The data analysis was conducted using R version 4.3 for calculating an area-weighted GLI for different application heights and swaths (Figure 2). SAS software was used to evaluate differences among means due to treatments. Nonlinear regression graphs were made in Origin Pro software (v 9.9, OriginLab) to identify the optimal sprayer height and swath combination.

Table 1. Wind speed and direction at the time of application.

Date	Time	Wind Speed	Wind Direction	Drone Flight
11 Apr. 2023	6:00 AM	0	S	-
11 Apr. 2023	7:00 AM	2	SSW	-
11 Apr. 2023	8:00 AM	7	SSW	T20
11 Apr. 2023	9:00 AM	10	SSW	T20
11 Apr. 2023	10:00 AM	10	SSW	T40
11 Apr. 2023	11:00 AM	11	SW	T40
11 Apr. 2023	12:00 PM	12	SW	Ground Sprayer

Results:

A two-way interaction between drone flight height and flight swath (Figure 2) was significant for the T-20 and T-40 drones (Table 2). The T-20 drone at a 5 ft height and 15 ft swath, 5 ft height and 22 ft swath, and 10 ft height and 15 ft swath had the lowest (-0.0090 to – 0.0086) GLI which indicated that these flight height and swath combinations had the best overall weed control (Table 2). The GLI was reduced when the T-20 drone was flying at a 15 ft height and 30 ft swath (Figure 3). For the T-40 drone, the lowest GLI (-0.0068) was achieved at a 5 ft height and 22 ft swath followed by a GLI of -0.0066 for a 10 ft height and 15 ft swath (Table 2). Figure 3 represents the change in GLI for the drone height and swath combinations measured as a 5-, 10-, 15-, 20-, 25- and 30-ft buffer area around the flight path (Figure 2). The maximum effective swath for the burndown application using the T-20 and T-40 drones was 22 ft when flying at a 5 ft height; however, the effective swath decreased to 15 ft when the flight height increased to 10 ft.

Recommendations:

The optimal spray height for the T-20 drone based on the GLI in Figure 4 is 8-9 ft above the canopy with a 15 to 22 ft swath width. The optimal sprayer height for the T-40 drone is 9-10 ft with a 15 to 22 ft swath. The efficiency of field coverage is greater for the T-40 drone since it has double the payload capacity when compared to the T-20.

Acknowledgements:

This material is based upon work supported by the United States Department of Agriculture Natural Resources Conservation Service.

Table 2. Mean difference in area-weighted green leaf index for drone height, swath, and their interaction. Similar letters within a column indicate no significant differences among treatments at $p \leq 0.05$.

Drone Height	Drone Swath	DJI-T20 Green Leaf Index	DJI-T40 Green Leaf Index
--------------------ft-------------------		----------greenness ft^{-2}----------	
5		-0.0074 b	-0.0046
10		-0.0062 b	-0.0059
15		-0.0026 a	-0.0052
	15	-0.0076 b	-0.0052
	22	-0.0057 b	-0.0058
	30	-0.0027 a	-0.0048
5	15	-0.0090 c	-0.0026 a
5	22	-0.0087 c	-0.0068 d
5	30	-0.0045 b	-0.0045 abc
10	15	-0.0086 c	-0.0066 cd
10	22	-0.0038 b	-0.0054 bcd
10	30	-0.0061 bc	-0.0056 bcd
15	15	-0.0052 b	-0.0063 bcd
15	22	-0.0051 b	-0.0052 bcd
15	30	0.0025 a	-0.0043 ab
Source of Variation	**df**†	***p-values***	
Height	2	<0.0001	0.1577
Swath	2	<0.0001	0.2892
Height x Swath	4	0.0005	0.0040

† Numerator degrees of freedom, df.

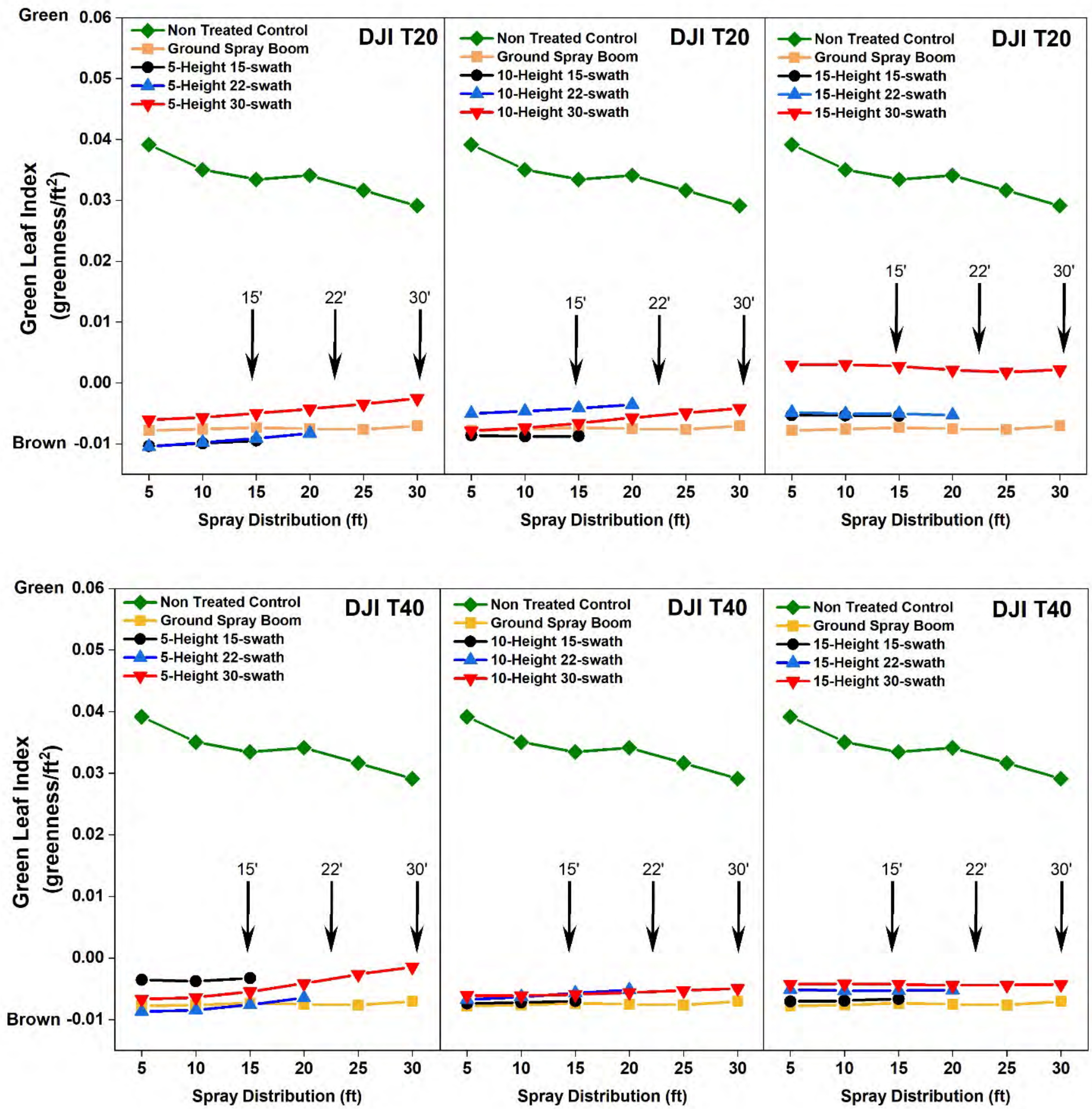

Figure 3. Area-weighted green leaf index (GLI) indicated by different symbols for drone height and swath combinations for the T-20 and T-40. A positive value of the GLI means the plot area was greener (poor control) while a negative value means it was browner (excellent control).

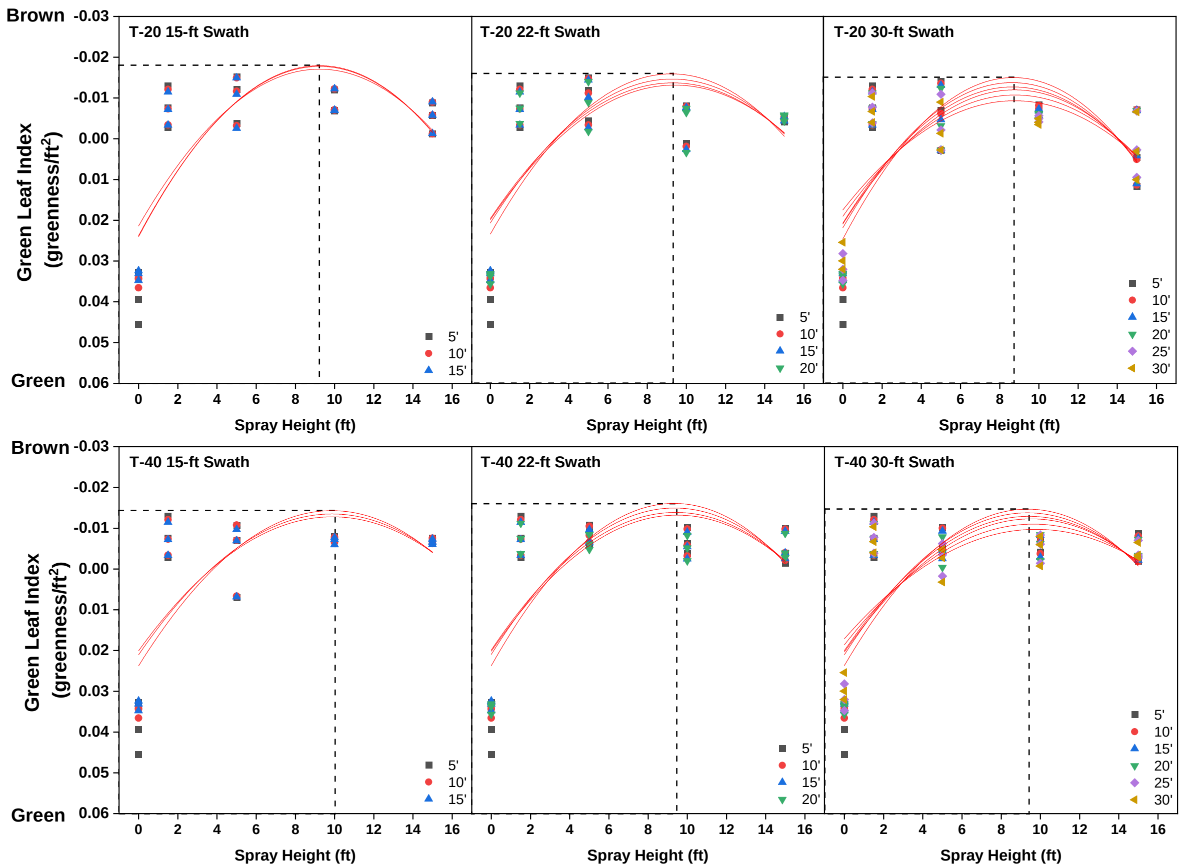

Figure 4. Area-weighted green leaf index (GLI) for drone height and swath evaluations comparing the non-treated control and ground spray boom application. The red line is the non-linear fit between spray height and GLI. The dashed line is the optimal drone sprayer height. A positive GLI value means the ground area was greener (poor control) whereas a negative value means the ground area was browner (excellent control).

References:

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DRONE CALIBRATIONS FOR SPREADING SEED AND FERTILIZER

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Assistant Professor
Gurpreet Kaur
Assistant Research Professor

Kelly A. Nelson
Professor

Introduction:

Spreader calibration is a fundamental step for achieving recommended product application rates for any field equipment whether it's a ground-driven broadcast or aerially applied. Incorrect spreader calibration may result in the misapplication of the product leading to increased expense to growers or poor crop response and plant establishment. Most farmers are aware of application issues associated with ground-driven dry broadcast applicators which include incorrect application rates and non-uniformity of spreader swaths. Like a ground-driven spinner disk broadcast spreader, the T-20 (DJI, Shenzhen, China) drone is also equipped with a spinner disk spreader (Figure 1). Several variables can affect the uniformity of application and the amount of product delivered by the spreader system of a drone which includes the density, size and structure of the product; spinner disk speed or rotations per minute (rpm); hopper size opening of the spreader system; wind speed and direction during a broadcast application; and flying speed, swath settings, and altitude of the drone. The dry product in the drone hopper is gravity fed to the spinner disk therefore the product remaining in the hopper can also affect the amount of product delivered by the spreader.

Figure 1. T-20 drone equipped with a broadcast spreader spinner disk V2.0.

Objectives:

The overall goal of this study was to develop spreader calibration curves for the most common cover crop seeds and dry fertilizers used by farmers and provide calibration charts which can be used as a reference for fine-tuning product delivered from the spreader system of the T-20 drone. We also evaluated the interactive effects of spinner disk rpm with hopper size opening for cereal rye, daikon radish, oat, wheat, and urea. Finally, a uniformity test was performed for wheat seed using the T-20 spreading system.

Procedures:

Materials required for developing calibration curves for drone spreaders included buckets to catch dry products, a weighing balance, a pencil, book to record readings, and basic skills in Microsoft

Excel to develop non-linear relations in order to determine trend lines. A list of the products evaluated in this study is provided in Table 1.

Table 1. Products evaluated for developing a non-linear relation between hopper size opening and the amount of product delivered by the T-20 spreading system. See the QR code provided in Figure 2 to download this table.

Product Name	Type	Density	Flight speed	Flight speed	Spread width or swath	Seeding rate desired	Hopper size based on targeted seeding rate
		lbs bu^{-1}	mile hr^{-1}	ft sec^{-1}	ft	lbs ac^{-1}	%
Annual Ryegrass	Crop	35.65	6.82	10	15	60.0	59.8
Canola	Crop	49.05	6.82	10	15	14.8	15.1
Cereal Rye	Crop	60.12	6.82	10	15	50	33.4
Crimson Clover	Crop	61.55	8.18	12	15	8.5	11.9
Daikon Radish	Crop	52.03	6.82	10	15	25	17.4
Oats	Crop	40.24	6.82	10	15	40	70.3
Purple Top Turnips	Crop	52.77	10.23	15	15	8	9.8
Red Clover	Crop	59.54	6.82	10	10	20	17.7
Wheat	Crop	60.63	6.82	10	15	40	26.0
Ammonium Sulfate	Fertilizer	66.9	6.82	10	15	16	10.0
ESN	Fertilizer	46.54	6.82	10	15	50	31.0
Lime Pelleted	Fertilizer	64.84	6.82	10	15	100	34.2
Super-U	Fertilizer	46.85	6.82	10	15	50	32.0
Urea	Fertilizer	90.35	6.82	10	15	50	31.4
Zinc Sulfate	Fertilizer	46.15	6.82	10	15	15	12.0

Figure 2. QR for downloading the T-20 spreader calibration Microsoft Excel spread sheet which provides calibration curves for the 15 products listed in Table 1. Flight speed, swath, and amount of product can be changed to for an accurate hopper size opening.

A basic procedure for developing drone spreader calibration curves is:

1. Remove the spreader from the drone but keep the spreader cable attached to the drone.
2. Remove the spinner disk from the spreader.
3. Record the empty weight of each bucket using a scale with adequate accuracy.
4. Set the spreader tank to dump into the bucket (Figure 3) and make sure there is plenty of capacity remaining in the bucket.
5. Fill the spreader tank with the desired product. It is a good practice to record the density of the product that is being calibrated for spreading.
6. Power on the drone and controller for the drone. Enter 'execute the spreading operation' and set the hopper outlet size to 10% or more for large-seeded crops (i.e. wheat or oats). For small-seeded crops (i.e. clover or canola), start with a hopper outlet size of 1%. Press ok to save the settings and use the button on the remote to turn the spreader on for 20 seconds.
7. Weigh the seed that was dumped out of the spreader. Use Table S1 from the Microsoft Excel sheet provided in the QR code of Figure 2 to record the Time On, Hopper outlet size, and Total pounds dumped in the bucket.
8. Table S1 will automatically calculate the average pounds per second. Repeat steps 6 and 7 for at least 4 to 5 different hopper outlet size openings. For each hopper outlet size opening record at least three weight readings from three test runs.
9. The Microsoft Excel sheet provided in the QR code will auto-update based on the values recorded in Table S1 from steps 6 to 8.
10. Changes in the flight speed and flight swath affects the hopper size opening. Therefore, Table S2 provided in the Microsoft Excel sheet gives users an option to update the speed and swath setting and recalculate the hopper outlet size.
11. After developing the product calibration table, add the value for the target seeding rate needed for the optimum seed rate in lbs ac^{-1} in the column named "Seeding Rate Needed" highlighted in yellow. The column highlighted in blue should give users the percent Hopper Size Opening which can be used in the drone settings program.

Figure 3. Spreader tank setup on a 5-gallon bucket with lid and hole cut (approximately 5-inch diameter) to collect the desired product.

To conduct a field uniformity test and measure the effective swath width of the spreader drone, a catch test was performed using a spread pattern test kit (New Leader Manufacturing, Cedar Rapids, IA). Spread pattern test kits are commercially available and contain step-by-step instructions to perform uniformity tests for ground-driven broadcast spreaders. The spread pattern test kits have plastic collection trays that need to be secured on the ground to ensure the plastic trays don't fly off with the downwind pressure from the drone propellers. The collection trays are placed in a line 2 ft apart from each other and cover 30 ft of the swath width. The manufacturer of the T-20 drone estimates a 15 to 22 ft swath width. One collection tray was placed in the center of the swath, and an equal number of collection trays were placed to the right and left of the center tray. It is recommended that the drone spreader should pass directly over the center collection tray; therefore, using RTK control for the drone is essential for spreader test evaluation. For collecting enough wheat seed in the pans, the T-20 drone was flown 5 times over the collection trays. The wheat seed collected in the trays was transferred to test tubes and weighed individually to check for uniformity of the spreading distance. The drone settings for the uniformity test were set to a flight speed of 6.82 mph, swath of 15 ft, and height of 6 ft. The spinner disk speed was set at 800 rpms and hopper size opening was set at 24% to deliver 35 lbs ac^{-1} of the wheat seed. The uniformity test was conducted on 6 December 2022 and wind speed during the uniformity test was 0 MPH.

Results:

Product density can affect the amount of material delivered through the spreading system; therefore, the results provided in this study should only be used as a guide for the starting point of the calibration. We evaluated the effects of spinner disk rpm with the hopper size opening for cereal rye, daikon radish, oat, wheat, and urea (Figures 4 and 5). A hopper size opening of 70% had a strong negative linear relation (R^2>68) with the spinner disk speed (rpm) for cereal rye, daikon radish, and wheat. When the hopper size opening was set to 10%, a positive linear relation (R^2>42) with the spinner disk rpm was observed for all five products evaluated in this study (data not presented). This indicates that spinner rpm can significantly affect the product delivered from the spreader; therefore, spinner disk rpm should be maintained at constant rate for product applications.

The uniformity test was performed for wheat at the settings described in Figure 6. The mean wheat application rate achieved by three test runs was 31 lbs ac^{-1} for a 15 ft swath distance; however, our target application rate was 35 lbs ac^{-1}. The spread uniformity is evaluated based on the cumulative variance (CV) for a 15 ft swath width. Cumulative variance for test run 1, 2, and 3 was 69%, 51%, and 74%, respectively. The accepted CV for a ground spreader is <15%. The T-20 drone spreader system was not close to the acceptable CV when compared to ground spreaders. The down force created by drone propellers had a significant effect on the distribution of wheat seeds (Figure 6).

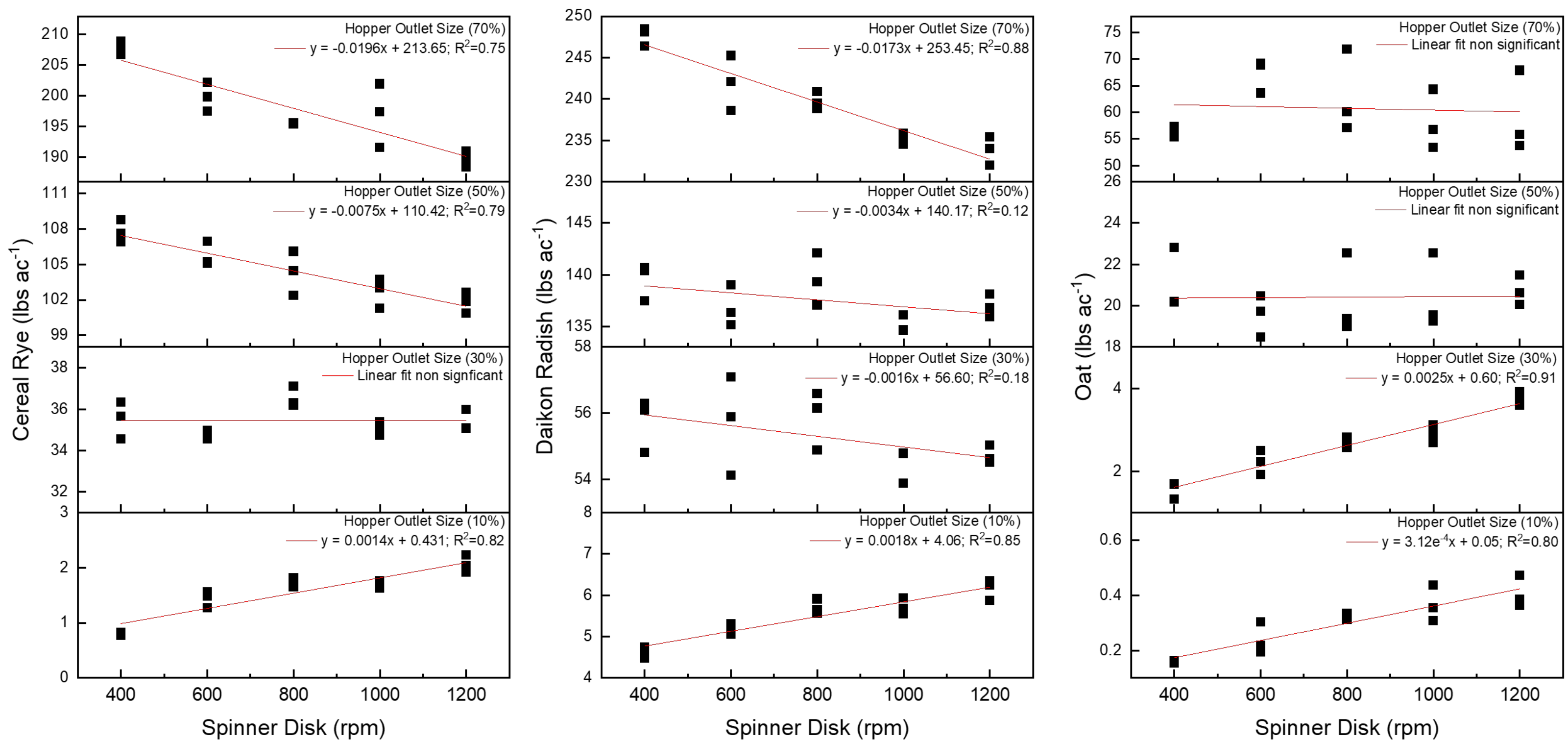

Figure 4. Spinner disk rpm and hopper size opening affect the amount of product delivered for cereal rye, daikon radish and oat. Flight speed and swath were kept constant at 6.82 mph and 15 ft, respectively.

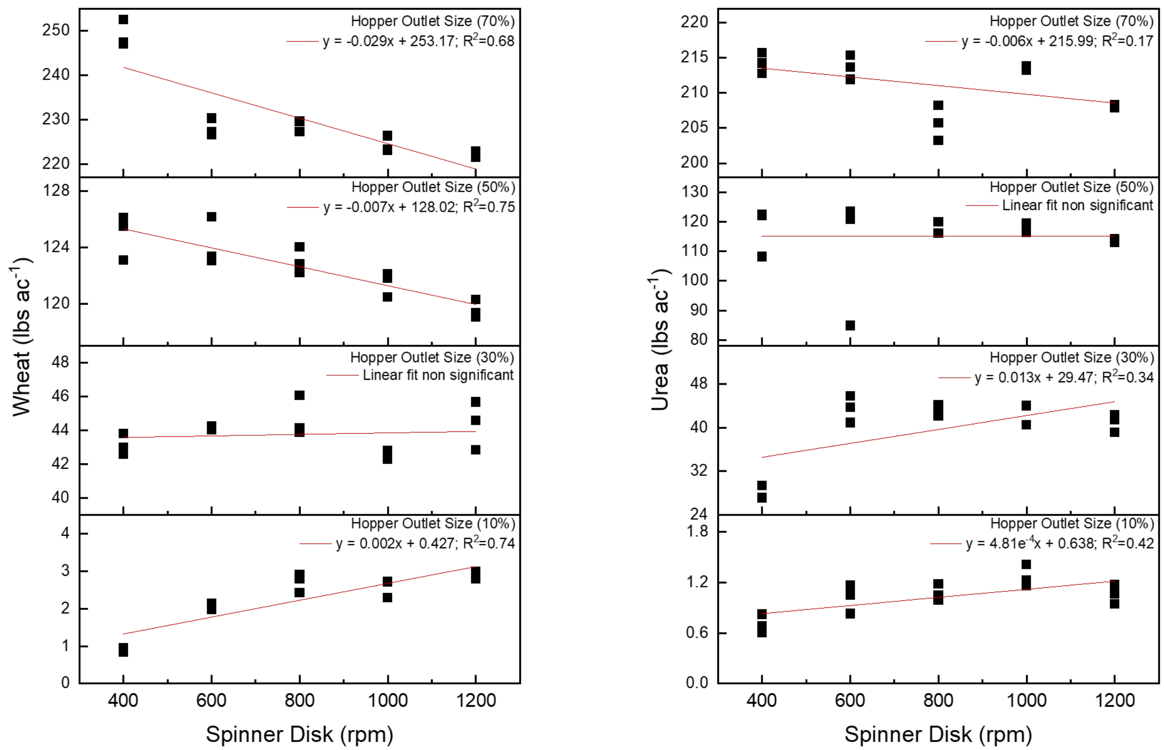

Figure 5. Spinner disk rpm and hopper size opening affect the amount of wheat (left) and urea (right) delivered. Flight speed and swath were maintained at 6.82 mph and 15 ft, respectively, throughout the test.

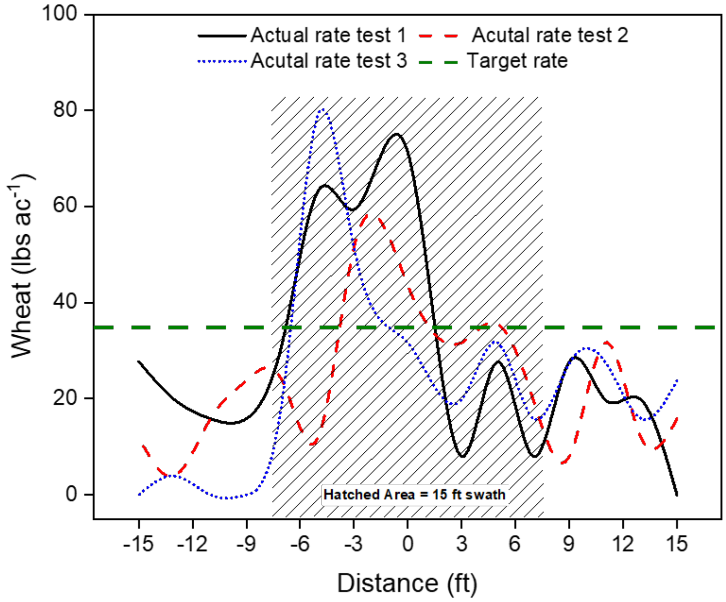

Figure 6. Wheat seed spread uniformity test for the DJI T-20 drone

Recommendations:

- Drone spreader systems must be calibrated for attaining at least 90 to 95% of the targeted application rates. Spread uniformity test needs to be carefully evaluated so the overall cumulative distribution variance can be reduced for specific products or product combinations.
- Calibrations are specific to product type and properties, density, application rate, and spread width. Any changes made in the product type (i.e. single product vs. blended products), product properties (i.e. shape, size or density), application rate, spinner disk rpm, flight height, or speed may require additional calibrations.
- Always refer to product calibration charts for recommended settings for the specific product types and densities provided by the drone supplier. If the calibration charts are not available, then users should develop them on their own using the procedure reported in this study. It is a good practice to start with the recommended settings and adjust the settings for fine-tuning the aerial spreaders.
- During the calibration process, do not change more than one drone spreader setting at a time between test passes to evaluate its influence on application rate or uniformity.
- Make sure to record all information for each test pass (i.e. spreader rpm settings, material density, target rate, fight swath and flight height) during the calibration process.
- The newer drone spreaders such as the T-40 are equipped with weighing systems build into the equipment. These drones have an auto-calibration feature that can be used for determining hopper size openings for target application rates. Manual calibration of product application rates should be performed to validate auto-calibration results otherwise the user may over or under apply the product. Finally, product distribution needs to be validated for each drone.

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MOLE PLOW DEMONSTRATION

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Introduction:

Subsurface tile drainage is a critical infrastructure investment to lower the water level in the soil profile. In this system, a perforated plastic pipe is installed at a specified slope which is connected to a main pipe to allow removal of water below the soil surface. Subsurface drainage systems allow farmers to manage wet soil conditions that directly affect timeliness of field operations, improves the aeration of the soil, reduces the incidence of soil diseases, and reduces yield loss due to water logging of the soil. There are some soil series that have a shallow impermeable layer that is close to the soil surface or are heavy clay soils that require very narrow drain tile spacings. In these soils, we hypothesize that a mole plow may be useful. The mole plow could provide more intensive drainage in soils while providing additional porosity to allow increased aeration and removal of water in a timely fashion. Mole plows are more common in other countries such as Ireland, England, New Zealand, and Australia in pasture and crop fields (Tuohy et al., 2015). Research in the 1940s evaluated the power requirements of mole drainage in Iowa soils (Schwab, 1947), but their use in the United States has been limited.

Figure 1. Main components of the mole plow.

Mole plows are typically 3-point hitch mounted, but it can be a pull-type unit. Water drains through the shank slot and fissures that are formed in the soil to the mole channel. This unlined channel can be formed in clay subsoils. The mole channel is usually less than 24 inches deep and ties into a subsurface tile drainage system arranged with permeable fill (similar to a French drain arrangement), or they can be linked to open ditches or surface drainage systems. Mole channel spacings may range from 3 to 15 ft apart depending on whether the field is a pasture or cropland.

A bullet or torpedo forms an initial channel in the soil while an expander follows to help compact the wall of the mole channel (Figure 1).

Typically, a mole drain would follow the slope of the soil and utilize a skid to maintain the depth of the mole channel. The direction of the mole channel is dependent upon the amount of slope in the field. A grade control system should allow us to install mole drains perpendicular to the slope and link them into controlled drainage systems where the subsurface tile drainage main is installed parallel the slope of the field and the size of the main can be minimized. Installing mole channels perpendicular to the slope could allow infiltration of surface water into the subsoil and reduce surface water runoff. The grade control system would also minimize uneven grades that can result from 3-point mounted mole plows. Recommended speeds for mole plow operation ranges from 1 to 2 miles per hour and will depend on the response time of the hydraulics to maintain grade. The life of a mole channel may range from a few hours when installed in the wrong soil conditions to several years. Research in Ireland indicated a life of 2 years in a clay loam soil before plowing the field again (Tuohy et al., 2015).

Some of the key components of the demonstrated mole plow include (Figure 1):

1. Receiver for the grade control system (SD Drain®)
2. Shank or beam with minimal surface soil disturbance
3. Bullet, torpedo, or foot
4. Expander or plug that ranges from 2.5 to 4 inches in diameter.

Objectives:

The objectives of this project are to: 1) demonstrate the efficacy of a mole plow in a claypan soil, and 2) evaluate soils and drainage systems for mole drainage in Missouri.

Procedures:

This demonstration is utilizing a 40 Caliber (Figure 1) mole plow (Komb, **Altona, MB** Canada). The shank is ¾ inches wide and is 30 inches long with a 3-inch diameter bullet followed by 4-inch diameter expander (Figure 2). The plow utilizes an SD Drainage® system (Harwood, ND) for grade control. The elevation for the RTK-GPS receiver controls the two cylinders (pitch and depth) on the 3-point hitch mounted mole plow.

Figure 2. Mole channel 20 inches below the soil surface with a 4-inch diameter in a claypan soil.

Recommendations:

- Soil conditions above the mole should be dry enough for good traction, avoid soil compaction, and allow cracking of the soil.
- The subsoil clay conditions should be moist enough to allow a stable channel to be formed, but not too wet to slough off.
- Mole channel can be 16 to 24 inches deep.
- Mole channels can be plowed into an open ditch or flow into permeable fill above a perforated tile line that is buried deep enough to avoid hitting it with the mole plow.

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INNOVATIVE LANDSCAPE-BASED CONSERVATION PRACTICES TO ENHANCE SURFACE WATER QUALITY AND CROP PRODUCTION

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Introduction:

Inlet technology and water quality: Fresh water resources are an essential component of long-term sustainable agriculture production systems. Integrated cropping systems that improve water use efficiency and promote soil conservation are essential for long-term sustainability of rural communities. At the NMREEC's Grace Greenley Conservation Showcase farm, current on-site research in collaboration with numerous partners is evaluating the impact of a saturated buffer and bioreactor (edge-of-field practices) along with controlled drainage on water quality, while additional research is evaluating the impact of cover crops on nutrient loss in a terraced field (Figure 1, Adler et al., 2020). Stacked conservation practices are needed to address conservation and crop production goals. Identifying stacked conservation practices (i.e. 4R nutrient management, no-till, terraces, cover crops, and others) that have synergistic effects will allow farmers to maintain highly productive and flexible cropping systems while conserving natural resources. Based on the results from Adler et al., (2020) and Kaur et al., (2023) in upstate Missouri, an integrated approach to address yield loss based on landscape position, soil health, and nutrient loss was initiated to with the support of the Department of Natural Resources Soil and Water Conservation Program to evaluate the effects of inlet technology on water quality and sediment loss.

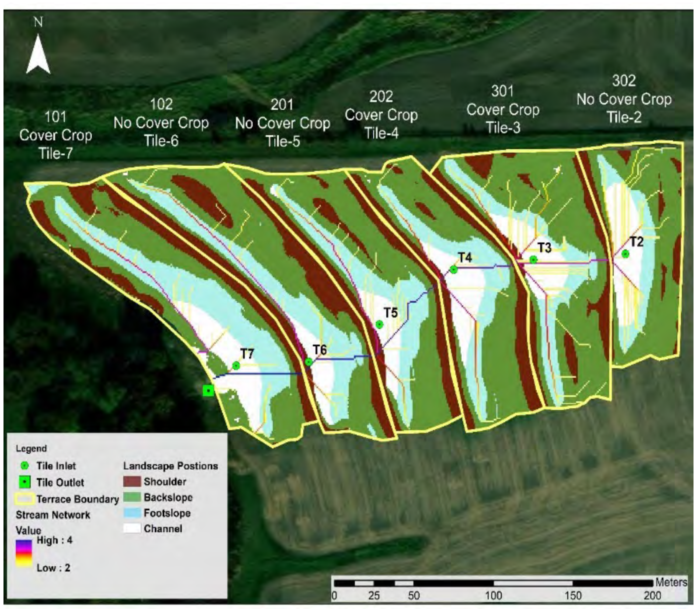

Figure 1. Delineation of landscape positions in a terraced field at the MU Grace Greenley Conservation Showcase farm (Adler et al., 2020).

The utility of innovative conservation systems needs to be validated on-farm. Additional on-farm research sites have been initiated to evaluate channel tiling and blind inlets. On-farm research evaluating channel tiling is being supported by the Missouri Soybean Merchandising Council while on-farm sites evaluating blind inlets are in partnership with the Natural Resources Conservation Service and Missouri Corn Merchandising Council.

On-farm Channel Tiling. Northern Missouri hosts over 60% of the soybean production in the state, includes more than one-third of state's counties, and over 40% of the land is classified as highly erodible land (HEL) by NRCS. To sustain crop productivity on HELs, terraces are installed to reduce surface water runoff and soil erosion. This is a critical infrastructure that has reduced erosion throughout the region. In this modified landscape, water is captured in a channel (Figures 1 and 2) which is then diverted to surface inlets that deliver water below the soil surface to an outlet. Inlets are designed to remove water in 24 hrs and may include an orifice. The orifice prevents pressurization of the pipes and slows the movement of water in the channels which encourages deposition of sediments. As a result, high soil moisture or waterlogging conditions are created in the channel (Figure 2) which can negatively impact crop stands and yield. Waterlogging damage in some cases extends to footslope areas of these landscapes (Figure 1). Four years of research in northern Missouri has shown 30 to over 50% lower crop yields in terrace channels compared to the shoulder position within a terrace landscape. Tiling of the channels may lower the water level in this portion of the landscape which could minimize yield losses. Channel laterals could also reduce the amount of denitrification and the severity of disease that occurs due to saturated soil conditions. We hypothesized that improved drainage in channels due to subsurface tiling could significantly increase yields and economic returns in strategic parts of the landscape.

Figure 2. Channel wetness differences on a farm along Highway 15.

Waterlogged soils are one of the most damaging abiotic stresses besides drought. Waterlogging affects crop stand establishment, disease severity, workability of soils, timely field operations, and seed yields (Nelson, 2017; Kaur et al., 2020; Mourtzinis et al., 2021). It is imperative to develop production practices that make cropping systems more resilient to extreme precipitation events (Kaur et al., 2020). In a synthesis of the benefits of artificial drainage on soybean in the North Central US (1/3rd of the global soybean production), we've seen that improved subsurface drainage has increased soybean yields 8% (Mourtzinis et al., 2021). In Missouri, 30 yrs of cultivar-management treatments from 2002 to 2015 showed subsurface drainage increased yields over 10% in poorly drained soils (Nelson, 2017). Additional research led by Dr. Kaur is evaluating the effect of saturation duration on yields of commercially available

Figure 3. Saturation duration (0, 3, and 7 days) of soybean cultivars in upstate MO.

soybean cultivars and selected seed treatments which is also supported by the Missouri Soybean Merchandising Council (Figure 3).

On-farm Blind Inlets. Currently, surface inlets are a direct conduit to the outlet and can cause a hindrance in farming operations. These inlets can be replaced with blind inlets. A blind inlet or French drain is an inlet structure that allows entry of surface water from depressions or potholes to a subsurface pipe conduit through a trench filled with clean coarse aggregate to reduce sediment and other contaminants which can be transported to receiving ditches, streams, or reservoirs (Sandstrom, 2020). A blind inlet can be used instead of a perforated tile riser (surface inlet) or pipe inlet orifice to improve water quality (Figure 4).

Blind inlets have reduced sediment loads (79%) and decreased P loads (65-85% from Apr.-Nov.) compared to a surface inlet riser (Smith and Livingston, 2013; Smith et al., 2015). Specifically, Feyereisen et al. (2015) reported total phosphorus (TP) and soluble reactive P loads were 66 and 50% less with a blind inlet while total suspended solids (TSS) were reduced over 60% with a blind inlet. They reported that a blind inlet had a service life that was greater than 10-yrs. In addition to a reduction in nutrient loss, Gonzalez et al. (2016) reported the ability of a blind inlet to reduce loss of 2,4-D, glyphosate, atrazine, and *S*-metholachlor ranged from 11 to 58% in farmed potholes. However, Williams et al. (2020) showed that a blind inlet installed in a drained closed depression in northeastern Indiana had infiltration rates that decreased 1.4 cm/h/yr which was affected by annual tillage practices. They estimated the service life of a blind inlet was 8-10 years under their study conditions that included frequent tillage. They indicated that data under no-tillage was needed. Smith and Livingston (2012) reported that this practice may be eligible for cost-share as USDA-NRCS Conservation Practice 620 (Underground Outlet) in Indiana since the blind inlet is approved practice (NRCS, 2022).

Blind inlets have decreased pesticide, sediment, and nutrient loads, but adoption has been met with hesitation over concerns regarding water ponding, crop damage or loss, and lifespan of the practice. While current research has evaluated blind inlets in closed depressions or potholes (Feyereisen et al. 2015; Smith and Livingston, 2013; Smith et al., 2015). This project is needed to demonstrate the effects of blind inlets on farm-scale terraced systems over diversified topographies and soil types (i.e. windblown loess soils in northwest Missouri to the claypan soils in northeast Missouri) that utilize stacked conservation practices such as no-till, cover crops, and 4R nutrient management in a terraced landscape topography. Blind inlets have been tested in other states for their impact on reduction in soil erosion and improvement of water quality. However, their use and adoption is low in Missouri due to lack of knowledge of their impact on crop production.

Objectives:

1. The inlet project objective is to evaluate the effect of a water quality inlet, blind inlet, and channel laterals (Figure 4) on crop production, sediment loss, and nutrient loss. This will be used to determine if this technology can be used in conjunction with edge-of-field conservation practices.
2. On-farm channel tiling project objectives are to 1) determine whether installing tiles in the channel region of terraces (Figure 4B) will be useful in improving soybean production or not, and 2) determine the cost-effectiveness of the practice.
3. On-farm blind inlet project was designed to evaluate the efficacy of blind inlets (Figure 4C) in a terrace-tiled landscape topography on crop production, economics, and water quality.

Procedures:

Innovative conservation technology. At the NMREEC's Grace Greenley Conservation Showcase farm, parallel terraces were designed by NRCS and installed in the summer of 2022 with blocks between each treatment. Inlet treatments included a water quality inlet replacing a Hickenbottom riser (Figure 4A), channel lateral with a Hickenbottom riser (Figure 4B), blind inlet (Figure 4C), and a Hickenbottom only riser (not pictured). We are currently evaluating crop response, water flow from each inlet, residue loss, and nutrient loss.

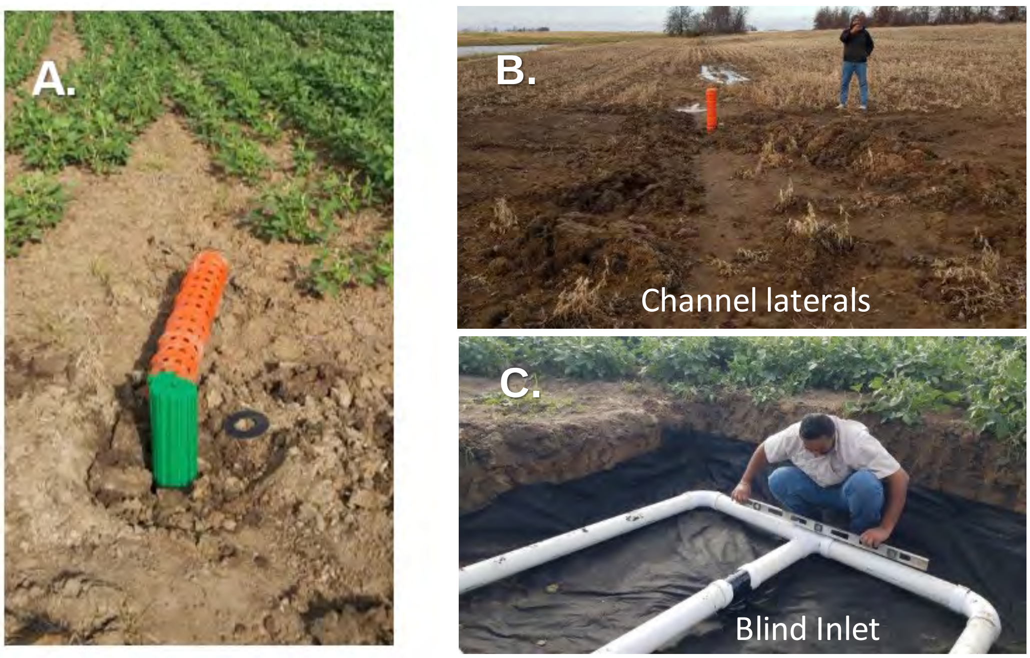

Figure 4. Water quality inlet (A), channel lateral (B), and blind inlet (C) technology at the Grace Greenley Conservation Showcase farm.

On-farm channel tiling. Tile laterals have been installed with a minimum of 2 ft of backfill and extended from the Hickenbottom inlet 5 ft downslope from the channel and 10 ft upslope from the channel in the footslope area. Contractors that utilize laser or RTK guided equipment for installation of subsurface drainage tile using a tile plow or trencher have been utilized for installation of the on-farm sites. Each site has at least three replications for each location. Data will be collected on soybean emergence, plant population, plant height, biomass production, seed yield and quality, and nutrient uptake based on the landscape position delineation (Singh et al., 2019a, 2019b). Yield monitor data will be utilized for validation of crop response.

On-farm blind inlets. Landscapes will be mapped for soil types, fertility, slope, outlet locations, and surface inlets to compare blind inlets with currently implemented surface inlets (Hickenbottom risers). Landscapes will be evaluated using existing LIDAR data and ground-based RTK surveys of existing fields that can also evaluate soil EC based on Singh et al. (2019a, 2019b). The topographic position index (TPI) tool in ArcGIS (v10.6) will be used to identify landscape positions (Figure 1). The model used for delineating landscape positions is a direct adaption of the slope position classification model by Evans et al. (2016), which delineates four landscape positions (e.g., shoulder, backslope, footslope, and channel). The TPI in the slope position classification model is the difference of a cell elevation (e) in the DEM from the mean elevation (me) of a user-specified area surrounding e. A radius of 6.1 m will be used to determine the TPI, and a TPI raster will be outputted from the DEM. A radius of 20 ft is chosen so that microscale topographic variation within each field could be omitted. This project will delineate the amount of area drained into the surface inlet so a planned blind inlet can be sized appropriately using a blind inlet sizing tool (Sandstrom, 2020).

Observations:

Visual differences in drying in the channel were evident in the spring of 2023 (Figure 5). Since we experienced dry spring conditions, there were limited effects on corn plant establishment in 2023. For the blind inlet, field operations including anhydrous ammonia application (Figure 6) and planting occurred unobstructed with the blind inlet.

Figure 5. Soil drying differences of channel lateral treatment (background) and non-treated channel (foreground) at the Grace Greenley Conservation Showcase farm in the spring, 2023.

Figure 6. Unobstructed anhydrous ammonia application through the blind inlet at the Grace Greenley Conservation Showcase farm in the fall, 2022.

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CORN RESPONSE TO ASYMBIOTIC NITROGEN FIXATION PRODUCTS IN UPSTATE MISSOURI

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Introduction:

Nitrogen (N) fixing bacteria convert atmospheric N into organic forms that can be utilized by the plant are common with legumes. The symbiosis between *Rhizobia* and legumes is a critical plant–microbe mutualism that is essential for high yielding soybean. Farmers have inoculated soybean seeds with commercially available products that contain nodulating strains of bacteria for years. Recently, an emphasis on developing technology to supply corn with additional N through biological processes has been a focus of several agribusinesses throughout the Midwestern U.S.

Nitrogen is one of the most expensive corn input costs and is critical for grain production. Currently, biological products are available to corn farmers that are promoted to enhance nitrogen use efficiency. These biological N efficiency enhancers ("bugs-in-a-jug") may increase plant-available nitrogen and could be incorporated into our current nitrogen recommendation systems if there is a valid and repeatable increase in corn grain yields. There is an opportunity to reduce uncertainty in Missouri N fertilizer recommendations through increased knowledge and understanding of this technology. A reduction in N rates using biological N efficiency enhancers could reduce environmental N loss (i.e. leaching and gaseous) commonly experienced in soils throughout Missouri. Some claims have noted that N amounts could be significantly reduced which would be a significant cost savings to corn farmers. However, data on the efficacy of these biological-based nitrogen enhancers is limited.

The main difference between symbiotic and non-symbiotic nitrogen fixing bacteria is that the host plant will send food/energy to the symbiotic microbes whereas non-symbiotic microbes have to find their own food. There are many factors that affect the amount of N which can be produced by non-symbiotic N fixing bacteria. Free-living N fixers need a high carbon to nitrogen ratio in the soil, adequate rainfall, and warm temperatures to be successful. If the soil contains a lot of available N, then the bacteria may reduce or stop converting N_2 gas into ammonia. This process of converting N_2 gas into ammonia requires the use of the enzyme nitrogenase which is a very energy intensive process; therefore, free N in the soil can affect the ability of microbes to fix N or reduce N fixation (Vadakattu, and Paterson, 2006).

In a study by Tufail et al. (2021), *Gluconacetobacter diazotrophicus* (Envita, Table 1) applied to corn increased shoot and root dry weight by 67% and 80%, respectively. When compared to the untreated control, *Gluconacetobacter diazotrophicus* increased the N concentration in corn shoots when grown under moderate drought stress, severe N deficiency, and moderate and severe combination of the drought stress and N deficiency treatments. These results have shown that the bacteria were able to colonize with the corn roots, increase plant N concentration, and increase plant growth. *Klebsiella variicola* and *Kosakonia sacchari* are both asymbiotic N fixing bacteria that are found in ProveN (Table 1). A study by Wen et al. (2021) showed that these bacteria increased corn yield by 5.2 bu ac^{-1} and reduced field variability by 8-25%. Depending on the product, some may be applied as a seed treatment, in-furrow, or foliar.

Objective:

The objective of this research was to quantify the N impact of biological management products on corn response.

Table 1. Biological product active ingredient organism or common chemical name, trade name, application rate, and placement in 2020, 2021, and 2022 in Missouri.

Biological product or common chemical name	Trade name	Application rate	Application placement
Gluconacetobacter diazotrophicus	†Envita™	4.5 oz ac^{-1}	In-furrow
Methylobacterium symbioticum	‡Utrisha™ N	5 oz ac^{-1}	Postemergence V4-V8
Klebsiella variicola + Kosakonia sacchari	ProveN™, ProveN®40⁋	13-14 oz ac^{-1}	In-furrow
Nitrapyrin (2-Chloro-6-(trichloromethyl)pyridine)	††Instinct NXTGEN®	24 oz ac^{-1}	Impregnated urea

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‡Corteva. 2022. UtrishaTM N Nutrient Efficiency Biostimulant. https://www.corteva.ca/content/dam/dpagco/corteva/na/ca/en/files/brochure/DF-Utrisha-N-Technical-Brochure-English.pdf. Accessed 13 Nov. 2022.
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Procedures:

Field research was conducted from 2020 to 2022 at the University of Missouri Lee Greenley Jr. Memorial Research Farm near Novelty, which is part of the Northern Missouri Research, Extension, and Education Center. A summary of the biological stimulant active ingredient organism or common chemical name, application rate, and timings of N efficiency enhancers is reported in Table 1. Experiments were arranged in a randomized complete block design with six replications. Plots were 10 by 40 ft. Corn was planted in 30 inch wide-rows at 34,000 seeds ac^{-1}. Urea or urea plus nitrapyrin (Instinct NXGEN) was broadcast surface applied to each plot and incorporated immediately after application on the 20 April 2020, 27 April 2021, and 10 May 2022. Planting date and in-furrow applications of products occurred on 30 April 2020, 27 April 2021, and 10 May 2022. The in-furrow application was made at 18.8 gallons ac^{-1} at 5 psi with water as the carrier. The postemergence broadcast application was applied at the V5 stage of development with a CO_2 propelled sprayer at 15 to 19 GPA using 8002 XR nozzles traveling at 2.9 MPH on 12 June 2020, 10 June 2021, and 13 June 2022. Leaf greenness was determined using a SPAD chlorophyll meter (Konica Minolta, Tokyo, Japan). Plant populations prior to harvest were determined from the entire length of one row. The center two rows of each plot were harvested for corn yield determination. Grain weight, moisture, and test weights were determined for each plot using a plot combine (Wintersteiger Delta) equipped with a HarvestMaster GrainGage. The harvest dates for this study were 23 September 2020, 21 September 2021, and 28 September 2022. Grain yields were adjusted to 15% prior to analysis. Grain samples were collected and analyzed for starch, protein, and oil concentrations (Foss 1241, data not presented). Data were subjected to ANOVA and means separated using Fisher's Protected LSD (P=0.1).

Results:

There was no significant interaction between years and treatments for leaf greenness in late June and plant population at harvest; therefore, data were combined over years (Table 2). Leaf greenness increased as N rate increased. All of the biological N management treatments had leaf greenness values similar to urea at 100 lbs N ac^{-1}. Plant populations at harvest were 32,150 to 34,640 plants ac^{-1}. All treatments had plant populations that were similar or greater than the non-treated control. Plant populations of all treatments were similar to urea at 100 lbs N ac^{-1}.

Table 2. Corn plant population at harvest averaged over years and corn yield response to biological N management treatments in 2020, 2021, and 2022. Corn grain yield average was combined over years.

	Leaf	Plant	Corn Grain Yield			
Nitrogen treatment (lbs ac^{-1})	greenness	population	2020	2021	2022	Average
	SPAD	No. ac^{-1}	-------------- bu ac^{-1} --------------			
0 N	44.6	32,150	84.7	89.9	78.4	84.3
50 N	47.3	34,440	101.9	124.5	117.0	114.4
100 N	50.7	33,660	124.7	135.2	155.7	138.5
150 N	51.5	33,940	166.9	156.3	163.7	162.3
200 N	53.5	34,124	184.7	177.6	183.6	182.0
100 N + Envita in-furrow	49.5	34,640	139.1	140.2	155.2	144.8
100 N + ProveN in-furrow	50.5	34,130	123.9	130.4	156.6	137.0
100 N followed by Utrisha postemergence	50.1	34,380	127.3	145.2	154.7	142.4
100 N + Instinct	50.4	34,610	128.1	154.3	154.6	145.6
100 N + Instinct followed by Utrisha postemergence	49.5	33,150	140.9	137.3	148.3	142.1
LSD (P=0.1)	1.7	1,180	---------- 9.9 ----------			5.7

A significant year x treatment interaction (P < 0.0001) for grain yield was observed; therefore, data were presented separately for each year (Table 2). In 2020, urea plus Instinct NXGEN followed by Utrisha increased yields 16.2 bu ac^{-1} compared urea at 100 lbs N ac^{-1}. Instinct NXGEN treated urea increased yields 19.1 bu ac^{-1} compared to urea at 100 lbs N ac^{-1} in 2021. No differences among biological soil N treatments were observed in 2022.

Average yields over the three years were reported in Table 2 and Figure 1. Grain yields increased as N rate increased. At 100 lbs N ac^{-1}, an in-furrow application of Envita increased average corn yields 6.3 bu ac^{-1} while treating urea with Instinct NXGEN increased yields 7.1 bu ac^{-1} compared to urea applied alone. This indicates that the nitrification inhibitor was most likely protecting against gaseous N loss on claypan soils (Nash et al. 2012, 2015) which have poor internal drainage and can contribute toward denitrification. In other research, deep placement of urea fertilizer using nitrapyrin has significantly reduced nitrous oxide emissions in claypan soils (Steusloff et al., 2019).

A summary of asymbiotic N-fixing products in the North Central U.S. was recently compiled by Franzen et al. (2023). In corn trials conducted in North Dakota, Minnesota, Illinois, Indiana, Missouri, and Michigan, Envita significantly increased yield at 1 of 12 trials compared to a similar rate of nitrogen alone. In North Dakota, Missouri, Michigan, Kentucky, and Ohio, Utrisha had no effect on corn grain yields compared to N rate alone in eleven different trials. Finally, ProveN or ProveN 40 applied in-furrow or seed treated significantly increased yield in 1 of 26 corn trials in Minnesota, Illinois, Missouri, Kansas, Michigan, and Nebraska compared to the same N rate alone.

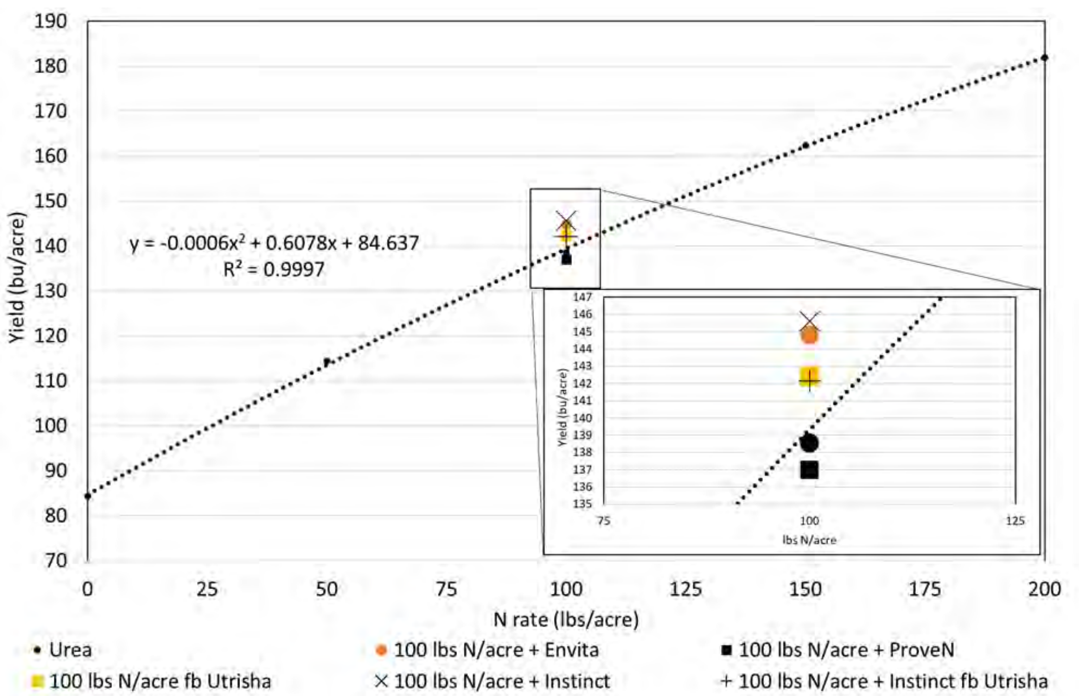

Figure 1. Corn grain yield response to nitrogen rates and biological N management products. LSD (P=0.1) was 5.7 bu ac^{-1}. The inset figure illustrates the average corn yields (2020-2022) for biological N management products following urea at 100 lbs N ac^{-1}.

<u>Recommendations:</u>

Through analyzing various data from Midwest land-grant universities (Franzen et al., 2023) along with three years of data in Missouri, additional research is needed to identify responsive locations and environments. This and other research (Steusloff et al., 2019) shows that the inclusion of a nitrification inhibitor such as nitrapyrin can increase corn yields and reduce gaseous N loss when used on poorly drained soils that are subject to dentification loss mechanisms. A research project in partnership with the Missouri Fertilizer Control Board is evaluating biological N products and cropping systems at multiple sites in Missouri to determine if N recommendations can be modified using new technology. Farmers should be skeptical of products claiming to be a quick fix but should also keep an open mind heading into the future as the utility of new technology in soil microbiology may help farmers increase N use efficiency.

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SITE-SPECIFIC SULFUR MANAGEMENT FOR SOYBEAN PRODUCTION ON TOPOGRAPHIC POSITIONS

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Introduction:

Topographic positions (summit, shoulder, hillslope, and footslopes), elevation, slope, aspect, curvature, upslope contributing area, flow length, flow direction, and flow accumulation are some of the landscape features that are responsible for soybean yield variability in an agricultural field. Therefore, site-specific nutrient management is key for enhancing soybean production. Although site-specific nitrogen management has been studied widely, no studies have evaluated sulfur (S) availability to crops based on topographic and landscape attributes. Low organic matter and eroded topsoil on backslope or footslope landscape positions might result in nutrient deficiency and may respond to a sulfur application. Additionally, S fertilizer recommendations in Missouri are based on research conducted by Hanson et al. (1984) and have not been updated since 2003. Missouri's current S recommendation is to apply 10-20 lbs S ac^{-1} annually when sulfate-S content is less than 7.5 mg kg^{-1} with a cation exchange capacity of less than 6.5 meq 100 g^{-1}. In a meta-analysis conducted on S fertilization of soybean, de Borja Reis et al. (2021) reported an increase in soybean yield by 1.6%, seed protein concentration by 0.3%, and S amino acids by 1% across 44 site-years and six states in the US.

Objectives:

The goal of this research is to evaluate S fertilizer source and rate impact on soybean yield, seed quality, and S removal at the shoulder, backslope and footslope topographic landscape positions.

Procedures:

The experiment was conducted at the Lee Greenley Jr. Memorial Research farm in 2022. The experiment was arranged as a randomized complete block design with three replications. The treatments included in the study were topographic position (shoulder, backslope, and footslope), S sources [ammonium sulfate (21-0-0-24), TigerS or elemental S, SymTRX 20S (16-1-0-20-2-16, N-P-K-S-Fe-Organic by dry wt.)], and S application rates (0, 5, 10, 15 lb S ac^{-1}). Soybean was planted on June 4th at 140,000 seeds ac^{-1} in 15-inch-wide rows. The plot size was 10 x 30 ft. The center four rows of each plot were harvested using a plot combine to obtain seed yield. The yield data was adjusted to 13% moisture content before analysis. Seed samples were collected at the time of harvest for seed S and oil content. The oil content in soybean seed was determined using the near-infrared grain analyzer (1241 Foss Infratech, Eden Prairie, MN). The S removal in soybean seed was calculated by multiplying S content in soybean seed and seed yield. The collected data was analyzed using the Glimmix procedure in SAS statistical software (SAS Institute Inc., Cary, NC). T-grouping of least-square means was used for mean comparisons at $P < 0.05$.

Results:

Sulfur sources showed no significant impact on the soybean yield, S removal, and grain quality. Soybean seed yield (P=0.0051), seed S removal (P=0.0202), and oil content (P=0.0118) were significantly affected by the interaction effect of S application rates and topographic positions

(Table 1). Sulfur application rate showed no impact on soybean grain yield at the shoulder topographic position. At the backslope topographic position, S at 10 lb ac^{-1} had 10.0 bu ac^{-1} higher seed yield compared to the non-treated control. At the footslope position, a 15 to 30% reduction in soybean yield was found when the S application rate was increased from 5 lb ac^{-1} to 10 lb ac^{-1} or 15 lb ac^{-1}. When S was applied at 10 and 15 lb ac^{-1}, soybean yield was lower at the footslope position than at the backslope and shoulder positions. In the absence of a S application, the backslope had 7.8 bu ac^{-1} lower yield than at the shoulder position.

Soybean seed S removal was reduced by 1.5 and 2.9 lbs ac^{-1} when S was applied at 10 and 15 lbs ac^{-1} compared to S at 5 lb ac^{-1} at the footslope position. Similarly, S application at 10 and 15 lbs ac^{-1} reduced seed S content by 1.6 and 3.0 lbs ac^{-1} compared to untreated control at the footslope position. No significant differences were obtained for seed S content at the shoulder position.

Oil content of soybean seed was 0.81% greater at the footslope position when compared to the other two landscape positions with S at 10 lb ac^{-1}. When S was applied at 15 lb ac^{-1}, soybean oil was 0.6 to 1.2% greater at the footslope position compared to the backslope and shoulder positions. No differences were obtained for oil content due to topographic landscape positions when S was applied at 0 or 5 lb ac^{-1}. At the footslope position, S at 10 and 15 lb ac^{-1} resulted in greater oil content than the 0 and 5 lb ac^{-1} S application rates. This research is ongoing and precision applications based on landscape position appear necessary.

Table 1. Soybean seed yield, S removal, and oil content as affected by the interaction of S application rates and topographic positions.

Topographic position	S application rate	Soybean seed yield	Soybean S removal	Soybean seed oil content
	lb ac^{-1}	bu ac^{-1}	lb ac^{-1}	%
Shoulder	0	53.1a[†]	10.1ab	20.2bc
Shoulder	5	49.4abc	9.8abc	20.4bc
Shoulder	10	52.3ab	10.2a	20.3bc
Shoulder	15	48.2abc	9.3abcd	20.0c
Backslope	0	45.3bc	8.4cd	20.5bc
Backslope	5	52.1ab	9.5abcd	20.2bc
Backslope	10	55.3a	10.1ab	20.3bc
Backslope	15	47.8abc	8.6bcd	20.6b
Footslope	0	52.3ab	9.8abc	20.4bc
Footslope	5	52.3ab	9.7abc	20.4bc
Footslope	10	44.2cd	8.2de	21.1a
Footslope	15	36.7d	6.8e	21.2a

[†]Same letters within a column indicate no significant differences between means at $p < 0.05$.

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POTENTIAL REDUCTION OF GREENHOUSE GAS EMISSIONS AFTER ANHYDROUS AMMONIA APPLICATION WITH PRONITRIDINE NITRIFICATION INHIBITOR

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Introduction:

Poorly drained soils can experience significant gaseous N loss as ammonia and nitrous oxide following N fertilizer application (Nash et al., 2012; 2015). In upstate Missouri, use of enhanced efficiency urea fertilizer reduced ammonia volatilization 71% and yield scaled nitrous oxide emissions 58% compared noncoated urea applied to a poorly drained soil (Nash et al., 2015). Anhydrous ammonia remains the most consistent N fertilizer source across tillage systems on poorly drained soils in the Midwest U.S. (Nelson et al., 2014). Centuro® nitrogen stabilizer (pronitridine) is a new nitrification inhibitor that has increased yields when used with anhydrous ammonia (Singh and Nelson, 2019).

The scientific community has yet to conclude the extent of nitrification inhibitors on reduced greenhouse gas emissions from soil gas flux when applied with anhydrous ammonia. Some promise has been shown for the reduction of nitrous oxide emissions from urea-ammonium nitrate with nitrapyrin (Graham et al., 2018). Both new nitrification inhibitor product development and sampling challenges have limited conclusive evidence for significant changes in cumulative nitrous oxide emissions. Inconsistencies in sampling methodology, inherent soil variability, and sampling intensity are three major challenges in reaching conclusive evidence (Charteris et al., 2021). However, new portable Fourier Transform Infrared Spectroscopy (FTIR) technology has the potential to account for spatial and temporal variability while reducing labor costs and sampling error through gas collection, storage, and analysis. In-field analysis also allows for real-time assessment of soil gas fluxes providing researchers with valuable data to alter sampling strategies in real time to account for temporal gas flux variability. Considering future carbon markets and producers' drive to unite economics with sustainability, comprehensive evaluations of greenhouse gas emissions from fertilizer application with nitrification inhibitors are needed.

Objectives:

The objective of this study was to examine the potential of pronitridine N stabilizer, Centuro®, to reduce greenhouse gas emissions (CO_2, CH_4, N_2O, NO_2, and NO) and NH_3 from corn fertilized with anhydrous ammonia while determining the effect of pronitridine on N uptake, nitrogen use efficiency, and yield.

Procedures:

Experimental plots were established at the University of Missouri Lee Greenley Jr. Memorial Research Farm near Novelty, MO. The soil series located at the experimental plots included Putman, Adco, and Mexico. Soil series represented are wet alfisols (aqualfs) and are typical of row crop agricultural soils in the central claypan region of Missouri. A total of 30 plots (10 x 40 ft) were established in a randomized block design. Within each block, a total of five treatments were randomized. Treatments included a 0 lb N ac^{-1} along with two fertilizer rates (120 and 180 lb N ac^{-1}) with and without the addition of pronitridine at a rate of 5 gal ton^{-1}. Fertilizer was applied on 10 May 2022. In addition to soil gas flux sample collection, yield data were collected from all six replications.

Greenhouse gas emissions were measured via soil gas flux from static chambers located in three of the six treatment replications. Two chamber anchors were installed after fertilization and planting in each plot. Anchors were 8 inches in diameter and constructed from schedule 40 polyvinyl chloride (PVC). Anchors were placed at the center of each plot, with one anchor centered over the band created by anhydrous ammonia injection and corn planting. The other chamber was placed in the interrow. The interrow sampling location represented 73% of the total plot surface area and the in-row sampling location represented 27% of the total plot surface area. The proportional average of the two-soil gas flux sampling locations was used to calculate cumulative daily flux averages and cumulative flux loads. Fifteen sets of soil gas fluxes were measured in 2022 using a FTIR portable gas analyzer (Gasmet GT5000 Terra). Concentrations of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), nitrogen dioxide (NO_2), nitric oxide (NO), and ammonia (NH_3) were collected every 20 seconds via a closed chamber placed at each sampling anchor location. Concentration data were collected for 5 minutes at each sampling location and fluxes were calculated using the universal gas law and the rate of change in gas species concentration. Ancillary data collected at each sampling location include soil temperature, soil moisture, and air temperature.

<u>Results:</u>

Corn grain yield:

Corn grain yield ranged from 100 to 249 bu ac^{-1} and was significantly affected by treatment ($P < 0.01$). Generally, yield increased with fertilizer rate and with the addition of pronitridine (data not presented). Anhydrous ammonia at 180 lb N ac^{-1} with pronitridine had the greatest yield (224 bu ac^{-1}). The second greatest yielding treatment was 120 lb N ac^{-1} with pronitridine, averaging 202 bu ac^{-1}. However, the 120 lb N ac^{-1} with pronitridine treatment was not significantly different from the 120 lb N ac^{-1} without pronitridine. The 0 lb N ac^{-1} treatment yielded the least, averaging 112 bu ac^{-1}.

Greenhouse gas emissions:

We observed measurable concentrations of CO_2, N_2O, and CH_4 from soil gas flux across all treatments. Concentrations of NO_2, NO, and NH_3 were not measurable from soil gas flux. These gases are very reactive gases and are likely not a major component of soil gas flux to the atmosphere. Methane was found to be produced and consumed from the soil surface, resulting in cumulative fluxes that were not significantly different from 0 g CH_4-C ha^{-1}. These data suggest soils in this study were not a producer of CH_4.

Carbon dioxide fluxes ranged from 0 to 125 kg CO_2-C ha^{-1} increasing with daily average temperature from May until late July. From August to November soil moisture was limited which likely limited CO_2 production. Cumulative CO_2 emissions were not significantly different between treatments. Nitrous oxide fluxes ranged from -0.1 to 1,886 g N_2O-N ha^{-1}(Figure 1). Sampling locations over the anhydrous ammonia band were significantly greater than locations located in the interrow. Nitrous oxide fluxes were greatest in the month following fertilizer application and planting. Cumulative nitrous oxide emissions ranged from 1.3 to 16.2 kg N_2O-N ha^{-1}. Nitrous oxide emitted from unfertilized plots was significantly less than fertilized treatments, except 180 lb N ac^{-1} without pronitridine. There was no significant difference between treatments of fertilizer with and without pronitridine. While cumulative N_2O emissions from fertilized plots with pronitridine exhibited greater averages than treatments without pronitridine, these differences were not significantly different (Figure 2). These data warrant further investigation. Nitrous oxide emissions are inherently spatially and temporally variable highlighting the importance of measurements from multiple growing seasons.

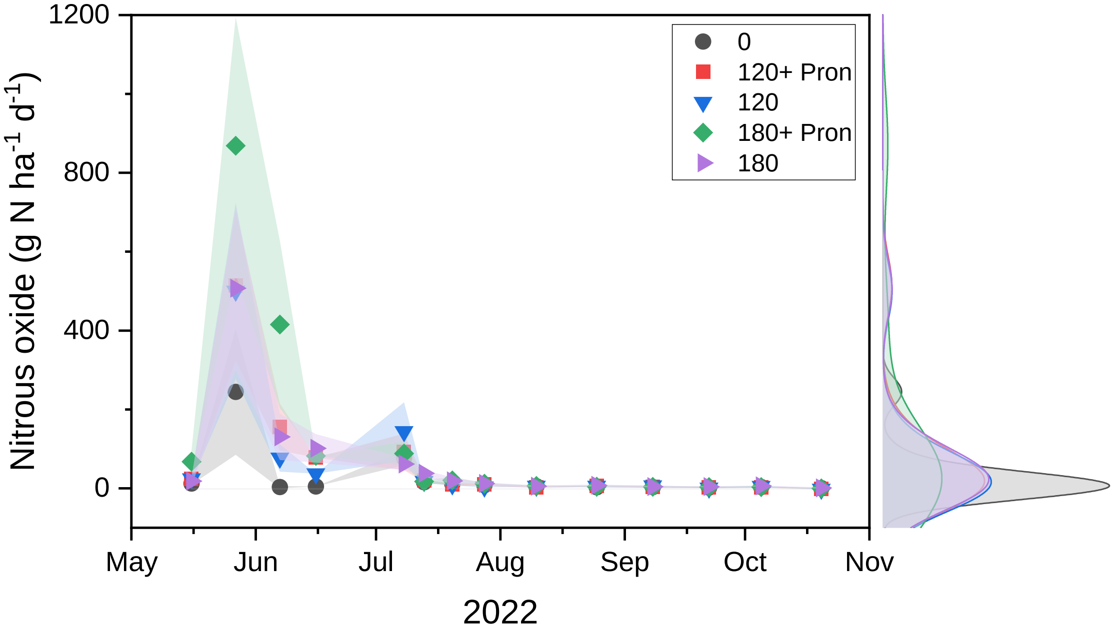

Figure 1. Measured nitrous oxide fluxes in g N_2O-N ha^{-1} day^{-1} from 0 lb N ac^{-1} (0), 120 lb N ac^{-1} (120), and 180 lb N ac^{-1} (180) with and without the addition of pronitridine (Pron) at a rate of 5-gal ton^{-1}. Shaded areas represent the standard error for each treatment. Curves to the right of the figure represent distribution areas of fluxes for each treatment. Fertilized treatments have a wider distribution with greater representation in fluxes over 200 g N_2O-N ha^{-1} day^{-1}.

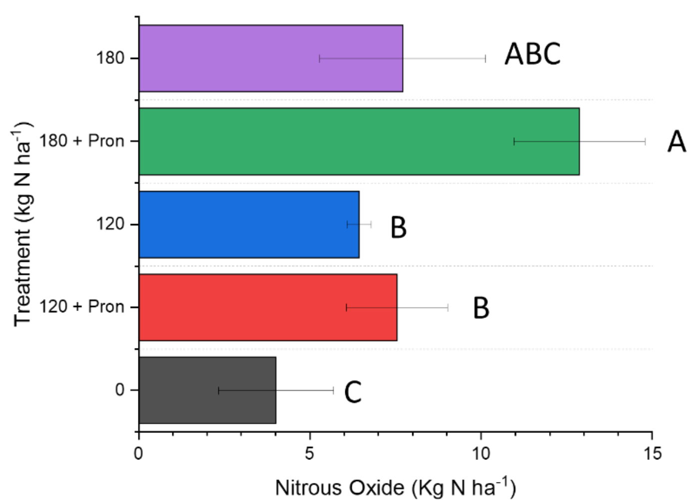

Figure 2. Cumulative nitrous oxide emissions in kg N_2O-N ha^{-1} from anhydrous ammonia treatments including 0 lb N ac^{-1} (0), 120 lb N ac^{-1} (120), and 180 lb N ac^{-1} (180) with and without the addition of pronitridine (Pron) at a rate of 5 gal ton^{-1}. Whiskers on bars represent standard

error for all replications in each treatment. Bars with different letters shows significant differences between the treatments.

Recommendations:

This study evaluated the effect of fertilizer rate and the addition of the nitrification inhibitor pronitridine. Yield significantly increased with fertilizer rate and the addition of pronitridine. Neither fertilizer rate nor pronitridine significantly impacted cumulative N_2O emissions. Research is ongoing and has expanded to examine autumn and spring applications of the presented treatments. Pronitridine as an N stabilizer may prove to influence fall applied anhydrous ammonia, considering the extended time the nitrogen source is expected to remain in place before planting. The continued research is designed to provide more conclusive evidence on the role of pronitridine in reducing nitrous oxide emissions from soil gas flux.

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DRAINAGE WATER MANAGEMENT IMPACTS SOIL PROPERTIES IN FLOODPLAIN SOILS IN MISSOURI

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Introduction:

Tile drainage systems are a commonly used agriculture management practice throughout the Midwestern United States to meet crop production goals (Fausey et al., 1995, Skaggs et al., 1994). The function of a drainage system in floodplain soils is to remove excess water in the soil profile and maintain a sufficient water level in the root zone to maximize crop production. A drainage water recycling (DWR) system consists of water level control structures in the outflow pipe to prevent excessive drainage and the reservoir component captures and stores surface and/or subsurface runoff for future use as irrigation water (Frankenberger et al., 2017, Hay et al., 2021). During the crop growing season, reservoir water and dissolved nutrients are pumped into subsurface tile drains to provide irrigation water to the crop root zone (Tan et al., 2007). This system utilizes DWR to mitigate drought and reduce agriculture non-point source pollution (Hay et al., 2021). Research in Missouri has shown increased corn (*Zea mays* L.) grain yield 14–50% and soybean (*Glycine max* L.) yield 7-29% with DWR compared to free drained or non-drained treatments (Nelson et al., 2011, Nelson and Smoot, 2012, Singh and Nelson, 2021). A limited number of studies have evaluated the quality of recycled drainage water for irrigation and its impact on soil properties.

Objectives:

The aim of this study was to examine the effect of free drainage (FD) and drainage water recycling (DWR) systems on soil properties compared to non-drained (ND) soils in continuous corn production in a floodplain soil of upstate Missouri.

Procedures:

The water samples from reservoir at the Lee Greenley Jr. Memorial Research Farm were collected during the summer months (July-August) in 2016, 2017, 2018, and 2019. The collected water samples were analyzed for pH, total suspended solids (TSS), electrical conductivity (EC), nutrients (NO_3-N, PO_4-P), cations (K, Na, SO_4-S), carbonates (CO_3^{2-}), and bicarbonates (HCO_3^-). The soil samples were collected at 0–4, 4–8, 8–16, and 16–24 inches depths using a Giddings probe (Giddings Machine Company, Windsor, CO) in the fall of 2015, 2016, 2017, 2018, and 2021. Soil samples were analyzed for soil pH, cations (Ca, Mg, Na, and K), nitrate-N (NO_3-N), total nitrogen (TN), total organic carbon (TOC), organic matter (OM), and soil texture. Collected data were analyzed using mixed model in SAS (SAS Institute Inc., Cary, NC).

Results:

Reservoir Water Quality:

Variation in water quality parameters was observed over years (Figure 1). Water pH was in a range of 6.8-7.8. Salinity of water is measured as electrical conductivity. Electrical conductivity of water below 0.25 dS m^{-1} is considered good for irrigation purposes. The variation in anions could have occurred due to differences in amount of water used from reservoir for irrigation purposes. Overall, there was decreasing trend in ion concentrations except in 2017 and 2018. A similar trend was observed for HCO_3^- concentration with the highest concentration observed in 2017. In Missouri, HCO_3^- < 90 mg l^{-1} in water is considered safe for irrigation water use with a slight to moderate risk at HCO_3^- 90 – 520 mg l^{-1} (Schultheis, 2017).

Soil Fertility:
In this research, no impact of drainage treatments was observed on sand, silt, or clay content (Table 1). Drainage treatments significantly impacted ($P < 0.05$) soil pH, Ca, Mg, K, NO_3-N, OM, TOC, TN (Table 1). Soil pH was reduced by 0.5–0.6 units in DWR (pH = 5.2) and FD (pH = 5.1) treatments compared to ND (pH = 5.7). Water table fluctuation and quality of irrigation water can influence soil chemical properties by changing the soil redox potential (Vadas and Sims, 1998). This can be explained with a reduction in cations (Ca, Mg, and K) in DWR compared to DO and ND. In DWR, soil test Ca was reduced by 33% and 44% compared to FD and ND, respectively (Table 1). Similarly, soil test K was lowered with DWR by 24% and 31% compared to FD and ND, respectively. Soil test Mg was reduced by 19% and 13% in DWR and FD treatments respectively, compared to ND. This could be due to 52% and 53% higher overall K and Mg grain removal with DWR compared to ND in this study (Kaur et al., 2021). In addition, elevated levels of bicarbonates in irrigation water in the DWR treatment may combine with Ca or Mg and precipitate out of the soil solution as Ca or Mg carbonates (Zaman et al., 2018).

Soil TN and NO_3-N content decreased in soils with the DWR treatment over the study period compared to FD and ND soils (Table 1). This could be due to the increased soil aeration with regular management of the water table during the growing season which increased nutrient uptake, grain yield, and N removal. In this study, reduced soil TN in this study could be attributed to 36% higher TN grain removal with DWR compared to ND due to improved water utilization and reduced waterlogging stress (Kaur et al., 2021). Similarly, a reduction in soil OM and TOC was observed with DWR compared to FD and ND soils (Table 1). Soil OM content was reduced by 2 % with DWR compared to ND and FD. Soil total organic carbon was reduced 19% in DWR compared to FD and ND treatments. Regular water table management in the DWR treatment during the growing season improved aeration and increased soil water content in the DWR treatment which may have resulted in accelerated OM and TOC decomposition. In addition, changes in soil temperature and moisture regimes lead to depletion of the OM pool due to accelerated mineralization (Lal, 2009), which could explain the observation in this study.

Conclusion:
The investigation of soil properties was used to highlight the key role of water table dynamics between different drainage treatments. Based on this research, it can be concluded that the quality of recycled water was safe for crop irrigation use over the 6 years that were evaluated in this research. It seems that the most apparent concern with drainage and subirrigation system is the changes in soil chemical properties and loss of soil OM and TOC. Similar results were reported in a 17-year study, showing suitability of recycled water for irrigation purposes (Kaur et al., 2023).

More information on this research is available at: Kaur, H., K.A. Nelson, G. Singh, K.S. Veum, M.P. Davis, R.P. Udawatta, and G. Kaur. 2023. Drainage water management impacts soil properties in floodplain soils in the Midwestern, USA. Agric. Water Manage. 279, 108193. https://doi.org/10.1016/j.agwat.2023.108193

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Table 1. Soil properties from drainage water recycling (DWR), drainage only (DO), and non-drained (ND) treatments collected in fall 2015–2018 and 2021 at four soil depths (0–4, 4–8, 8–16, 16–24 inches). Within a column means followed by same letters are not significantly different at $\alpha = 0.05$.

Treatment	pH[†]	CEC	Ca	Mg	K	Bray-1 P	NO_3-N	OM	TC	TN
		cmol kg^{-1}	---------------------lbs ac^{-1}				------------------------------	---------------%		------------------
DWR	5.2 b	14.5	2209 b	435 b	164 b	47	9.8 b	2.2 b	1.5 b	0.18 b
FD	5.1 b	14.3	3303 b	453 b	217 a	54	16.1 a	2.4 a	1.8 a	0.21 a
ND	5.7 a	14.2	4006 a	521 a	237 a	56	9.8 b	2.4 a	2.0 a	0.22 a
p-value	< .0001	0.8378	< .0001	0.0004	< .0001	0.2942	< .0001	0.0137	< .0001	< .0001

[†]pH, pH measure with 0.01 M $CaCl_2$; CEC, cation exchange capacity; NA, neutralizable acidity; Ca, calcium; Mg, magnesium; K, potassium; P, phosphorus; OM, organic matter; TC, total carbon; TN, total nitrogen

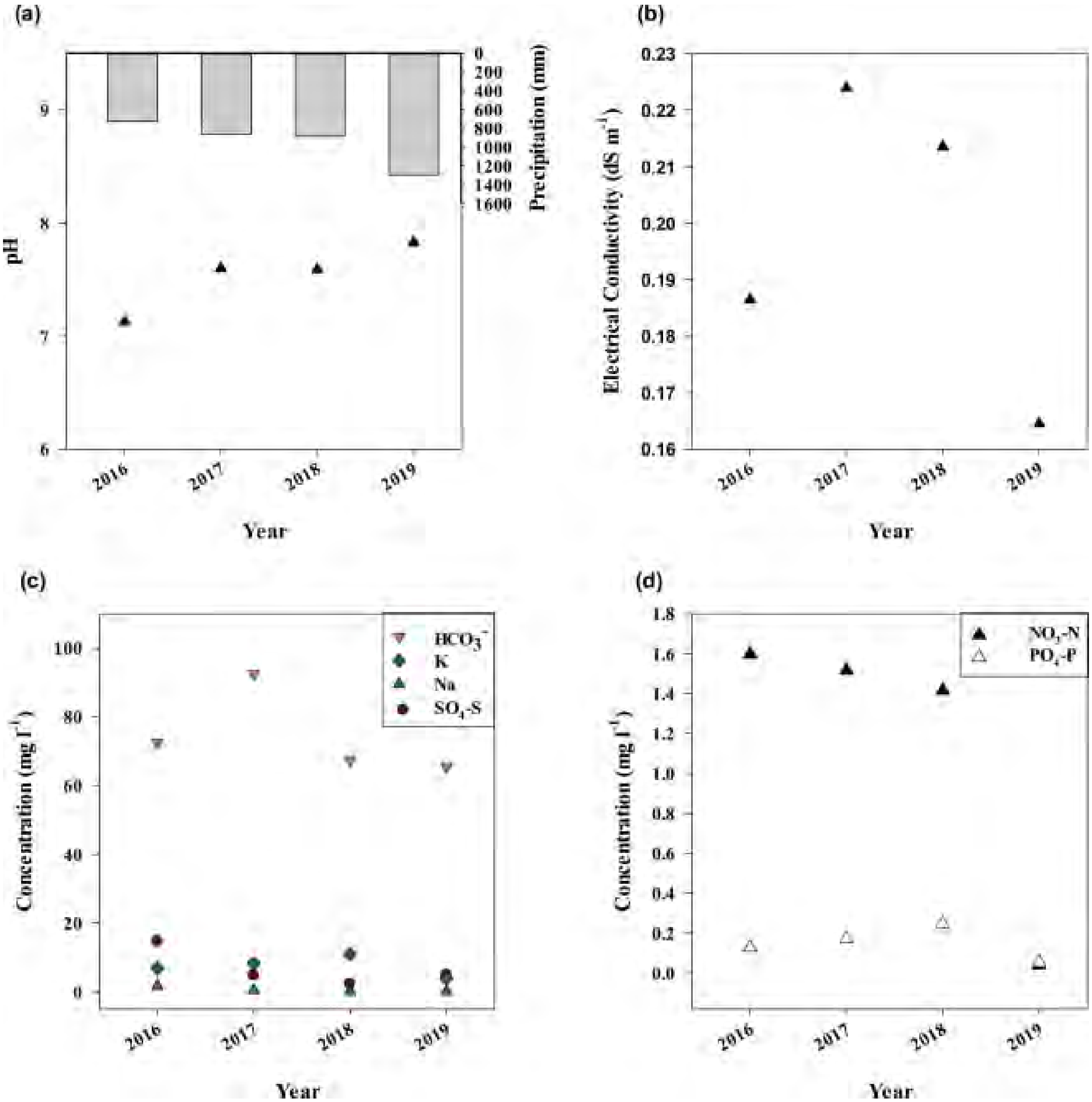

Figure 1. Average reservoir irrigation water quality parameters including (a) pH and bars represent cumulative annual precipitation; (b) electrical conductivity (EC); (c) bicarbonates (HCO_3^-), potassium (K), sodium (Na), and sulfate (SO_4-S) concentrations; and (d) nitrate-N (NO_3-N) and orthophosphate (PO_4-P) concentrations in 2016–2019. Vertical bars in (a) represents annual precipitation for 2016–2019.

LONG-TERM DRAINAGE WATER RECYCLING AFFECTS SOIL HEALTH AND SOIL PROPERTIES

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Introduction:

Drainage water recycling (DWR) is a new innovative agriculture drainage water management system that consists of a water storage reservoir linked to farm fields that contain a network of subsurface drainage pipes. Recycled water can be applied to the field through various irrigation systems such as sprinklers, drip irrigation, and subirrigation (Hay et al., 2021; Willison et al., 2021). Surface water runoff and subsurface drainage water contains nutrients, sediments, salts, organic compounds, and trace elements that can be transported as the water moves over and/or through the soil profile which can accumulate in a DWR reservoir (Corwin & Bradford, 2008). Recycled drainage water has been found to have improved water quality and increased crop yield when applied during the late vegetative and early reproductive stages of corn development in the Midwest (Kaur et al., 2021; Willison et al., 2021). However, safety of the recycled irrigation water is questionable as drainage water can be enriched in soluble mineral salts and trace elements that are influenced by agricultural activities and geographic location (Wang et al., 2010). This may subsequently influence soil properties by influencing salinity levels in the soil. Few studies have been conducted in tile-drained fields to identify the influence of recycled water systems on soil health properties in the Midwestern U.S.

Objectives:

The objectives of this research were to 1) monitor nutrient concentrations in a DWR reservoir over time, and 2) evaluate the effects of DWR, free drainage (FD), and non-drained (ND) treatments on soil properties in a corn-soybean rotation.

Procedures:

The experiment was a randomized complete block design evaluating three treatments including a non-tile drained (ND) control, free drainage (FD), and drainage water recycling (DWR) which was managed using controlled drainage along with subirrigation. Each treatment was replicated four times. Irrigation water captured in a reservoir collected subsurface drainage water from the site as well as surface water runoff. The reservoir was periodically sampled over a 17-year time period (2002-2019). Collected water samples were analyzed for dissolved solids, nutrients (NO_3-N, PO_4-P) and cations (Ca, Mg, K, Na, Fe, Cu, Zn). In the fall of 2017 and 2018, soil samples were collected at 0–4, 4–8, 8–12, 12–16 inch soil depths from each treatment following harvest. Soil samples were analyzed for soil fertility (pH, CEC, NA, Ca, Mg, K, P, Fe, Mn, Zn, Cu, and OM) and texture using standard soil testing analytical procedures for Missouri (Nathan et al., 2012). Collected data were analyzed using a mixed model in SAS (SAS Institute Inc., Cary, NC).

Results:

Reservoir Water Quality:

The research site experienced abnormally wet and exceptional drought conditions (Singh & Nelson, 2021) which contributed to a variation in irrigation water quality parameters in the DWR reservoir (Figure 1). The pH values of recycled water ranged from 6.38 to 7.89 with the lowest value in 2009 (6.38) followed by the highest (7.89) in 2010 (Figure 1). Based on the pH criteria set by the University of Missouri Extension, the pH values in the reservoir were suitable for irrigation use. Electrical conductivity of irrigation water was between 0 and 0.25 dS m^{-1} and total dissolved solids (TDS) was < 175 mg l^{-1} which represents a low hazard of irrigation water use for plants. Irrigation water with an EC and TDS values in this range is acceptable for all crops on all soils (Tracy & Hefner 1993). The concentration of nutrients in water samples collected over the remainder of the study period were lower than those observed in initial years. Similarly, concentration of ions (K, Na, Cl, NO_3-N, and SO_4-S) were higher and became stable during later periods of irrigation. In general, there were no concerns about the irrigation water analysis from the reservoir and its possible impact on corn or soybean crops.

Soil Fertility:

The drainage treatments influenced soil fertility parameters significantly over soil depths (Table 1). Soil pH decreased significantly ($P < 0.001$) with soil depth and was significantly lower at 8–12 and 12–16 inch soil depths in DWR plots compared to the ND treatment (Table 1). Soil CEC, Mg, and Ca contents were not affected by DWR at 0–4 and 4–8 inch soil depths, but they significantly ($P < 0.001$) increased at 8–12 and 12–16 inches soil depths compared to the ND and FD treatments possibly due to drainage and leaching. In the DWR treatment, K was significantly lower at 0–4 inch depth but increased by 12% at 8–12-inch depth. There was no effect of FD treatment on K levels in soils compared to ND. This indicates that subirrigation may have resulted in salt (K and Na) accumulation at a deeper soil depth (Ayars et al., 2006). Additionally, limited water movement at deeper depths due to higher clay content may have resulted in organic matter decomposition (Marwanto et al., 2018; Wang et al., 2010). At a 0–4-inch depth, soil test P was 9 and 20% lower in FD and DWR treatments compared to ND, respectively. Reduced soil test P content in drainage and DWR treatments can be explained by increased crop removal over time (Singh & Nelson, 2021). The shallow water table in the DWR treatment may increase Fe content which has shown a temporary reductive dissolution of Fe-bound P in waterlogged soils (Valero et al., 2007).

In the DWR and ND treatments, soil OM content decreased by 28% and 21%, respectively, at 12–16 inch in 2018 compared to 2017. Changes in soil redox potential with water table fluctuations could enhance mineralization of soil OM at deeper soil layers. The changes in irrigation water pH probably caused a breakdown of soil aggregates and increased sediment loss resulting in a change in soil texture over the time-period. Soil samples collected in fall 2017 and 2018 represented an 11% reduction in silt ($P < 0.001$) and a 13% increase in clay ($P < 0.001$) content at 8–12 inch depth in DWR treatment compared to ND while there was no treatment effect on sand ($P = 0.1159$) (Table 1). Therefore, the DWR treatment altered the soil texture significantly by increasing the clay content and lowering silt content in the soil.

Conclusion:

This research concludes that the quality of recycled water was safe for crop irrigation use over 17 years. However, the evident concern with drainage and subirrigation system is a greater loss of soil P from the topsoil and changes in soil texture at deeper depths. The water table fluctuations in a DWR system caused differences in soil texture including reduced silt content and increased clay content. In addition, the waterlogged conditions at deeper depths might have also increased OM decomposition. Overall, no negative effects of DWR have been observed compared to ND claypan soil over 17-years since establishment. Continued research to address the water and conservation policies and programs will need to be developed.

For more details on this research, please see: Kaur, H., K.A. Nelson, G. Singh, and R.P. Udawatta. 2023. Long-term drainage water recycling affects soil health and soil properties. *J. Soil and Water Conservation*. 2023, 00159:1-13. doi:10.2489/jswc.2023.00159.

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Table 1. Soil properties from non-drained (ND), free drainage (FD), and drainage water recycling (DWR) treatments collected in fall 2017 and 2018 at four soil depths (0–4, 4–8, 8–12, 12–16 inches). Within a column means followed by same letters are not significantly different at $\alpha = 0.05$. Data were combined over years.

Treatment	Sampling Depth (in.)	pH_s †	CEC	Ca	Mg	K	Bray-1 P	NO_3-N	OM	Silt	Clay
			$cmol_c\ kg^{-1}$	-------------------	-------lbs ac^{-1}	-------	----------------	ppm	-------------------	%	-----------------
ND	0-4	6.1 bcd	14 e	3223 g	279 e	334 a	96 a	6.01 a	2.5 a	71.6 a	16.9 d
	4-8	6.6 a	14 e	3674 ef	286 e	186 e	22 d	4.3 b	1.8 e	67.5 abc	21.6 cd
	8-12	6.3 bc	19 d	4390 c	494 d	193 e	11 e	4.5 bc	1.9 cde	50.6 d	38.8 b
	12-16	5.4 f	25.8b	4939 b	837 b	246 c	13 e	4.8 c	2.1 bcd	42.2 e	48.8 a
FD	0-4	5.9 e	14.5e	3269 g	300 e	351 a	87 b	5.5 a	2.5 a	70.0 ab	18.1 d
	4-8	6.3 bc	14.2e	3485 efg	294 e	179 e	21 d	3.8 bc	1.8 e	63.7 c	25.3 c
	8-12	6.1 cde	18.1d	4017 d	494 d	183 e	8.8 e	3.9 bc	1.8 e	50.3 d	36.6 b
	12-16	5.2 g	26.3b	4756 b	901 b	248 c	13 e	3.7 bc	1.9 de	41.9 e	47.8 a
DWR	0-4	6 de	14.4e	3358 fg	285 e	309 b	77 c	6.1 a	2.6 a	69.7 ab	18.8 d
	4-8	6.4 ab	14.8e	3736 de	300 e	193 e	21 d	3.8 bc	1.9 de	65.0 abc	24.7 c
	8-12	5.9 de	22.03c	4878 b	606 c	218 d	7.8 e	3.9 bc	2.1 bc	44.7 e	44.1 a
	12-16	5.1 g	29.3a	5412 a	1003 a	269 c	14 e	5.3 bc	2.1 b	44.4 e	46.3 a
p-value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

†pH_s, pH (0.01 *M* $CaCl_2$); CEC, cation exchange capacity; Ca, calcium; Mg, magnesium; K, potassium; P, phosphorus; NO_3-N, nitrate-N; OM, organic matter.

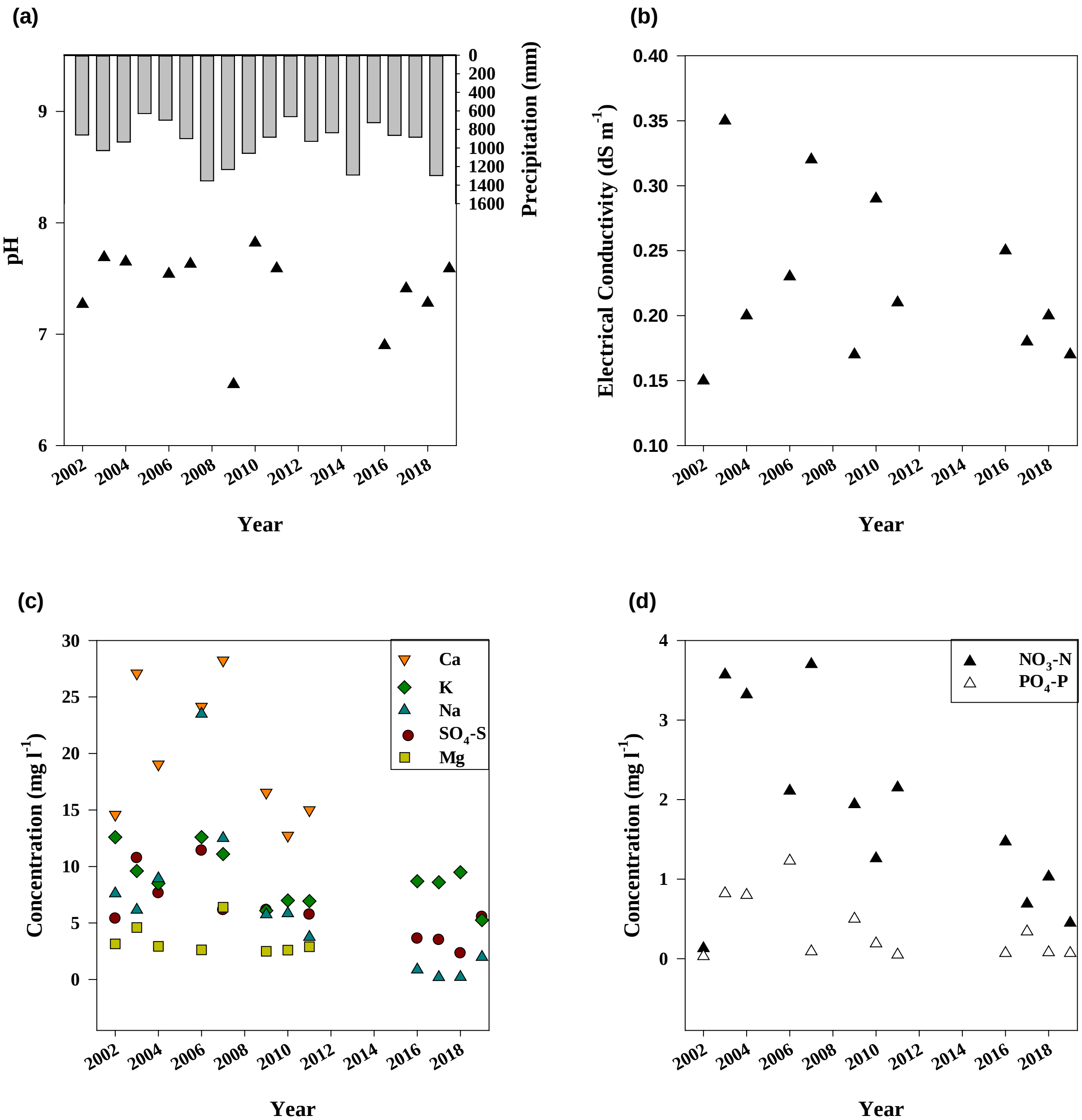

Figure 1. Average reservoir irrigation water quality parameters including (a) pH; (b) electrical conductivity (EC) (c) sulfate (SO_4-S), calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) concentrations; and (d) nitrate-N (NO_3-N) and orthophosphate (PO_4-P) concentrations over the 17-year study period. Samples were not collected in 2005, 2008, 2011, 2012, 2013, 2014, or 2015. Vertical bars in (a) represents annual total precipitation for 2002-2019.

NON-POINT SOURCE POLLUTION REDUCTIONS IN RUNOFF BY 25-YEAR AGROFORESTRY BUFFERS

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Introduction:

Water pollution is a critical health and environmental issue that is often associated with agriculture. Together, nitrogen (N), phosphorus (P), and sediments are the main stressors in water bodies and are byproducts of unsustainable agriculture (USEPA, 2017). Treating polluted water bodies would be costly and impractical. Thus, practices that help retain nutrients and sediments in fields are key to reducing agricultural non-point source pollution effectively.

Agroforestry buffers are a conservation practice that can help reduce the export of nutrients and sediments from agricultural watersheds. Trees and grasses purposely established on farmlands in strategic locations can act as a barrier to surface runoff, favoring infiltration, sedimentation, and nutrient reduction mechanisms (Udawatta et al., 2006, 2011). Perennial vegetation can reduce nutrients in the runoff by increasing the retention time of water in the field and subsequently taking up nutrients and by enhancing soil properties that favor N and P immobilization and denitrification (Lowrance et al., 1997).

Few studies have analyzed the effect of agroforestry buffers on runoff nitrogen, phosphorus, and sediments in agricultural watersheds using a paired watershed approach. A paired watershed approach is a methodology that recognizes the uniqueness of watersheds and consists of monitoring of two or more watersheds before applying desired changes (treatment) and a monitoring period after the treatment is applied (Clausen & Spooner, 1993).

In a paired watershed study, one of the watersheds must be kept under the same conditions as during the first monitoring period (Control watershed), and the other watershed can have a treatment of interest (Treatment watershed). A paired watershed approach accounts for the response of watersheds to changes and the innate differences among watersheds due to the relationships between watersheds before and after the establishment of treatments (Udawatta et al., 2002).

Objective:

The main objective of the study was to quantify agroforestry benefits on water quality of a corn-soybean watershed and compare recent improvements with early stages of the establishment.

Procedures:

A study was conducted at the University of Missouri Lee Greenley Jr. Memorial Research Farm near Novelty, MO. The study consisted of three adjacent watersheds under a corn-soybean rotation. One without a treatment, one with agroforestry buffers (AB), and the third with grass only buffers (GB). Agroforestry buffers consisted of a mix of pin Oak (*Quercus palustris* Muenchh.), Swamp White Oak (*Q. bicolor* Willd.), and Bur oak (*Q. macrocarpa* Michx.) and native perennial grasses (Figure 1). The grasses in both types of buffers were Redtop (Agrostis gigantea Roth), brome grass (*Bromus inermys* Leyss.), and birdsfoot trefoil (*Lotus corniculatus* L.) (Figure 1). The buffers were 4.5 m wide and 36.5 m apart. The calibration period (no treatments applied) started in 1991. Trees and grasses were planted in 1997, and the spacing between trees was 3-m. Runoff samples were collected after rain events with automatic samplers (ISCO 3700). The total volume discharged was recorded by bubbler flow measuring devices (ISCO 4230) (ISCO, Inc, Lincoln, Nebraska). Power shortages and technical issues that included instrument functioning and animal damage limited the number of runoff events fully recorded.

Figure 1. Soybean plants are in the front and between the yellow strips, the grass-only buffers are the yellow strips, and the agroforestry buffer is in the back where trees can be seen. Photo taken in July 2022.

Results:

The AB and GB watersheds had an increase in runoff, which suggested a possible incoming of water from adjacent areas. The increase in runoff was more noticeable in the GB watershed than in the AB watershed. Despite the runoff increase, significant reductions in non-point source pollution were found. The AB and GB watershed had reductions in sediment, nitrate-nitrite (NN), and total P (TP) losses due to the buffers. The GB watershed had greater reductions in sediment (71.40%) and TP (33.12%) than the AB watershed. On the other hand, the AB had a more significant reduction in NN (24.95%) and total N (TN, 63.85%) than the GB. Sediment relationships were the only not significant relationships at a 95% confidence level.

Both treatments proved to be efficient in reducing non-point source pollution from agricultural fields after 25 years of buffer establishment (Figure 2). Sediment loss reductions after 25 years in the AB and GB were more significant (62% and 71%) than reductions found after three years (increases by 35% and 17%) (Udawatta et al., 2002) and eleven years (reductions by 30% and 28%) (Udawatta et al., 2011). The AB and GB watersheds also had greater NN reductions compared to the findings of previous studies on the same watersheds (26% and 39%) after three years of buffers (Udawatta et al., 2002). The GB watershed had greater TN reductions after 25 years (64%) than after three (21%) (Udawatta et al., 2002) and eleven years (11%) (Udawatta et al., 2011). The GB watershed had an increase in TN losses, possibly due to the runoff entering the GB watershed from surrounding areas.

Results from the current study indicate that agroforestry buffers can increase their potential to reduce sediment and nutrients with time, which can be attributed to the better establishment of the perennials and improvements in soil properties. More research on the long-term effects of agroforestry buffers under different soil and climate conditions is advised. The study site had a shallow claypan that restricted the infiltration capacity of the soil and favored runoff. More paired watershed studies are needed to quantify the effect of agroforestry on water quality on a field scale.

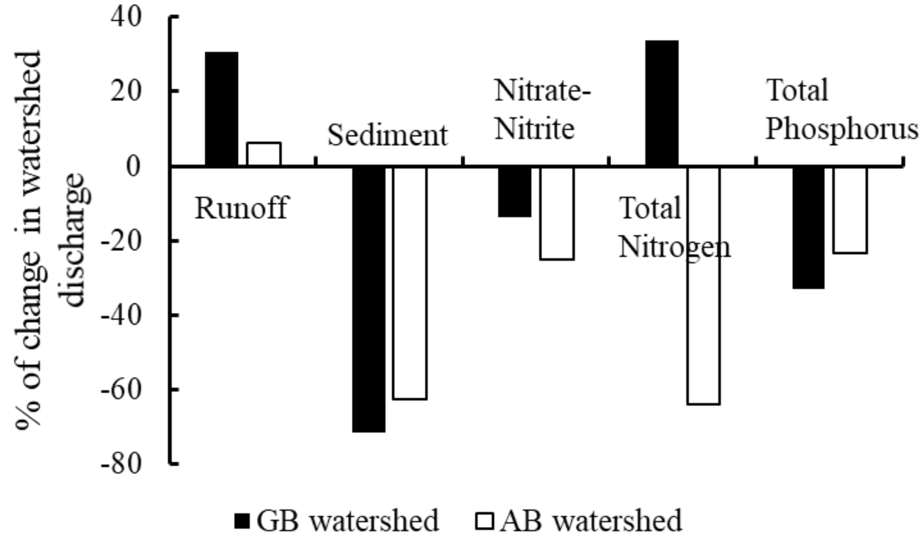

Figure 2. The runoff and sediment loss, nitrate-nitrite, total nitrogen, and total phosphorus losses for grass buffer and agroforestry watersheds.

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NITROGEN MANAGEMENT AND VARIETY TESTING FOR INDUSTRIAL HEMP PRODUCTION IN MISSOURI

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Introduction:

Industrial hemp (*Cannabis sativa* L.) production has grown exponentially since the passing of the Agricultural Act of 2014, Public Law 113-79 (the 2014 Farm Bill). The University of Missouri industrial hemp research program operates under Senate Bill 133 which was signed into law on 24 June 2019. The Missouri Department of Agriculture currently operates the Industrial Hemp Program which regulates the production and sale of industrial hemp following federal and state law. This bill has allowed researchers to evaluate the best management practices for growing industrial hemp with less than 0.3% THC (tetrahydrocannabinol) in Missouri. Missouri has a history of industrial hemp production that dates back from the late 1800s to the early 1900s. However, current cultivars, management practices, pests, soil conditions, and technology has been changed. Therefore, it is important to test production practices for industrial hemp throughout Missouri to provide growers with the best management practices and determine the production potential of industrial hemp in Missouri.

Objectives:

The objectives of this experiment were to evaluate cultivars and nitrogen application rate on industrial hemp grain and fiber production in Missouri.

Procedures:

The experiment for evaluating nitrogen application rates in industrial hemp production was conducted in 2021 at the University of Missouri Graves-Chappel Research Center (GCRC) near Rock Port, MO. Nitrogen (N) was applied at three rates; 100, 150, and 200 lb ac^{-1} using SuperU as the N source at GCRC. 'Jinma' was planted in 8-inch-wide rows at 50 lbs ac^{-1} on a Dockery silt loam soil.

A second experiment evaluating cultivars for fiber and grain yield was conducted in 2022 at the University of Missouri Lee Greenley Jr. Memorial Research Farm (GRF) near Novelty, MO. The experiment was set up as randomized complete block design with four replications and plot size was 10 by 30 feet. Twenty-two industrial hemp varieties were evaluated at GRF in 2022. The industrial hemp varieties included in the trial were: CFA-2, Altair, Ferimon, Canada, Anka, Orion 33, Fibror 79, Trihocomo, Bila, US 031, Felina 32, Vega, Yuma, Tygra, Puma, Santhica 70, Fibranova, Jinma, Fugura 83, Hilyana, MS-77, Rajan. The hemp was planted on 20th May in 2022 in 30-inch-wide rows at seeding rate of 50 lbs ac^{-1} on a Kilwinning silt loam. The data was analyzed using the GLM procedure in SAS statistical software (Cary, NC) and means were separated by least square difference (lsd).

Results:

In 2021, N rates showed no significant differences in the plant population, grain, and biomass yield at the GCRC. The plant population was 319,700, 433,900, and 257,900 plant ac^{-1} in the treatments receiving 100, 150, and 200 lbs ac^{-1}, respectively. The dry biomass yield for the N application rates of 100, 150, and 200 lb ac^{-1} was 5433, 4841, and 5547 lb ac^{-1}, respectively. Similarly, the grain yield for the N application rates of 100, 150, and 200 lb ac^{-1} was 555, 643, and 835 lb ac^{-1}, respectively.

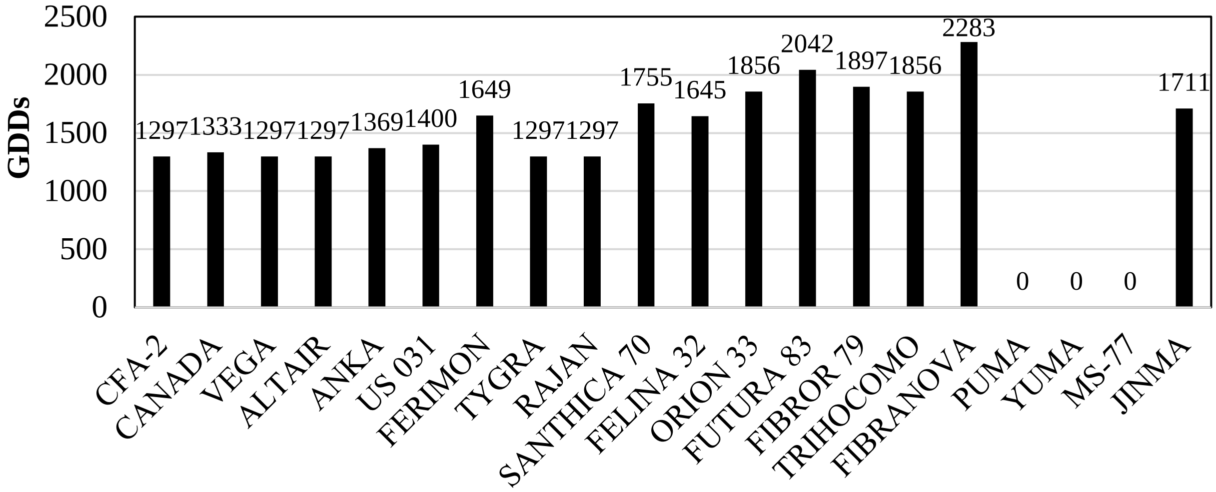

Figure 1. Industrial hemp cultivar maturity measured in number of growing degree days (GDDs) to reach male flowering. The 0 GDDs value indicates the cultivar has not flowered as of 5 August 2022.

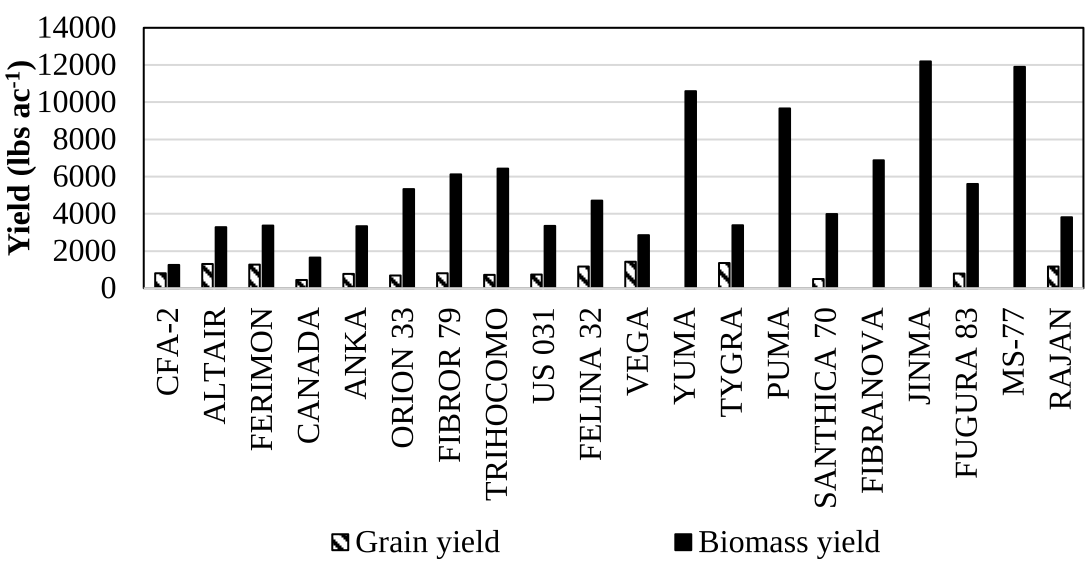

Figure 2. Grain and biomass yield of hemp varieties evaluated in 2022 at the Lee Greenley Jr. Memorial Research Farm near Novelty. The lsd for the grain and biomass yield was 271.5 and 2361.5 lbs ac^{-1}, respectively.

In 2022, crop maturity based on the date of observed male flowers was evaluated. The growing degree days (GDDs) were calculated for the growing season and the average GDDs for each variety are reported in Figure 1. Maturity of hemp varies dramatically among the industrial hemp cultivars. The biomass and grain yield from the cultivar testing experiment conducted at GRC is presented in Figure 2. The highest grain yield (1431 lbs ac^{-1}) was produced by Vega which was similar yields produced by Tygra, Altair, Ferimon, Felina 32, and Rajan. Yuma, Puma, Fibranova, Jinma, and MS-77 were later maturing cultivars and did not produce any grain yield in 2022. The highest biomass was produced by Jinma which was similar to MS-77 and Yuma. In 2023, 13 industrial hemp cultivars are currently being evaluated at five locations across Missouri. Cultivar selection, weed and disease management, nutrient management, drainage water management, and economics are key issues to keep in mind when producing industrial hemp.

RADISH COVER CROP MANAGEMENT AND GRAZING EFFECTS ON WEED CONTROL AND CORN RESPONSE IN DROUGHT CONDITIONS

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Introduction:

Commodity crops typically are in the field for only five to six months and fields stay fallow for the remaining months of each year. Planting cover crops (CCs) may improve soil health, protect from soil erosion, interrupt disease and pest cycles, minimize weed infestations, provide grazing opportunities, and increase commodity crop yields. Radish (*Raphanus sativus* L.) has become a popular CC because of its rapid fall growth, deep taproot, good fall soil cover and ability to scavenge soil nutrients. Radish is sensitive to freezing air temperatures and planting date affects the duration of growth, above and belowground biomass, and total biomass yield. Previous research has reported that grazing *Brassica* species can serve as a supplemental or alternative forage since forage and roots have good digestible energy (Guillard and Allinson, 1988). Using a radish CC as a forage source for grazing cattle following corn harvest would help promote diversified cropping systems. Research is limited in the Midwest on the use of radish as a CC for grazing cattle under various tillage systems, planting dates, and the subsequent impact on winter annual weeds and corn production specifically in drought years when forage resources are desperately needed.

Objective:

This research evaluated the effect of tillage (reduced and no-till), planting date (non-seeded, early, and late September) of radish, and grazing (grazed and non-grazed radish) on winter annual weed control, radish production, and corn grain yield the following year.

Procedures:

Field research was conducted from 2011-2012 and 2012-2013 at the University of Missouri Lee Greenley Jr. Memorial Research Farm near Novelty, which is part of the Northern Missouri Research, Extension, and Education Center. Brown mid-rib sorghum was spring seeded, grazed multiple times through the summer, and terminated with a herbicide prior to establishment of the radish management treatments. A disk or finishing tool (Tilloll 875) was used for the tillage treatment prior to planting radish. Radish was planted with a Great Plains drill on 1 September 2011 and 31 August 2012 for the early planting dates and 26 September 2011 and 1 October 2012 for the late planting dates. The late planting date corresponded with a typical corn harvest date in the region.

On 22 November 2011 and 28 November 2012, plots were flash grazed with Angus cows. This is approximately the last date to graze radish prior to a killing freeze which would render the plants undesirable for grazing. Radish foliage and tubers were collected on 5 December 2011 and 10 December 2012 which corresponded with an extended cold period that was below freezing. Control of common chickweed and henbit in 2012 and 2013 as well as downy brome in 2013 was visually rated prior to planting corn. Corn was no-till planted on 10 April 2012 and 4 May 2013. Heights 30 to 50 days after planting, plant populations prior to harvest, and SPAD meter readings at VT were recorded. Grain yields were determined with a small plot combine and grain samples were analyzed for moisture, test weight, protein, oil, and starch concentrations. All data were subjected to ANOVA and means separated using Fisher's Protected LSD at 0.05.

Results:

The results of this research during 2011-2012 and 2012-2013 were achieved under extreme drought and flash drought conditions (US Drought Monitor, 2020). Preplant tillage did not affect radish population, tuber volume, length, diameter, tuber mass, to leaf dry mass (data not presented). Tuber volume, length, diameter, and radish leaf mass was greater when radish was planted early in both years compared to a late planting (Table 1). For the early planted radish, average leaf dry mass was 3,600 to 4,000 lbs ac^{-1} in 2011 and 2012, respectively, while the tuber dry mass was over 2,400 lbs ac^{-1}. These yields represent a substantial amount of high-quality forage production that can be used to extend the grazing season and reduce production costs for livestock producers. Late planted radish tubers resembled "baby carrots". Radish as a cover crop may have greater adoption following winter wheat harvest (Sandler et al., 2015a) or corn silage as there is ample time for radish establishment and growth. Herbicide carryover from a previous crop can be an issue establishing cover crops such as radish, but this was not the case in this research. Winter annual weed populations were primarily henbit and chickweed in both years while downy brome was present in 2013. Winter annual weed control was 58 to 79% with early planted radish and 6 to 56% with late planted radish when combined over grazing systems and tillage treatments (Figure 1, data not presented).

Figure 1. Winter annual weed control (spring, 2012) following early (late Aug.-early Sep.) planted radish (left) and the non-seeded control (right).

Tillage, grazing, or radish planting date did not impact vegetative development of corn 30 to 50 days after planting (data not presented). Similarly, there was no effect of tillage (31,900 to 32,600 plants ac^{-1}), grazing (31,900 to 32,600 plants ac^{-1}), or radish planting date (31,300 to 32,800 plants ac^{-1}) on corn plant population at harvest. Corn plant greenness (SPAD meter reading at VT) was similar among tillage, grazing, and radish planting date treatments (data not presented). Extreme and severe drought conditions in 2012 and 2013, respectively, reduced overall grain yields in both years (Figure 2). Other studies have shown that a radish cover crop increased drought tolerance of the rotational crop due to the rooting characteristics (Williams and Weil, 2004; Chen and Weil, 2011). In Missouri, corn grain yield was not affected by preplant tillage or grazing of radish (data not presented). Corn grain yield following early planted radish was similar to the non-seeded control. Corn grain yield was slightly higher with late planted radish in 2013 (Figure 2) which was probably due to winter annual grass weed suppression since limited tuber development occurred. In general, the effects of grazing on corn grain yield were minimal possibly because the site was grazed only once during a dry period in the fall.

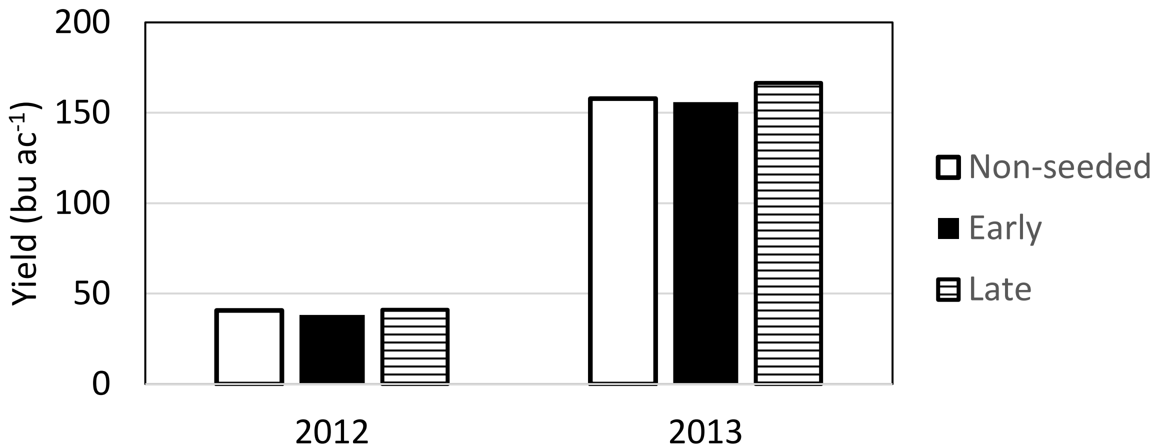

Figure 2. Corn grain yield response to early planted, late planted, and non-seeded radish treatments in 2012 and 2013. Early radish planting date was 1 Sep. 2011 and 31 Aug. 2012. Late radish planting date was 26 Sep 2011 and 1 Oct. 2012 which is when the first commodity crops are harvested in the region.

Recommendations:

Use of cover crops such as radish following preventive planting or silage harvest during drought conditions can help alleviate forage shortages for livestock producers. This and other research in Missouri (Sandler et al., 2015a, 2015b) demonstrates the importance of radish planting date on establishment and production. Early planted (first week of September) radish produces greater tuber and foliage mass than a late planting date (last week of September). Early planted radish provides good winter annual weed control while the winter-kill characteristics make it a favorable cover or forage crop prior to corn. Nonetheless, early planted radish did not increase corn grain yield during a drought the following year compared to the non-seeded control.

Additional details related to this research are available in the following publication: Nelson, K.A., L.N. Sandler, D. Dhakal, Z.L. Erwin, D. Brake, G. Singh, and G. Kaur. 2023. Radish management and grazing effects on weed control and corn response. *Agronomy Journal.* https://doi.org/10.1002/agj2.21431

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Table 1. The effect of planting date on radish plant population, tuber volume, length, diameter, and mass, and radish leaf mass in non-grazed plots in 2011 and 2012.

Planting date[†]	Plant population		Tuber volume		Tuber length		Tuber diameter		Leaf dry mass		Tuber dry mass
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	
	---- No. ac^{-1} --		----- ml -----		----- cm -----		----- cm -----		--------- lbs ac^{-1} ----------		
Non-seeded	0e[‡]	0e	0c	0c	0e	0e	0d	0d	0c	0c	0c
Early	299,500a	174,100c	320b	548a	16.0b	19.3a	3.8b	4.3a	3,670a	4,070a	2,460a
Late	250,600b	158,900d	47c	1c	8.9c	3.0d	1.0c	0.3d	1,260b	100c	200b

[†]Early radish planting date was 1 Sept. 2011 and 31 Aug. 2012. Late radish planting date was 26 Sept. 2011 and 1 Oct. 2012 which is when the first commodity crops are harvested in the region.

[‡]Means followed by same letter are not statistically different (α=0.05).

IMPROVING EASTERN GRASSLANDS THROUGH NATIVE WARM SEASON GRASSES

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Introduction:

A considerable number of the nation's cow-calf operations are located in the eastern United States, where a large portion of these operations depend upon cool-season grasses in their forage production systems, with tall fescue (*Schedonorus arundinaceus*), or fescue, as the principal grass. Fescue grows on over 15 million ha within a section commonly denoted as the Fescue Belt. Cow-calf producers typically use fescue because of its simple management, productivity, and lack of pests (Sleper & West, 1996). However, both fescue toxicosis and the 'summer slump' issue are hindrances for producers. As a C3 grass, fescue provides a considerable amount of forage in the spring, with a second yield in the fall. In the warmer months of June, July and August however, fescue is dormant, particularly during periods of drought or intense heat. Pastures comprised of only fescue are no longer feasible for grazing during these months, leaving producers without forage, known as the 'summer slump.' Warm season grass pastures can provide the necessary forage during the summer, eliminating the need for hay and supplementing the poor forage quality of fescue (or lack thereof) during this time (Hoveland et al., 1977).

Further, incorporating native warm-season grasses (NWSG) into cool-season forage systems can help lessen the impact of fescue toxicosis and lower the need for hay during the summer slump, which can improve profits for a cow-calf operation. Eastern Gama grass (EG) (*Tripsacum dactyloides*) and big bluestem (BB) (*Andropogon gerardii*) are two NWSG options that could be used as a compliment to fescue systems. However, little data is available on how such grasses affect the productivity of cow-calf operations or how such forages can impact an overall forage system at the farm scale.

Objectives:

The objective for this study was to develop and evaluate a forage production system that will strengthen productivity, profitability, sustainability, and ecosystem health in the eastern U.S. We evaluated three forage systems: 1) the most frequently used forage system within our region, one that relies on tall fescue only (TF100), 2) a system where separate areas of a drought-tolerant native C_4 species (big bluestem; BB) blend is grazed along with tall fescue (TF), or 3) a drought/flood tolerant native C_4 species (eastern Gama grass; EG) is grazed along with tall fescue (TF). Among these three systems (BB-TF, EG-TF, and TF100), we evaluated:

1. Productivity (beef produced per ha, net hay balance)
2. Profitability (input costs, cost of gain, net return)
3. Sustainability (grazing days per year, animal health – calving rates, weaning weights, ratio of mass of calf weaned to mass of cow at weaning, and hair coat score; and resiliency – hay feeding days, stand loss).
4. Ecosystem health as measured by soil health.

Procedures:

Three locations were used in this study: the Blount Unit, ETREC in Louisville, TN (35.84, -83.95), the Missouri Forage Systems Research Center in Linneus, MO (39.86, -93.14) and the Dale Bumpers Small Farms Research Center in Booneville, AR (35.09, -93.99). This study consisted of two treatments, with two replicates in each. Treatment 1 characterizes the most common grazing system in the region, a cool-season pasture comprised of mostly toxic endophyte infected fescue and serves as the control. Treatment 2 is a complementary cool-season/warm-season system. The warm-season system in Louisville consists of eastern gamagrass (EG), big bluestem (BB) at Linneus, MO and the Booneville, AR site consists of both BB and EG. Cows (mature cows ≥3 years old, spring calving) were randomly assigned (n = 12) to one of four groups and were similar in parity, body condition, and weight. The EG and BB pastures were grazed on a rotational basis with cattle moved within assigned paddocks based on stand condition and ended no later than September 20 annually or when the stand conditions could no longer support grazing. Fescue pasture rotations were based on stand condition with grazing concluded at canopy height of approximately 10 cm. Two paddocks within each fescue systems (Treatment 1 and 2) were allotted for hay during spring and for fall stockpiling and were documented for both systems. Forage mass was collected from 0.25 m^{-2} from fifteen randomized locations within an actively grazed paddock per treatment unit at the beginning of grazing, and once every 28 days during the grazing season, and finally, at the conclusion of active grazing per each experimental unit. Harvested forages were tested for standard forage quality analyses (crude protein, neutral detergent fiber and acid detergent fiber). Sward vigor occurred once annually by using a Vogel grid (0.75 m x 0.75 m) with eight samples per paddock. Analysis for weed cover used the same approach twice annually, once near May 1 for cool-season weed cover and once near July 1 for warm-season weed cover with four frequency grids (100 cells in total) per actively grazed paddock for weeds. Fescue toxicity was documented in May and September of year two, for both percent infection and ergovaline concentration. Unshrunk cattle weights were taken on two consecutive days, prior to and following the movement on and from native warm-season grasses in April/May and again in August/September. Latter weights were taken after cows were on cool-season grasses for three to five days for comparable gut fill, at breeding and at weaning. Four weights were taken per year per cow, all based on gut fill from fescue. Weights were taken on calves at birth, again when pairs were removed in late summer, and finally, at weaning. Body coat scoring was conducted, and grazing days were calculated. Water use efficiency (WUE) was documented by yield from three, randomly placed exclusion cages (3-m diameter) within two paddocks of each forage species (fescue and EG or BB) per experimental unit, with movements to new random locations within the paddock once every 28 days. Annual rainfall was documented as well as soil moisture. At initiation of the project, soil samples (15 cm) were taken to evaluate basic fertility (P, K, electrical conductivity, and pH), soil organic matter, bulk density, and soil aggregation and will be taken again at the conclusion.

Results:

At the Dale Bumpers Small Farms Research Center (Booneville, AR), installation of fencing, shade structures and water access were delayed, and subsequently, delayed the commencement of the project until 2022. In at least two locations, cattle weights were higher in a complementary system (Tables 1 and 2). At the AR location, weaning weights were greater on TF/BB and lower on TF/EG; however, EG stands were very weak ($P < 0.01$). August cow weights and BCS at AR on TF/EG were comparable to the other groups ($P > 0.99$, $P > 0.13$). At the MO site, weaning weights were greater in the complementary system ($P < 0.00$). At TN, we did not detect any differences between treatments. While there were no significant differences between treatments, cattle spent less time on EG pastures at the TN location because of poorly stocked stands resulting from management during previous research, combined with poor establishment success during renovation preceding the current study. EG pastures averaged 49% stocked. Potentially, the decreased grazing time in NWSG pastures for the TN location did not allow for these grasses to provide a noted benefit. Further, the TF pastures at the TN location have a considerable percentage of warm-season grasses (averaged 44%) growing within gaps in the TF pastures, such as foxtail (*Setaria* spp.), johnsongrass (*Sorghum halepense*) and dallis (*Paspalum dilatatum*). While efforts are ongoing to maintain stronger TF dominance within the TF stands, it was a significant concern for the 2021 season and may explain the lack of variation within the data. Grazing days were similar among treatments at all locations, although a severe drought at the AR location in 2022 lowered the grazing days for all treatments. In MO, cattle were able to maintain summer grazing on TF pastures because of above-average annual rainfall during 2021. The grazing season in MO extended well into winter for the TF-only groups because of the lower stocking density (12 ha available for grazing vs. only 8 in the complementary system). In TN, EG stands will need to be strengthened in order to provide an increased grazing time during the summer.

Table 1. Cow weights and body condition scores (BCS), 2021-2022 for AR, MO and TN locations.

Cow Weights and BCS, 2021-2022							
Site	Treatment	August Cow Weights (lbs)	P>*F*	BCS (on NWSG)	P>*F*	BCS (NWSG Removal)	P>*F*
AR	TF	1164	0.99	7	0.07	5	0.13
	TF/BB	1166		7		5	
	TF/EG	1168		7		5	
MO	TF	1362	0.63	5	0.62	6	0.82
	TF/BB	1380		6		6	
TN	TF	1504	0.40	6	0.86	6	0.85
	TF/EG	1475		6		6	

Table 2. Calf weaning weights, 2021-2022 for AR, MO and TN locations. Means followed by different letters within a site differ.

Calf Weaning Weights, 2021-2022					
Site	Treatment	205-day Adjusted Weaning Weights (lbs)	P>*F*	Weaned weight (lb ac^{-1})	P>*F*
AR	TF	573 AB	0.01	183 AB	0.01
	TF/BB	602 A		191 A	
	TF/EG	538 B		171 B	
MO	TF	589 B	<0.00	187 B	<0.00
	TF/BB	655 A		208 A	
TN	TF	591	0.33	195	0.86
	TF/EG	604		199	

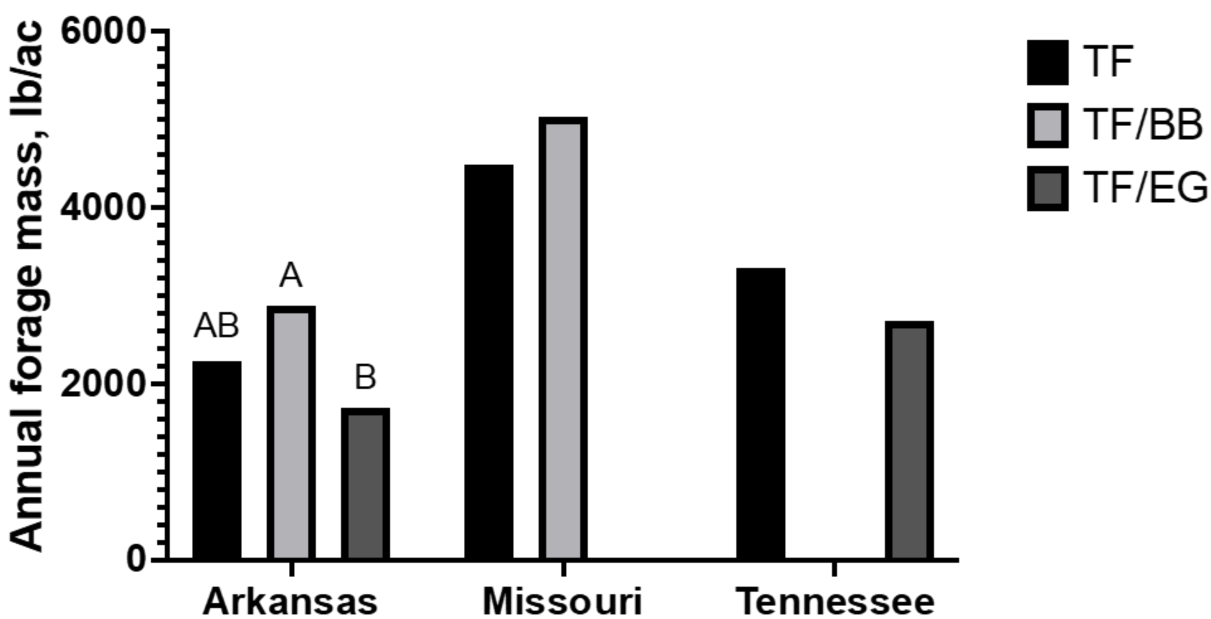

Figure 1. Mean annual forage mass for AR, MO and TN (2021-2022). Means without a common letter are different (P <0.05).

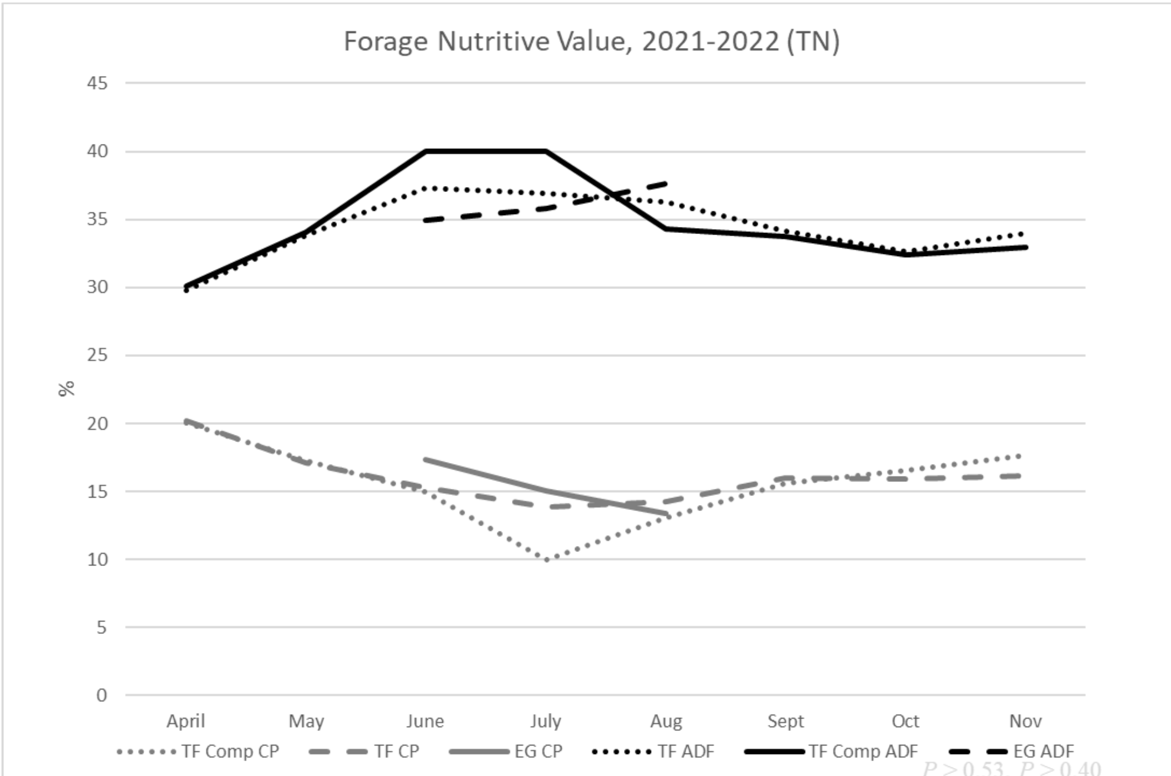

Figure 2. Crude protein (CP) and acid detergent fiber (ADF) nutritive values for TN, 2021-2022.

Forage mass was consistent among treatments at MO and TN, but differed at AR, due to the summer drought and weak EG stands (Figure 1). Nutritive values did not differ among treatments at all locations. CP and fibers followed a similar pattern to TN, as shown in Figure 2. Hay production was also comparable between treatments at Missouri, but production was higher in a mixed system ($P < 0.01$). Soil samples from all locations are currently under analysis.

In all locations, preliminary results were mixed between treatments in 2021-2022, but with promising results for weaning weights and under drought conditions. In AR and MO, higher weaning weights in a complementary system indicate that native warm season grasses may have the potential to combat fescue toxicosis and the summer slump .While differences were not noted between treatments in this study at the TN location, this is potentially due to the lack of grazing time on the native grass stands and to the influence of warm season grasses within the fescue pastures at the Tennessee site. This could potentially indicate that a mixed fescue stand may be of some benefit to a producer. These results also reiterate the importance of taking full advantage of grazing NWSG during the summer, in order to reap their full benefits. If producers do not utilize NWSG pastures in the duration of their productive season, little to no gain may be noted.

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TICKS ON MISSOURI CATTLE PASTURES

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Ram Raghavan
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Introduction:

Ticks are important to the cattle industry both as nuisance pests and as vectors of disease. The most common tick-transmitted disease of cattle in the U.S., and worldwide, is bovine anaplasmosis caused by *Anaplasma marginale*. More recently, *Theileria orientalis* Ikeda genotype has emerged as an important concern to cattle producers in the U.S., along with its tick vector, the invasive longhorned tick (also known as the Asian longhorned tick), *Haemaphysalis longicornis.*

Anaplasma marginale and *T. orientalis* are different organisms, but both infect bovine red blood cells and cause similar effects such as weight loss, spontaneous abortions, and death. On average, anaplasmosis costs U.S. cattle producers $660 per affected animal (Railey, 2021). Less data is available regarding the impact of *T. orientalis* in the U.S.; however, its economic impacts on the cattle industries in Australia and New Zealand are well documented. Bovine anaplasmosis is often treatable with tetracycline antibiotics, but there is no approved treatment for bovine theileriosis.

Anaplasmosis can be spread by biting flies and by blood-contaminated instruments such as shared needles but is most efficiently transmitted by ticks. In the Midwest, the primary vector of bovine anaplasmosis is the American dog tick, *Dermacentor variabilis*. *Theileria orientalis* is transmitted by the invasive longhorned tick in its native range as well as in the U.S. (Dinkel, 2021). The longhorned tick does not transmit bovine anaplasmosis.

Objectives:

This ongoing project has two major objectives. First, to estimate the proportion of American dog ticks infected with *A. marginale* on beef grazing operations in Missouri. Second, to better understand tick population dynamics on beef cattle pastures, including the potential presence of the invasive longhorned tick. Our results will contribute to better evidence-based management of tick-borne disease risk for beef producers.

Procedures:

Ticks are collected April through August on four University of Missouri-owned beef grazing operations (Figure 1). Pastures are actively grazed by cattle. Ticks are collected with flannel drags over 750-meter transects according to published guidelines (CDC, 2020). Ticks are transported to the laboratory, identified, and subsequently stored at -80° C to await molecular analysis. Adult male American dog ticks are routinely processed and tested for the presence of *A. marginale* using real-time polymerase chain reaction (PCR) designed to detect one of the organism's specific genes (*msp1b*).

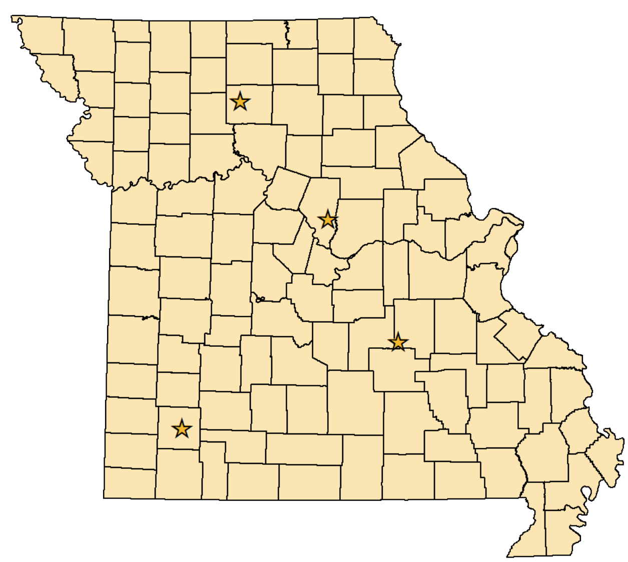

Figure 1. Sites where ticks are collected.

Results:

In 2022, ticks were collected from 79 transects on 20 days in May-August. Tick collection for the spring/summer of 2023 is ongoing. So far this season, ticks have been collected from 95 transects on 19 days in April-June. Overwhelmingly, the most common tick encountered is the lone star tick, *Amblyomma americanum* (97%), with nymphs being most frequently collected (Table 1).

Table 1. Ticks collected, in total, by life stage and year of collection.

Species	**Life Stage**	**2022** (79 transects)	**2023*** (95 transects)
Amblyomma americanum (Lone star tick)	Adult females	7	95
	Adult males	12	103
	Nymphs	108	1323
	Larvae	44	0
Dermacentor variabilis (American dog tick)	Adult females	37	9
	Adult males	28	5
Haemaphysalis longicornis	Nymphs	2	12
Miscellaneous and/or final classification pending	All Stages	0	28
Total		**238**	**1575**

*Tick collection still in progress. Note that collection started one month earlier in 2023, and the number of collection personnel is twice as many as in 2022. Thus, while more ticks were collected per transect in 2023, the increase is an effect of additional effort.

- Molecular analysis of American dog ticks for *A. marginale* is currently ongoing.
- Prior tick surveys in Missouri indicates that American dog ticks are more likely to be collected from open grassland than forested areas (Petry, 2010). Our findings are consistent with this observation.
- High numbers of *A. americanum* nymphs in 2023 may be attributable to starting collection earlier in the spring, when these nymphs are most active (Hroobi, 2021).
- We have collected nymphs of *H. longicornis* from vegetation in Linn and Boone counties (Figure 2). This invasive tick has become established in many portions of the eastern U.S. and has continued to spread westward since it was first recognized in 2017.

Figure 2. A nymph of the invasive longhorned tick (*H. longicornis*), at approx. 45x magnification.

Recommendations:

Producers can reduce risk of tick exposure by excluding cattle from wooded areas when feasible and clearing brush regularly. Consider inspecting for ticks when handling cattle, along with checking and/or treating newly introduced animals (including dogs). Consult your local veterinarian for advice on tick control products.

For humans and pets, strategies to minimize the risk of tick bites are effective for both invasive and native ticks. Additional information is available in MU Extension’s “Guide to Ticks and Tick-Borne Diseases” (IPM1032). If you suspect you have found an invasive tick, contact your local veterinarian, county extension agent, or county health department to have the tick identified.

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MISSOURI MESONET

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

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

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

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

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

For access to the Missouri Mesonet, please visit:

mesonet.missouri.edu

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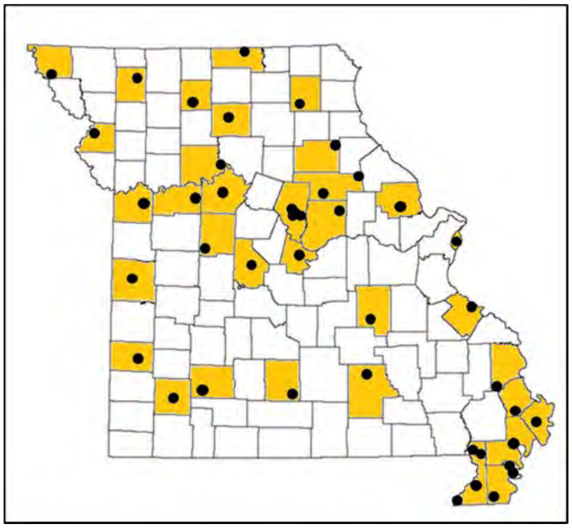
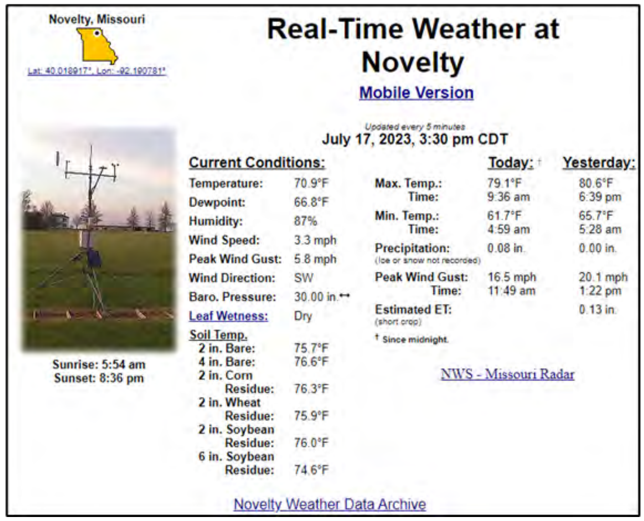
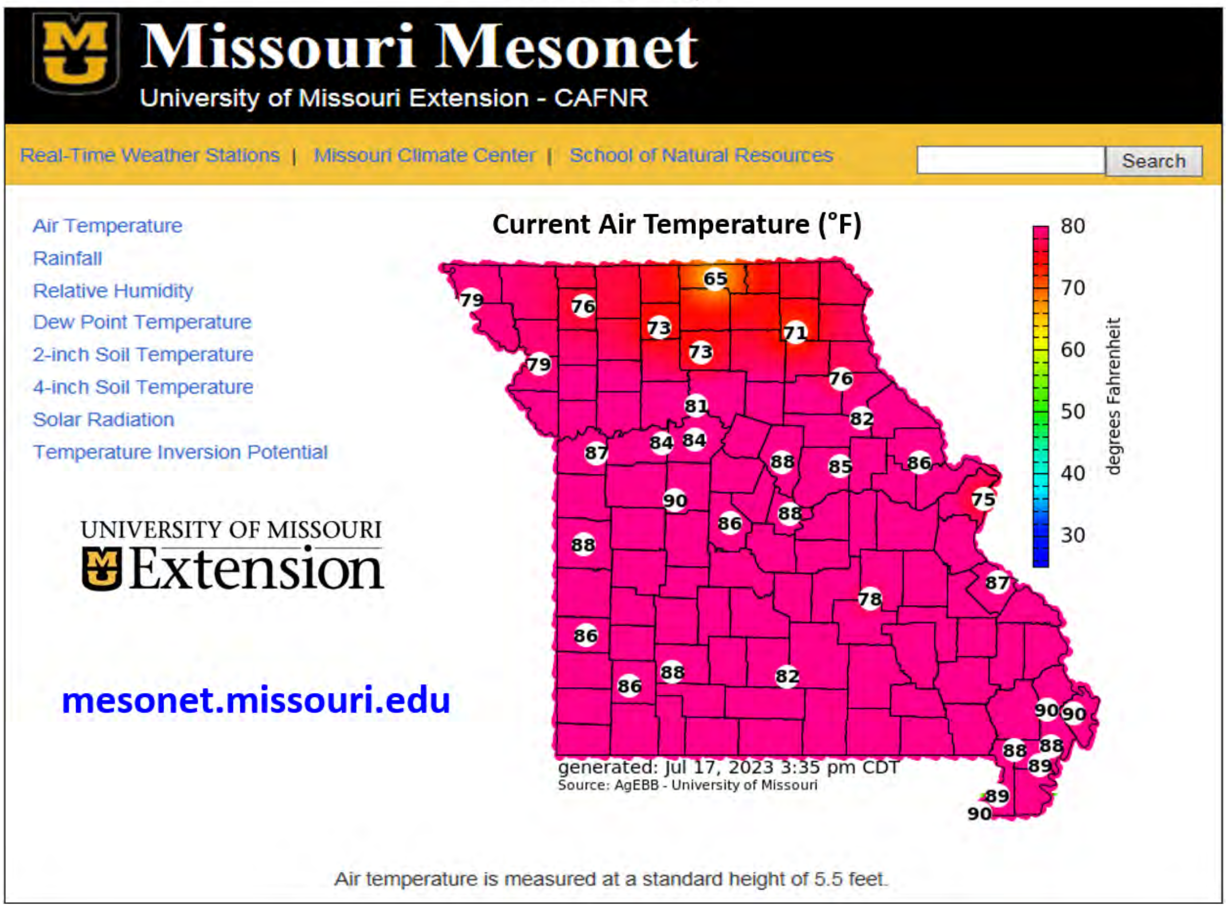




Real-time maps



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

Patrick Guinan
Extension Associate Professor Emeritus

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 has a tendency 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 in regard to 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 grass roots 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, in order to provide consistent and accurate precipitation data, all observers are required to use a particular rain gauge model, which cost $34.25 plus shipping.

Once enrolled, the weather observer is assigned a station ID and uses an interactive website to submit their observation. The web site 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. Anthony Lupo (LupoA@missouri.edu) or one of the state coordinators for Missouri CoCoRaHS.

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 include:

- 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 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
- PRF Rainfall Index Monitor
- Fall Nitrogen Application Chart
- Design Storm Report
- Insect Scouting Aids
- Rainfall Runoff Estimator
- Animal Comfort Indices

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

Horizon Point subscribers are given a secure account page where they can manage such selections as email frequency and which advisories are received. Farmers can also access archives of site-specific daily reports for the last month. For more information about the Horizon Point system, contact us at 573-882-4827 or email us at HorizonPoint@missouri.edu

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The peer-reviewed journal articles published prior to 2022 can be found in the NMREEC field day annual report 2022 at:
https://mospace.umsystem.edu/xmlui/bitstream/handle/10355/91761/sr0604.pdf?sequence=4

NOTES

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