**NCCC-31 - Report 2023**
**Ecophysiological Aspects of Forage Management**

## Annual meeting

*Date and location*: June 20-21, 2023, Virginia Tech, Blacksburg VA.

Participants: Ben Tracy (Host Virginia), Jennifer McAdam (Utah), Bill Lamp (Maryland), Haley Mosqueda (North Dakota), Shelby Gruss (Michigan), Dirk Phillip (Arkansas), Jim Kells (Admin Advisor), Jeff Volenec (Purdue), Valentin Picasso (Wisconsin), John Fike (Virginia), Marília Chiavegato (Ohio), Marta Kohman (Wisconsin), Dr. Gabriel Pent, McCormick Farm/Shenandoah Valley AREC, (VT), Parry Kietzman, Research Associate (VT), John Benner, Virginia Cooperative Extension, Adam Downing, Virginia Cooperative Extension.

Host – Ben Tracy. Chair: Valentin Picasso. Secretary and upcoming chair: Marília Chiavegato. Administration Advisor for NCCC31: Jim Kells.

Grad students - Ali Shokoohi (UM - Lamp), Amanda Brucchieri (UM - Lamp), Robert Salerno (UM - Lamp), Helen Craig (UM - Lamp), Jonathan Kubesch (VT - Tracy), Summer Thomas (VT – Tracy), Harry Stewart (VT - Tracy). Dr. Sanjok, Poudel (VT – Fike, post-doc)

*Resolutions 2023 NCCC31:*

Be it resolved that the members of NCCC-31 enjoyed an inspiring exchange of information and ideas during their meeting at the Virginia Tech University, in Blacksburg, from 20 to 21 June 2023, and that

Ben Tracy was a fantastic host who effectively coordinated all local arrangements, tours, meals, accommodations and discussions, and that

The field trips and discussions with Dr. John Fike, Dr. Gabriel Pent, Superintendent of the McCormick Farm/Shenandoah Valley Agriculture Research and Extension Center, John Benner, Virginia Cooperative Extension, Adam Downing, Virginia Cooperative Extension, Summer Thomas and Jonathan Kubesch, graduate students at Virginia Tech, and Dr. Sanjok, Poudel, post-doctoral researcher at Virginia Tech were extremely innovative, stimulating and informative; and that

Presentation by Dr Kang Xia, Interim Associate Director, Virginia Agricultural Experiment Station and Director of the Center of Advanced Innovation in Agriculture were insightful and educational, and that

Assistance and support provided by Parry Kietzman, Research Associate Virginia Tech, who helped organizing the meeting, Jonathan Kubesch and Harry Stewart, who provided transportation were enlightening and enjoyable, and that

Valentin Picasso provided excellent leadership as Committee Chair;

Marília Chiavegato provided excellent service as secretary;

Jim Kells, administrative advisor for NCCC-31, provided timely and constructive advice, and lastly that

The members of NCCC-31 are deeply grateful for the vision, collegiality, and friendship that have made the 2023 meeting a great success.

## State Reports

### USDA-ARS Fayetteville, AR

1. Impact Nugget:
The USDA-ARS Unit, located at the University of Arkansas, conducts research and technology transfer on practices that reduce negative environmental impacts of poultry litter on air, soil, and water resources, while improving the agronomic value of this resource in pasture agroecosystems.

2. New Facilities and Equipment:
Volumetric Water Content (VWC) sensors, drone (hyper and multi-spectral camera), an electrical conductivity (EC) meter, GPS cattle collars, and a C:N analyzer were procured to attain research-quality accuracy in measurement of soil-water in integrated forage-animal grazing systems.

3. Unique Project Related Findings:
1. Animal manures, which are valuable sources of nutrients, may also contain antimicrobial resistant (AMR) genes. Following 14-years of continuous pasture management, AMR genes in grassland soils following 14-years of poultry litter and cattle manure deposition were evaluated. Continuous grazing (relative to conservation best management practices such as rotation grazing) had the greatest abundance of AMR genes, thus suggesting overgrazing and continuous cattle manure deposition may increase AMR gene presence. Results suggest that conservation pasture management practices may minimize the presence and number of AMR genes in grassland soils by 32%.

2. Systems-level studies aimed at determining how soil properties are linked to plant production and ultimately animal response are lacking. A study was carried out to identify if grazing pressure is linked to soil properties, terrain attributes, and aboveground plant accumulation and nutritive value using GPS cattle tracking devices. Cattle avoided grazing areas with deeper soils (i.e. > 100 cm), which corresponded to reduced elevation and increased soil moisture spatially. Combining spatial behavioral monitoring technologies with pasture availability may improve grazing systems management spatially and temporally.

3. Data repositories using legacy data are needed to minimize research redundancy, enable knowledge synthesis, and optimize productivity and resiliency of agricultural systems, particularly for forages. Therefore, the NCCC-31 community developed a forage database (Forage Data Hub) using legacy datasets encompassing multiple temporal and spatial scales and species to analyze system functionality and resiliency. The utility of curating these diverse datasets was demonstrated by quantifying forage system resiliency during extreme weather occurrences (relationship between standardized yields and yields during years receiving 25th percentile of the 30-year normal precipitation) for three systems (monocrop annual, monocrop perennial, and mixed perennial) spanning 52,997 data entries (108 unique locations and 51 years). Overall, development of the Forage Data Hub underscores the benefits of community-driven data sharing and curation for a given commodity to provide systems-level sustainability assessments for identifying practices that promote ecological intensification and resiliency to climatic stochasticity.

4. Accomplishment Summaries:
Quantified best management practice effects on soil health. A series of experiments set out to identify long-term (>15 years) conservation practices influence on soil quality, as understanding the impacts of long-term agricultural practices on soil quality is key for sustaining agroecosystem productivity. Researchers at the Fayetteville, AR; Booneville, AR; and Lincoln, NE units and University of Arkansas and the Federal Rural University in Lavras, Brazil used the Soil Management Assessment Framework to quantify soil health in grassland, cropping, and agroforestry systems. Researchers found that practices such as animal manure applications, non-tillage, crop rotations, and rotational grazing improved soil quality relative to business-as-usual practices (e.g. monocropping, tilled, and inorganic fertilizer management). Soil health improvements corresponded to increased carbon storage, primary productivity, and water quality improvements, which underlines the benefits of conservation soil management in diverse perennial circular systems.

Identified alternative management practices to ensure long-term sustainable use of poultry litter. Broiler (meat chicken) production in the southeastern US is a leading enterprise totaling $31.7 billion USD in agricultural receipts, with about half of the production occurring in four southeastern states. The use of by-products from poultry production, or poultry litter, has the potential to close nutrient loops, as by-products are re-applied the following season to marginal soils. Although, conventional application methods entail spreading poultry litter on the soil surface, which can result in up to 60% of nutrients being lost to the air, soil, and water. In efforts to improve management options that aid in nutrient sustainability and improve crop yield, an ARS research team developed an implement for subsurface applications of poultry litter in conservation tillage systems. This 'Subsurfer' lowers nutrient runoff and ammonia emissions by 90%. This practice was compared to poultry litter surface applications in small watersheds. Researchers found that the ARS Subsurfer reduced nutrient losses in runoff by 66% and improved crop yields by 39%. Therefore, subsurface incorporation of poultry litter relative to surface applications of poultry litter can enhance soil and water conservation and improve crop yields.

Identified practices that minimize the spread of antibiotic resistant gene movement in the environment. Veterinary pharmaceutical usage is an essential component of treating infections in poultry and bovine production. Manure from treated animals, which is an abundant source of valuable nutrients, may also contain antimicrobial resistant (AMR) bacteria. The existence of AMR bacteria in soil and water is a significant public health concern. According to the Organisation for Economic Cooperation and Development, 2.4 million people will die from infections with resistant microorganisms in the next 30 years, costing up to 3.5 billion USD per year. Yet the fate and transport pathways from animals to the environment is poorly understood in the largest U.S. land-use category, or grasslands. A series of studies tracked the movement of AMR bacteria following animal manure (cow and poultry) land applications. After 14-years of continuous management, AMR bacteria were greatest under continuous grazing (relative to conservation best management practices), suggesting continuous cattle manure deposition may increase AMR gene presence. In general, AMR genes increased downslope, suggesting potential lateral movement and accumulation based on landscape position. Researchers found that poultry litter had lower abundance of AMR bacteria relative to cattle manure. Adoption of conservation pasture best management such as riparian buffer strips improves water quality while disrupting AMR bacteria movement, which will contribute positively to disease management.

Developed a method for rapidly quantifying spatial overlaps and gaps for precision agriculture tools in pastures. Scientists from Fayetteville and Booneville, Arkansas and University of Arkansas research partners developed an automated method for rapid determination of spatial coverage of precision agriculture technologies, such as auto-guided tractors and other self-propelled machinery that reduce over-application of on-farm nutrients and inputs by 10-20%. It is estimated that auto-guided tractors reduce on-farm inputs by as much as 20% and can save producers $10.8-13.5 million annually by improving gains in equipment efficiency and enhancing yields. Moreover, producers can also reduce the over-application of fertilizers and herbicides, which reduces the negative environmental footprint of crop production and avoids unintentional input costs to the producer. Currently, roughly half of large-scale row crop producers are using tractor guidance, however, 82% of the total farms in the US are small farms but are largely not adopting these cost and environmental saving technologies. Therefore, this team: 1) developed a method to calculate overlaps and gaps, and 2) quantified overall gains by tractor guidance systems. Field research was conducted using fertilizer (inorganic and poultry litter) and sprayer applications with and without tractor guidance. USDA-ARS researchers developed a novel automated method for quantifying overlaps and gaps and proposes a new method for calculating spatial coverage efficiency. Results suggests that tractor guidance systems reduce overlaps (up to 6% of the total field area) and gaps (up to 16%) during field operations and improves the average overall efficiency by 8%. Hence, tractor guidance systems likely result in reduced input-use and shorter in-field operation time leading to improved economic and environmental savings. Our approach to estimate tractor guidance efficiency on small farms using actual field research is novel and may aid in adoption of tractor guidance, thus potentially improving efficiency gains on 82% of US farms.

Developed first ever continuous soil property maps on Tribal Lands. Knowledge, data, and understanding is key for advancing agriculture and society, although not all sectors of U.S. societies have received information and technology transfer at the same rate. Tribal Reservations have very basic agronomic information relative to other producers in the U.S. This research created first ever high-resolution digital maps of soil properties on 22,880-ha for sustainable soil resource management. It is expected that these maps and future versions will be useful for soil, forage crop, and land-use decisions at the farm and Tribal-level for increased agricultural productivity and economic growth. Research was funded by the Foundation for Food and Agriculture Research.

5. Impact Statements

During 2021-2022, Arkansas (USDA-ARS, Ashworth et al.) published data on BMPs for reducing nutrient losses and antibiotic resistance, while improving forage production and soil health in pasture systems at the soil-plant-water nexus on Tribal and non-Tribal pasture systems. Outreach activities included the delivery of our findings during in-service training sessions, field days, and through technology transfer. A summary of all publications (34 total) and funding procured ($1.25 Mil) from 2022-2023 is included at the end of this document. Selected project impacts are listed above in detail.

1. Developed first ever continuous soil property maps for forage management on 22,880-ha Tribal Lands.

2. Identified pasture best management practices of sub-surface applications of nutrients and pasture aeration for minimizing nutrient losses to the air, soil, and water by 75%.

3. Quantified that tractor guidance can reduce input use by 10-20% and save U.S. producers $10.8-13.5 million per year by increasing equipment efficiency gains in pasture systems.

4. Used machine learning to tease apart driving factors in silvopastoral systems and found that soil nutrient distribution patterns drove grazing response, with animal grazing preference also being influenced by aboveground (forage and tree), soil, and landscape attributes.

5. Decomposition of forage root C affects potential soil C pools as the root system of grasslands accounts for up to 60% of C entering soils with native grass roots decomposing quicker than non-native forages.

6. <u>Published Written Works</u>

*Refereed publications*

Ashworth, A.J. and C. Nieman. 2022. Evaluating optimum seeding distances from subsurface banding poultry litter in crop rotations. Agricultural & Environmental Letters. 7: e220063. doi.org/10.1002/ael2.20063

Keyser, P.D. and A.J. Ashworth. 2022. Wheat cover crop and seed treatment for improving native warm-season grass establishment. Crop, Forage, & Turfgrass Management. 8, e20147. doi.org/10.1002/cft2.20147 e20147.

Kharel, T.P., A.J. Ashworth, and P.R. Owens. 2022. Linking and sharing technology: partnerships for data innovations for management of agricultural big data. Data. 2: 12. doi.org/10.3390/data7020012

Zhou, V., J.A. Larson, V.R. Sykes, A.J. Ashworth, and F.L. Allen. 2022. Long-Term Conservation Agriculture Effects on Corn Profitability in West Tennessee. Crop Science. 62, 1348– 1359. doi.org/10.1002/csc2.20727

Ashworth, A.J., S. Katuwal, P.A. Moore, Jr., and P.R. Owens. 2022. Multivariate evaluation of watershed health based on longitudinal pasture management. Science of the Total Environment. 824, 153725. doi.org/10.1016/j.scitotenv.2022.153725.

Bagnall, DK., C. L.S. Morgan, M. Cope, G.M. Bean, SB. Cappellazzi, K.L.H. Greub, D. Liptzin, C.E. Norris, E.L. Rieke, P.W. T. Ezra Aberle, A.J. Ashworth, et al. 2022. Carbon-sensitive pedotransfer functions for plant available water. Soil Science Society of America Journal. 86, 612– 629. doi.org/10.1002/saj2.20395

Ashworth, A.J., T.C. Adams, and A. Jacobs. 2022. Long-term sustainability implications of diverse commercial pollinator mixtures for the conservation reserve program. Agronomy. 12, 549. doi.org/10.3390/agronomy12030549.

Ashworth, A.J., C. Nieman., T.C. Adams, J. Franco, and P.R. Owens. 2022. Subsurface banding poultry litter influences edamame yield, forage quality, and leaf greenness. Agronomy Journal. 114, 1833– 1841. doi.org/10.1002/agj2.21048

Ashworth, A.J., T. Kharel, T.J. Sauer, T.C. Adams, D. Philipp, A. Thomas, and P.R. Owens, Spatial monitoring technologies for coupling the soil plant water animal nexus. 2022. Scientific Reports. 12, 3508. doi.org/10.1038/s41598-022-07366-2

Amorim, H.C.S., A.J. Ashworth, T.J. Sauer, and Y.L. Zinn. 2022. Soil organic carbon and fertility based on tree species and management in a 17-year agroforestry site. Agronomy. 12, 641. doi.org/10.3390/agronomy12030641

Rieke, E.L., S.B., Cappellazzi,M. Cope, G.M. Bean, K.L.H. Greub, C.E. Norris, P.W. Tracy, E. Aberleb, A.J. Ashworth, et al. 2022. Linking soil microbial community structure to potential carbon mineralization: A continental scale assessment of reduced tillage. Soil Biology and Biochemistry. 168, 108618. doi.org/10.1016/j.soilbio.2022.108618.

Burgess-Conforti, J.R., P.A. Moore, Jr. P.R. Owens, D.M. Miller, A.J. Ashworth, P.D. Hays, M.A. Evans-White, and K.R. Anderson. 2022. Relationships between land use and stream chemistry in the Mulberry River basin, Arkansas. River Research and Applications. 38: 1031– 1040. doi.org/10.1002/rra.3970

Lee, D.T., J.T. Lee, A.J. Ashworth, M.T. Kidd, A. Mauromoustakos, and S.J. Rochell. 2022. Evaluation of a threonine fermentation product as a digestible threonine source in broilers, J. of Applied Poultry Research, 31, 100252, doi.org/10.1016/j.japr.2022.100252.

Ashworth, A.J., B. Putman, T. Kharel, G. Thoma, A. Shew, M. Popp, and P.R. Owens. 2022. Environmental impact assessment of tractor guidance systems based on pasture management scenarios. American Society of Agricultural and Biological Engineers. 65; 645-653. doi:10.13031/ja.14930

Katuwal, S., A.J. Ashworth, P.A. Moore Jr., K. Brye, M. Schmidt, M. Vanotti, and P.R. Owens. 2022. Preferential transport of phosphorus from surface-applied poultry litter in soils from karst and non-karst landscapes. Soil Science Society of America Journal. 86, 1002– 1014. doi.org/10.1002/saj2.20424

Bagnall, DK., C. L.S. Morgan, M. Cope, G.M. Bean, SB. Cappellazzi, K.L.H. Greub, D. Liptzin, C.E. Norris, E.L. Rieke, P.W. T. Ezra Aberle, A.J. Ashworth, et al. 2022. Selecting soil hydraulic properties as indicators of soil health: measurement response to management and site characteristics. Soil Science Society of America Journal. doi.org/10.1002/saj2.20428

Ashworth, A.J., P.A. Moore, Jr., T. Bacon, K. Anderson, and J. Martin. 2022. Twenty-year phosphorus trends in forage systems receiving aluminum sulfate treated poultry litter. American Society of Agronomy Journal. 114, 2310– 2319. doi.org/10.1002/agj2.21132

Liptzin, D., C.E. Norris, S.B. Cappellazzi, G.M Bean, M. Cope, K.L.H. Greub, E.L. Rieke, P.W. Tracy, E. Aberle, A.J. Ashworth, et al. 2022. Carbon indicators of soil health in long-term agricultural experiments. Soil Biology and Biochemistry, 172, 108708. doi.org/10.1016/j.soilbio.2022.108708.

Kharel, T.P., A.J. Ashworth, and P.R. Owens. Evaluating how operator experience level affects efficiency gains for precision agricultural tools. 2022. Agricultural & Environmental Letters. 7, e20085. doi.org/10.1002/ael2.20085

Smith, H., P.R. Owens, and A.J. Ashworth. 2022. Applications and analytical methods of ground penetrating radar for soil characterization in a silvopastoral system. Journal of Environmental and Engineering Geophysics.

Keyser, P.D., K.E. Zechiel, G.E. Bates, A.J. Ashworth, R.L. G. Nave, J.D. Rhinehart, and D.W. McIntosh. 2022. Evaluation of five C4 forage grasses in the tall Fescue Belt. Agronomy Journal. 114, 3347– 3357. doi.org/10.1002/agj2.21195

Smith, H.W., A.J. Ashworth, and P.R. Owens. 2022. GIS-based evaluation of soil suitability for optimized production on U.S. Tribal Lands. Agriculture. 12(9):1307. doi.org/10.3390/agriculture12091307

Katuwal, S., A.J. Ashworth, R. Nur-Al-Sarah, and P. Kolar. 2022. Characterization of poultry litter biochar and activated biochar as a soil amendment for valorization. Biomass. 2: 209-223. doi.org/10.3390/biomass2040014. (Cover Article).

Rieke, E., Bagnall, D.K., Morgan, C.L.S., Flynn, K.D., Howe, K.L.H. Greub J.A., Bean G.M., Cappellazzi S.B., Cope M., Liptzin D., Norris C.E., Tracy, Aberle E., A.J. Ashworth, et al. 2022. Evaluation of aggregate stability methods for soil health. Geoderma. 428, 116156. doi.org/10.1016/j.geoderma.2022.116156

Katuwal, S., A.J. Ashworth, P.A. Moore, Jr., and P.R. Owens. 2022. Nutrient runoff from perennial and annual forage species following broiler litter application. Journal of Environmental Quality. 2023. 52, 88– 99. doi.org/10.1002/jeq2.20425

Ashworth, A.J., S. Katuwal, P.A. Moore Jr., T. Adams, K. Anderson, and P.R. Owens. 2023. Perenniality drives multifunctional forage-biomass filter strips' ability to improve water quality. Crop Science. 63, 336– 348. doi.org/10.1002/csc2.20878 (Cover Article).

Ylagan, S., K.R. Brye, A.J. Ashworth, P.R. Owens, H. Smith, and A.M. Poncet. 2022. Using apparent electrical conductivity to delineate field variation in an agroforestry system in the Ozark Highlands. Remote Sensing. 14, 5777. doi.org/10.3390/rs14225777

Winzeler, H.E., P.R. Owens, Q.D. Read, Z. Libohova, A.J. Ashworth, and T. Sauer. 2022. The topographic wetness index as a proxy for soil moisture in a hillslope catena: flow algorithms and map generalization techniques. Land. 11, 2018. doi.org/10.3390/land11112018

Ashworth, A.J., P.A. Moore, Jr. 2023. Trace metal uptake in forage systems receiving long-term applications of alum treated or untreated poultry litter. Crop Science, 63, 1634– 1645. doi.org/10.1002/csc2.20918

Winzeler, H.E. P.R. Owens, T. Kharel, A.J. Ashworth, and Z. Libohova. 2023. Identification and delineation of broad-base agricultural terraces in flat landscapes in northeastern Oklahoma, USA. Land 2023, 12, 486. doi.org/10.3390/land12020486

Anapalli, S., K. Reddy, A.J. Ashworth. 2023. Eddy covariance assessment of alternate wetting and drying floodwater management on rice methane emissions. Heliyon. e14696. doi.org/10.1016/j.heliyon.2023.e14696

Liptzin, D., C.E. Norris, S.B. Cappellazzi, G.M Bean, M. Cope, K.L.H. Greub, E.L. Rieke, P.W. Tracy, E. Aberle, A.J. Ashworth, et al. 2023. An evaluation of nitrogen indicators for soil health in long-term agricultural experiments. Soil Science Society of America Journal. 87, 868– 884. doi.org/10.1002/saj2.20558

Katuwal, S., N.S. Rafsan, A.J. Ashworth, and P. Kolar. 2023. Poultry litter physiochemical characterization based on production conditions for circular systems. Bioresources. 18, 3961-3977.

Smith, H., A.J. Ashworth, P.R. Owens, and A. Schmidt, L. Nalley, and M. Soleil-Turmel. In press. Boundary line analysis and machine learning models to identify critical soil values for major crops in Guatemala. Agronomy Journal.

*Other publications*

Keyser, P.D., A.J. Ashworth. 2022. What Type of Grass is Best for Beef Cattle. Science News. American Society of Agronomy. https://www.agronomy.org/news/science-news/what-type-grass-best-beef-cattle?utm_source=facebook&utm_medium=1f9eccb0-431d-40ed-a45b-d595d9412f0c

Ashworth, A.J., and C. Neiman. 2022. Subsurface Banding Litter Reduces Nutrient Losses and Improves Yields. Crop, Soils, Agronomy News. May, Issue; pg. 22.

Ashworth, A.J., S. Ylagan, H. Amorim, P.R. Owens, and T.J. Sauer. Agroforestry, Poultry Litter, and Soil Health. 2022. Features Article in Soil Science Society of America, American Society of Agronomy, and Crop Science Society of America News. https://doi.org/10.1002/csan.20637

Ashworth, A.J., and C. Neiman. 2022. Subsurface Banding Litter Reduces Nutrient Losses and Improves Yields. Crop, Soils, Agronomy News. May, Issue; pg. 22.

Ashworth, A.J., S. Ylagan, H. Amorim, P.R. Owens, and T.J. Sauer. Agroforestry, Poultry Litter, and Soil Health. 2022. Features Article in Soil Science Society of America, American Society of Agronomy, and Crop Science Society of America News. https://doi.org/10.1002/csan.20637

*Proceedings publication*

Marshall, L. A.J. Ashworth, J. Volenec, M. Berti, E. van Santen, C. Williams, V. Gopakumar, J. Foster, J. Su, and V. Picasso. International Grasslands Congress. Forage Data Hub – a platform for sharing valuable datasets for resilience. 2023.

6. Scientific and Outreach Presentations

*Invited presentations*

By Request of the National Academies of Science, Engineering, and Medicine serve on a panel for the Committee on Exploring Linkages Between Soil Health and Human Health and give an invited talk on “Exploring One Health Linkages in Agricultural Systems” in Washington D.C., 2023.

Invited to present at the Southwest Indian Agriculture Associate on “Advancing the State of Soil Information to Close Yield Gaps and Manage Soils to Manage Water” in Tucson, AZ, 2023.

Invited to present at the USDA-ARS wise ARS AMR/ATA Research Webinar Series: Mitigation - Alternatives to Antibiotics Mitigation – Farm and Production Environments, 2022.

Invited to present the seminar “Data-driven Technology Applications for Improved System Sustainability” University of Kentucky, Department of Plant and Soil Sciences, Departmental Webinar Series, 2022.

Invited to present the seminar “Soil Quality Assessments of Long-Term Conservation Agricultural Practices in the Southeastern US” Sustainable Soil Management Course, University of Fraser Valley, British Columbia, Canada, 2022.

*Abstracts , symposium and conference presentations*

Manter, D.K., K. Reardon, A.J. Ashworth, T. Ducey, P.M. Ewing, M. Ibekwe, M. Lehman, J. Maul, D.N. Miller, H.L. Tyler, K. Veum, and S.L. Weyers. 2022. Operator introduced greater variability in soil community diversity than DNA extraction, amplification or sequence device: A cross-lab comparison. Preferential transport of phosphorus from surface-applied poultry litter in soils from karst and non-karst landscapes Soil Science Society of America. [CD-ROM]. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America (ASA, CSSA, and SSSA), International Meetings, Madison, WI. (Oral Presentation).

Seyoum, M., A.J. Ashworth, P.R. Owens, and P.A. Moore, Jr. 2022. Long-term impacts of conservation agriculture on systems-level microbial communities and antibiotic resistance genes. [CD-ROM]. ASA, CSSA, and SSSA, International Meetings, Madison, WI. (Oral Presentation).

Ashworth, A.J., S. Katuwal, P.A. Moore Jr., T. Adams, and P.R. Owens Perenniality drives multifunctional filter strip ability to improve water quality in poultry litter amended soils. [CD-ROM]. ASA, CSSA, and SSSA, International Meetings, Madison, WI. (Poster Presentation).

Janorschke, Matthew, M.C. Savin, D. Phillipp, C. Nieman, and A.J. Ashworth. 2022. Productivity within a Midsouthern US forest under various thinning treatments. [CD-ROM]. ASA, CSSA, and SSSA, International Meetings, Madison, WI. (Poster Presentation).

7. Collaborative Funded Grants

*Funded 2022-2023*

2022 USAID, "Supporting Vulnerable Smallholder Communities during Climate Change Through Improving Soil Nutrition for Grain and Coffee Production", $56,000 for 2022-2024 with with Amanda Ashworth, Phillip Owens, and Axel Schmidt, PI ($56,000 Ashworth portion).

2022 USDA-Agricultural Research Service funding Opportunity in Antimicrobial Resistance, "Scaling up Potential AMR and Phage Transport to Groundwater in Karst Geologies Through Digital Tools" $69,202 for 2022-2024 with Amanda Ashworth, Mary Savin, Lisa Durso, Phillip Owens, Sheela Katuwal, and Jennifer DeBruyn, PI ($69,202 Ashworth portion).

2022 AFRI Foundational Knowledge of Agricultural Production Systems, entitled "Coupling Human and Machine Knowledge To Optimize Tribal Food Systems", $649,684, PI ($293,167 Ashworth portion).

2022 AFRI Sustainable Agricultural Systems, entitled "Fostering Resilience and Ecosystem Services in Landscapes by Integrating Diverse Perennial Circular Systems", $10,000,000, Co-PI. ($277,777 Ashworth portion).

## University of Arkansas, Animal Science

1. Impact Nugget

The group from the University of Arkansas is engaged in applied research and extension activities pertaining to the use of native and introduced annuals, perennials, warm and cool season forages. Our current activities, based on external funding, focus on determining nitrogen fluxes at the soil-plant-animal interface, soil water retention under grazing to different canopy heights, forage establishment and growth in wooded areas, and prairie reconstruction for roadside management.

2. New Facilities and Equipment

No updates.

3. Unique Project-Related Findings

We finished a major silvopasture project in the fall of 2022. Tall fescue and orchardgrass were less affected by woody, low-growing vegetation than would have been expected in a light-poor environment. Groundcover from both grasses held back typical forest floor vegetation by maintaining cover year-round. Forage establishment in pine alleys was less successful, however. While perennial and annual introduced forages could be established, maintaining these was difficult as weeds started to encroach in the second year of the experiment.

In Fall of 2021, we started a prairie restoration project (small-plot trials) with the goal to develop maintenance plans for roadside establishment. While establishment failed in the first year (2022), we were able to successfully establish several species planted in April of 2023. Species assessments showed that black-eyed Susan, rattlesnake master, various milkweeds, ashy sunflower, partridge pea, Illinois bundleflower, and some grasses (switchgrass and little bluestem) were the most common one. Overall number of individual plants of prairie species is still considerable low.

4. Accomplishment Summaries

During the last reporting period, we started and/or continued the major following projects:

1) Sheep grazing effects on soil water status in cool season perennial pastures:

This project comprises of stocking 0.25-acre paddocks with ~30 grown ewes and defoliating forage to ~50% or ~85% of forage mass measured pre-stocking. Included control paddocks were not stocked. Water measurements are being accomplished by taking soil samples and collecting data from permanently installed soil sensors. The project will continue throughout 2024.

2) AR DOT Roadside project:

Native tall grasses, short grasses, and forbs were grown in combination to test establishment success and effects of mowing intervals on native plant persistence. Although we were able to establish several species, overall success has been low so far given the long periods necessary to restore prairie plant communities.

5. Impact Statement

Issue:

Forage-based production systems dominate production of meat and milk but are inefficient in terms of feed conversion and nitrogen use efficiency. Besides carbondioxide and methan, nitrous oxide is a very potent greenhouse gas resulting from ruminat enteric emissions and losses from soil through various processes including manure deposition. Reducing overall nitrous oxide emissions and balancing nitrogen in feed will lead to reduced environmental impacts while increasing feed conversion efficiency.

Action:

We secured funding for 5 years (2018 – 2023) to feed sheep with high- and low-tanning containing alfalfa/lespedeza silages as those will affect the amount of nitrogen converted in the rumen vs. bypass protein for digestion in the lower gut. Feces and urine were collected while 80 field plots were established in an existing tall fescue pasture to measure nitrous oxide, methane, carbon dioxide, and ammonia emissions and measuring nitrate leaching in soil cores of different diameters to which urine and a slurry of urine and feces that were applied in two different experiments in fall of 2018, spring/summer 2019, and summer/fall 2022. An additional greenhouse experiment was conducted in 2022 and data collection and analyses finalized in 2023.

Impact:

These studies may lead to a more efficient use of natural resources and farm inputs. A potential improvement of nitrogen use efficiency and feed conversion efficiency will help in using natural resources more efficiently as well. Research progress and updates will be communicated throughout the duration of the experiments through appropriate media outlets.

Contact:
Dirk Philipp, Department of Animal Science
479/575-7914 / dphilipp@uark.edu
Cooperators: M. Savin, K. Coffey, J. Zhao, and R. Rhein

Funding:
This project was conducted with appropriations USDA-NIFA and from the University of Arkansas – Division of Agriculture/Agricultural Experiment Station.

6. Published Written Works (selected peer-reviewed and outreach-oriented)

*Peer-reviewed:*

Nieman, C., Coffey, K., Young, A., Kegley, E., Hornsby, P., Hollenback, J., Philipp, D. (2022). Intake, digestibility, and rumen fermentation by lactating beef cows offered bermudagrass hay with different sources of dried distillers grains. *Applied Animal Science, 22*(3).

Niyigena, V., Coffey, K., Coblentz, W., Philipp, D., Althaber, C., Diaz, J., Rhein, R., Pruden, M. (2022). Intake, digestibility rumen fermentation and nitrogen balance in lambs offered alfalfa and tall fescue-mixtures harvested and ensiled after a frost. *Animal Feed Science and Technology, 286*, 115-268.

Ashworth, A., Kharel, T., Sauer, T., Adams, T., Philipp, D., Thomas, A., Owens, P. (2022). Spatial Monitoring Technologies for Coupling the Soil Plant Water Animal Nexus. *Scientific Reports, 12* (3508).

*Abstracts:*

Collins, E., M. Savin, and D. Philipp (2022). Increasing the Concentration of Hippuric Acid in Sheep Urine as a Method to Improve Retention of Manure-Nitrogen Soil Inputs. Agronomy Society of America, annual meeting. (Baltimore, MD)

Matthew Janorschke, Mary Savin, Dirk Philipp, Christine Nieman, Matthew Bertucci, David Miller, Amanda Ashworth. (2022). Usefulness of Glomalin-Related Soil Protein as a Functional Indicator for Soil Health When Establishing Forage in Midsouthern US Forest. Soil Ecology Society Biennial meeting, Richland, Wash. USA.

*Outreach publications:*

Philipp, D. and J. Lovett (2022). Native grasses, silvopasture part of Arkansas carbon sequestration study.

Philipp, D. and J. Lovett (2022). Study identifies cattle forages for wooded settings to establish productive silvopastures

Philipp, D. and R. Mc Geeney (2022). Plant species diversity is key to enhance soil carbon in grassland

Philipp, D. and R. Mc Geeney (2022). To give native grasses a good start, limit grazing and stay on top of weeds.

Philipp, D. (2022) Ranchers confront drought in state (Interview by Cristina La Rue Arkansas Democrat Gazette)

7. Scientific and Outreach Presentations

Philipp, D., Webinar – Beginning farmers and ranchers, "Pasture production," University of Arkansas - Pine Bluff, Online. (2022).

Philipp, D., Webinar – Forage establishment and management in Arkansas' silvopasture for small beef producers (2022). USDA National Agroforestry Center & SARE Research and Education Grant Program

Philipp, D. (2022). Research update. NCCC-31 Forage Physiology Multistate Research Coordinating Committee and Information Exchange Group)

8. Collaborative Grants
    - Morris, M. et al. (Philipp Co-PI): Soil for Water.
        - USDA-Southern SARE; $1,000,000
    - Richardson et al. (Philipp Co-PI): Developing a sustainable approach to roadside vegetation management in the State of Arkansas
        - Arkansas Department of Transportation; $350,000
    - Jagadamma, S. et al. (Philipp Co-PI): Native Warm Season Perennials: An Enduring Solution To Summer Drought And Slump For Fescue Belt Organic Forage Production
        - USDA, Organic Agriculture Research & Extension Initiative; ~$105,000

9. Graduate Students
    - Matt Janorschke, MS Student co-advised with Dr. Mary Savin (Univ. of Arkansas, Crop and Environmental Sciences)
    - Ethan Collins, MS Student (Univ. of Arkansas, Crop and Environmental Sciences)
    - Kolten Wright, MS Student (Univ. of Arkansas, Department of Animal Sciences)

## Maryland State Report (University of Maryland)

1. Impact Nugget

The beneficial biodiversity on farms, such as predators of insect pests, depends on the presence and locations of suitable habitats for their survival and reproduction. Predatory ground beetles, lady beetles, and parasitic wasps are examples of those beneficial species. Our studies within forage crops and the surrounding landscape are designed to better understand their role in these ecosystems and their potential for conservation biological control.

2. New Facilities and Equipment

None

3. Unique Project Related Findings

We have discovered that predatory and parasitic insect species are more abundant in a leafhopper-susceptible cultivar than in a leafhopper-resistant cultivar. Parasitic hymenopterans (wasps) were especially abundant in samples, with more from the susceptible plots and from the resistant plots.

Agricultural drainage ditches sampled along Maryland's Eastern Shore contain an abundant and ecologically diverse population of ground beetles as well as other types of natural enemies. Over 50 families of predatory and parasitic insects have been discovered in ditches, with many of these detected in the adjacent crops. We are studying their movement into adjacent crop fields as a means to provide conservation biological control of insect pests.

4. Accomplishment Summaries

Shokoohi, Alireza, and William Lamp. Enhancing biological control by ground beetles through agricultural drainage ditch management practices. Conservation biological control seeks to mitigate pest damage by enhancing populations of naturally occurring predators on farms. As semi-natural field margin habitats with high plant and arthropod biodiversity relative to adjacent crops, agricultural drainage ditches provide food and shelter resources that may help increase populations of predatory insects such as ground beetles (Coleoptera: Carabidae). Ground beetles are a diverse, widespread, and abundant family of beetles that are desirable on farms as predators of weed seeds and common invertebrate pests such as caterpillars, aphids, and slugs. Our objectives are 1) to quantify the diversity and abundance of ground beetles in agricultural drainage ditches, 2) to investigate ground beetle movement between ditches and crop fields, and 3) to compare the effects of ditch management practices on carabids including timing of mowing and spreading of straw along ditch banks.

To assess the diversity of ground beetles in drainage ditches, sweep, sticky trap, and pitfall trap samples were collected from six agricultural drainage ditches on the Delmarva Peninsula throughout summers from 2020 to 2022. To date, we have found adults of 19 genera of ground beetles and larvae of 8 genera of ground beetles from pitfall traps at least some number of ground beetles use drainage ditches for reproduction. Data from one drainage ditch at the Wye Research and Education Center (WyeREC) on the Eastern Shore of Maryland (Fig. 1) for which all ground beetle specimens have been identified to the genus level indicates that about half of captured ground beetles, by activity-density, are primarily granivorous (*Harpalus, Amara*), while about one-third of captured ground beetles are primarily predaceous (*Pterostichus, Poecilus, Dicaelus, Stenolophus*), with the feeding habits of other common genera being either mixed or not well-described in the literature.

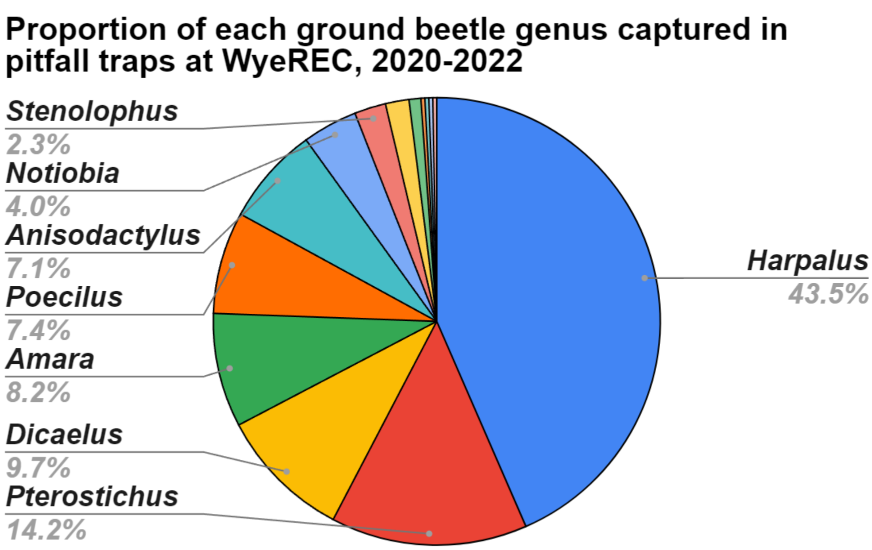



Fig 1. Relative percentages of each genus of ground beetle captured in pitfall traps from a drainage ditch at the Wye Research and Education Center during April-September of 2020-2022.

To investigate ground beetle movement between ditches and crop fields, we used directional pitfall traps consisting of an I-shaped frame with two pitfalls on either side of a central wall. These traps were placed parallel along the margins of six drainage ditches across the Delmarva Peninsula in 2022 such that beetles moving from the field into the ditch would tend to be caught by the field-side traps, and vice versa. We observed consistent movement across the ditch-field boundary, with no significant differences in numbers of ground beetles caught in field-side traps compared to ditch-side traps from June to September (Fig. 2).

To compare the effects of the seasonal timing of ditch mowing and the addition of straw to ditch banks on ground beetle communities, we divided one drainage ditch at the Wye Research and Education Center on the Eastern Shore of Maryland into four blocks spaced 50 feet apart, with each block containing four 40-foot plots. Each plot was assigned one of the following treatments in a randomized block design: (1) straw added in the fall, plot mowed in the fall, (2) straw added in the fall, plot mowed in the spring, (3) no straw added, plot mowed in the fall, (4) no straw added, plot mowed in the spring. Plots were sampled using pitfall traps to measure ground-running ground beetle activity-density. Two traps were placed at each plot, with one on each side of the ditch, and were collected one week after being placed. This was repeated for a total of five sampling rounds from April to September each year. Sampling was conducted during summer 2020 as a control before treatments had been applied, then again in 2021 and 2022 with treatments having been applied during each spring and fall prior. We did not observe significant changes in ground beetle activity-density in 2021 compared to the 2020 control samples. However, ground beetle activity-density was 97% greater in plots treated with straw compared to plots with no straw added the following year in 2022 (Fig. 3). This increase largely consisted of a corresponding increase in the activity density of *Harpalus* spp., a genus of predominantly granivorous ground beetles.

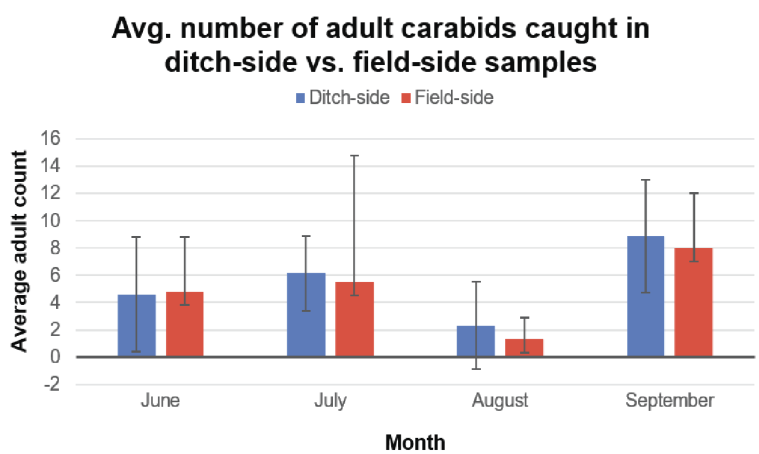



Fig 2. Average abundance of adult ground beetles caught in ditch-side vs. field-side pitfalls using 25 directional pitfall traps placed from June to September of 2022.

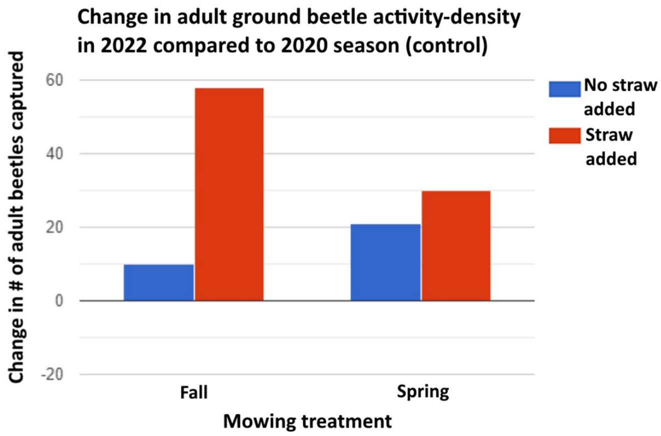



Fig 3. Differences in ground beetle activity-density in plots assigned with each treatment in 2022 as compared to the observed activity-density in those plots during the 2020 control sampling season.

In this study, we have found evidence that diverse ground beetle communities live and reproduce within ditches, that there is consistent movement of ground beetles across the ditch-field boundary throughout the field season, and that the addition of straw may have a positive effect on the activity-density of certain ground beetle genera. Results of this study can be used to develop inexpensive methods to help farmers enhance the ecological functions of agricultural drainage ditches and thus enhance populations of predatory insects and reduce damage caused by pests with less need to resort to chemical pest controls.

Stewart, Jillian, and William Lamp. Potato leafhopper resistant alfalfa plots have fewer natural enemies than non-resistant alfalfa. To compare insect natural enemy diversity and abundance in two cultivars of alfalfa, we use a RCBD field study including two treatments: one resistant cultivar (Pioneer 55H96) to the potato leafhopper (PLH) and the other a similar nonresistant, susceptible cultivar (Pioneer 55V50). Though the resistant cultivar is in widespread usage, it may suffer greater injury from other pests like aphids and alfalfa weevil. Our project is one branch of a line of research aimed at elucidating how insect communities and their (dis)services are affected by the resistant alfalfa.

This study is taking place at the University of Maryland Research and Education Center - Clarksville farm. Eight plots of alfalfa, four resistant and four nonresistant, were planted in 50 by 50 ft plots within a larger field of resistant alfalfa. From 2022 to 2023, each plot is sampled by sweep nets, sticky traps, and D-vac to catalog the arthropods present. Over the course of the growing season the alfalfa was harvested about every 5 weeks. From the data collected, we analyze how natural enemy presence and diversity varies between the two cultivars over time.

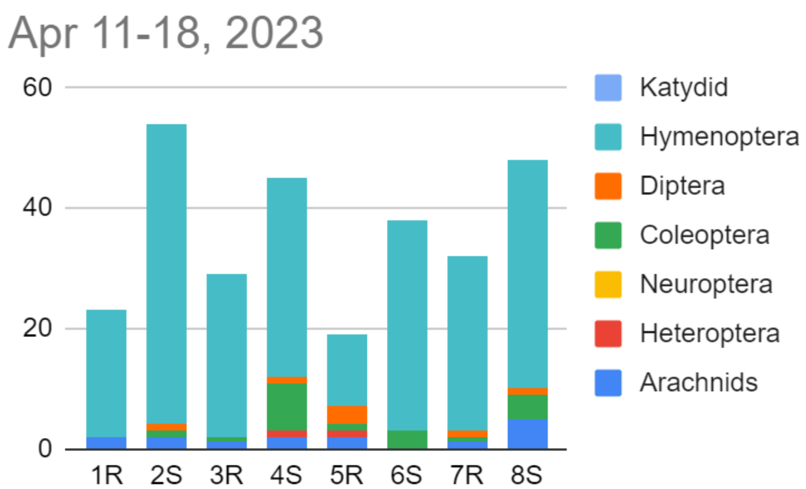



Chart 1) Data from sticky traps set from April 11-18. Early in the growing season, susceptible alfalfa plots (even numbers) tend to have more natural enemies than resistant plots (odd numbers). Coleoptera were more abundant in susceptible plots, though the same does not hold true across all orders.

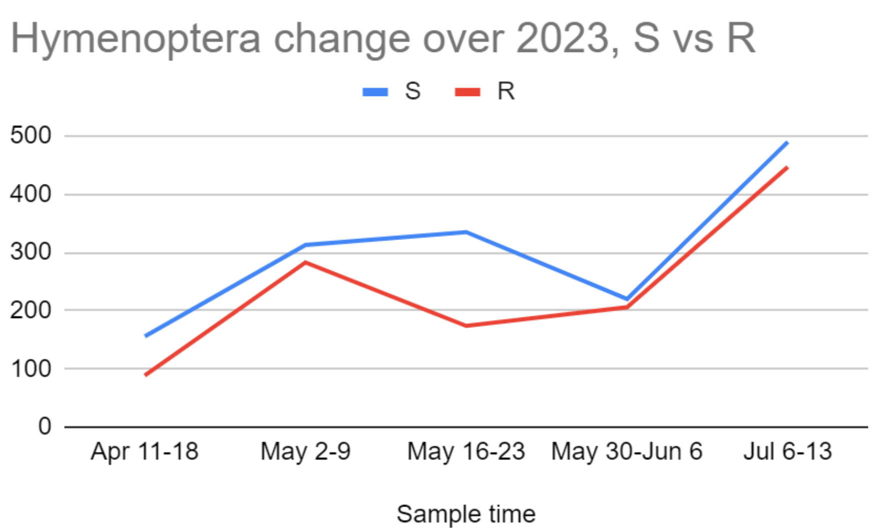



Chart 2) Hymenoptera numbers from four sticky trap sampling periods in 2023. Susceptible plots consistently had more Hymenoptera than resistant plots during the first four sampling periods of 2023. During some periods, their numbers moved in sync with each other. However from early May (May 2-9) to mid May (May 16-23), Hymenoptera numbers dropped in the resistant plots and rose in the susceptible plots. The opposite then occurred from mid May to early June (May 30-Jun 6). A harvest occurred in mid May, possibly causing the drop in Hymenoptera from early to late May. No such harvest occurred between late May and early June, leaving no apparent explanation for the drop in Hymenoptera numbers in susceptible plots.

Samples are still being collected and processed from 2023. Our preliminary results show differences in natural enemy numbers between resistant and susceptible plots, though the extent of the differences varies month to month. It is not yet clear if susceptible plots tend to have lower or greater diversity of natural enemies than resistant plots. The trend suggests diversity will be higher in susceptible plots, though this could fluctuate over time like total natural enemy numbers.

Craig, Helen, Anthony Righter, and William Lamp. Assessment of ecosystems services provided by arthropods on farms: Preliminary use of sticky traps to sample flying insects. Insects are responsible for many ecosystem services, such as pollination, biocontrol, decomposition, nutrient cycling, water filtration, bioturbation, habitat formation, food production, pharmaceuticals, cultural services, and more. It has been calculated that insects have an annual value of at least $70 billion for their ecosystem services (Losey and Vaughan, Bioscience 56 311-323, 2006). However, recent research published in 2017 described an "insect apocalypse" that brought signs of general, unexplained reductions in insect abundance to the public and suggested a catastrophe awaits our planet (Hallmann et al., PLoS One, 12 (2017), p. e0185809). Scientists have long documented the loss of species of insects at a rate exceeding the extinction rates associated with the major geological events in the Earth's history, but the loss in abundance was surprising to entomologists (currently at a rate of 1-2% loss each year) (Wagner, Annu. Rev. Entomol. 2020. 65:457–80).

As a part of a large nation-wide USDA Resilience CAP grant, we are studying on farm management of plant diversity, crop perenniality, and circular economic systems (DPCS) as potential catalysts for improved ecosystem services, in part by enhancing insect biodiversity. A diverse agroecosystem includes diversity in crops over time, like crop rotations, and space, like intercropping. Perenniality involves including perennial crops such as alfalfa and other crops to provide soil cover and nutrient retention. Circularity in an agroecosystem enables recycling nutrients as opposed to losing them to air or water as pollution (i.e., animal manure). We hypothesize that increasing diversity, perenniality, and/or circularity will improve insect biodiversity and their ecosystem services on farms. Here, we investigated the use of sticky traps to assess the flying insects on farms towards documenting the ecosystem services that DPCS farms can provide. Our goal is to determine if this sampling approach will be useful in our nation-wide assessment of farm insect biodiversity.

Starting in June, 2022, and continuing through 2023, we used 9x11" yellow sticky traps (see Images 1 and 2) set up in five distinct locations on two University of Maryland farms (Western Maryland Research and Education Center and Central Maryland Research and Education Center-Clarksville). With two traps at each location, the five locations were labeled as center, northwest, northeast, southwest, and southeast. Sticky traps were set out five times during the summer season in May, June, July, August, and September. Each month the traps were left out for one week before collection. Crop, vegetation, and weather data were documented at each collection period. The sticky traps were transported back to the lab for identification, which included the number of arthropods for each family, and their association with the ecosystem services that they provide.

Although we have not finished collecting and processing the samples, there is a lot of potential in the data we have collected thus far. Using these data sets, we can compare the different locations on each farm, and their respective crop types, to the number of individuals in various functional groups collected from that area (example in Figure 1) or the composition of insect orders over time (example in Figure 2). This information can provide insight into the types of crops that contribute to a variety of ecosystem services present in an agroecosystem. Over the course of this project we will continue to keep track of the diversity, perenniality, and circularity of each farm's agroecosystem over time and relate farm characteristics to the ecosystem services provided by the presence of flying insects and other arthropods.

Image 1: Assembled sticky trap in soybean field (Anthony Righter '24, Lamp Lab)

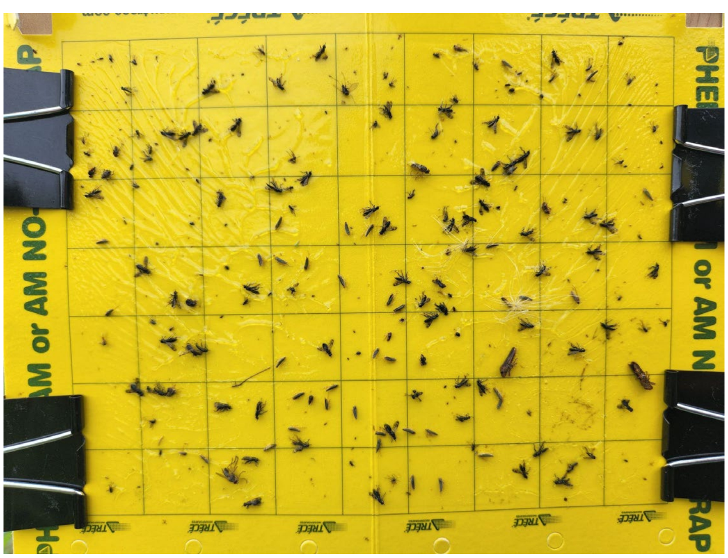


Image 2: Sticky trap close up (Anthony Righter '24, Lamp Lab)

Figure 1. Preliminary biodiversity sampling data showing the average number of individuals per location in June, 2022. NW was near a soybean/alfalfa intercropped field, soybean/rye cover crop field, and a wheat field. NE was near a mixed grass pasture field and a corn field. SW was near a soybean field and a corn field. SE was near a soybean field and cut lawn. Finally CN was near an unmanaged area, a wheat field, and a corn field.

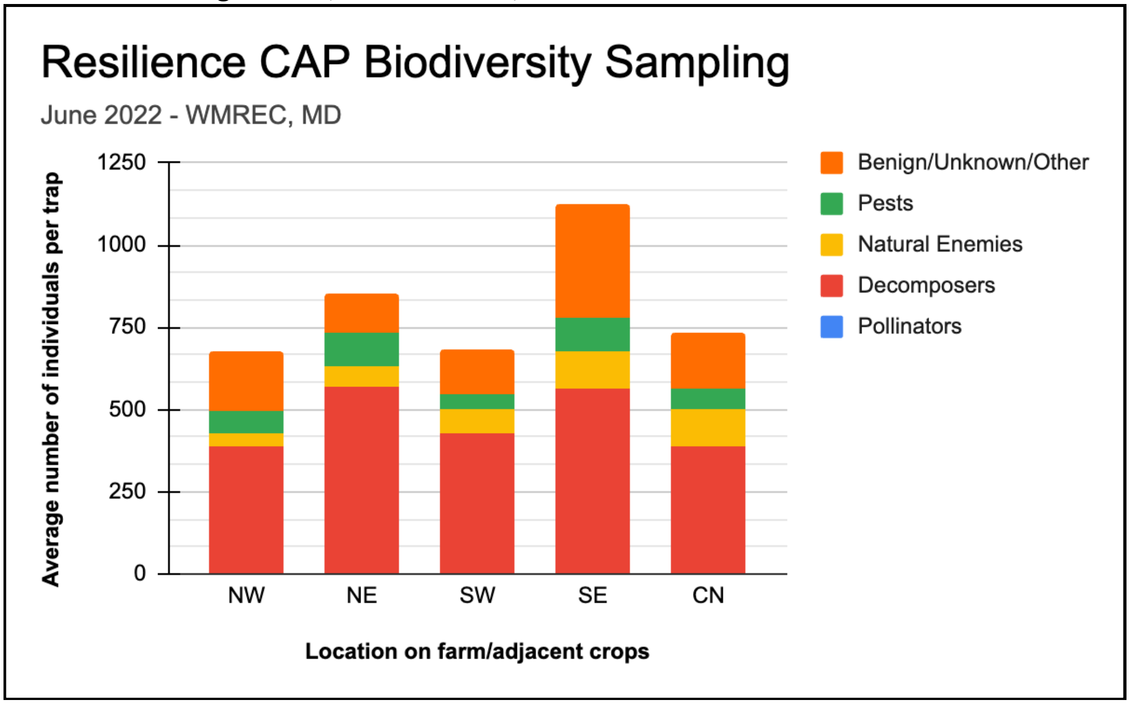
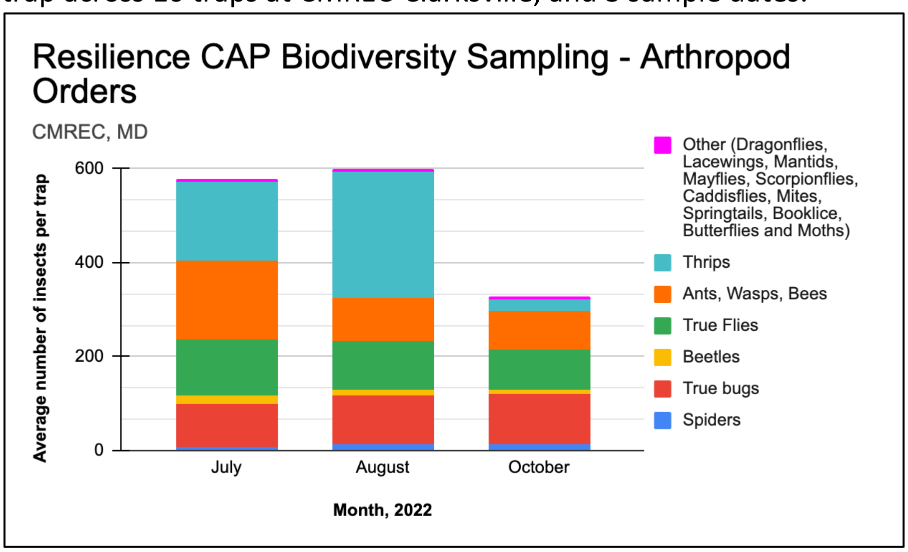



Figure 2. Preliminary arthropod sampling data showing the average number of individuals per trap across 10 traps at CMREC-Clarksville, and 3 sample dates.




5. <u>Impact Statements</u>

Integrated Pest Management (IPM) of crops depends on naturally-occurring predators and parasitoids to reduce pest populations as they develop in crops. Pest population suppression by biological control can often replace the need for pesticide use. The reduction of pesticide use not only helps the farmer to reduce his/her costs, but it also protects the biodiversity on the farm that provides many valuable ecosystem services for the farmer as well as the public at large.

Our studies on conservation biological control broaden our understanding of predator communities in forage crops as well as nearby habitats such as water sources and drainage ditches. Subtle changes in the management of these crops and habitats may lead to increased levels of biological control, and reduce losses by insect pests.

6. Published Written Works

*Refereed publications*

Avanesyan, A., C. McPherson, and W.O. Lamp. 2022. Analysis of plant trait data of host plants of *Lycorma delicatula* in the US suggests evidence for ecological fitting. Forests 2022 13: 2017. https://doi.org/10.3390/f13122017

Picasso, V.D., M. Berti, K. Cassida, S. Collier, D. Fang, A. Finan, M. Krome, D. Hannaway, W. Lamp, A.W. Stevens, and C. Williams. 2022. Diverse perennial circular forage systems are needed to foster resilience, ecosystem services, and socioeconomic benefits in agricultural landscapes. Grassland Research 2022.1: 123-130. DOI: 10.1002/glr2.12020

McPherson, C., A. Avanesyan, and W.O. Lamp. 2022. Diverse host plants of the first instars of the invasive *Lycorma delicatula*: Insights from eDNA metabarcoding. Insects 2022 13: 534. https://doi.org/10.3390/insects13060534

Avanesyan, A., and W. Lamp. 2022. Response of five *Miscanthus sinensis* cultivars to grasshopper herbivory: Implications for monitoring of invasive grasses in protected areas. Plants 2022, 11, 53. https://doi.org/10.3390/plants11010053

7. Scientific and Outreach Presentations

Shokoohi, A. and W. Lamp. 2023. Developing management practices for agricultural drainage ditches to enhance biological control by ground beetles. Eastern Branch, Entomological Society of America Meeting, Providence, RI.

8. Collaborative Grants

Craig, Helen, and William Lamp. University of Maryland Sustainability Fund, 2022-2023, "Educating and Empowering UMD Students on the Importance of Insect Biodiversity in Sustainability", $7,000.

9. Graduate students

Shokoohi, Alireza, MS, December-2023, "Investigating the Impact of Agricultural Ditches on Beneficial Ground Beetle Populations"

Salerno, Robert, MS, May-2025, "Carabid beetle movement between field and ditch environments and subterranean fauna within agricultural ditches"

Brucchieri, Amanda, MS, May-2025, "Use of farm ponds to promote dragonfly reproduction for conservation biological control"

Craig, Helen, MS, May-2026, TBD.

## University of Kentucky

1. Impact Nugget

The forage group at the University of Kentucky (UK) conducts research on how symbioses between forage species and microbes affect forage production, nutritive value, secondary plant metabolites, invasive potential, resilience to climate change and mitigation potential. The forage extension program at UK is productive, well-known and respected for providing sound, timely advice to forage growers in the region. Both the research and extension teams work closely with the co-located USDA-ARS Forage Animal Production Research Unit (FAPRU).

2. New Facilities and Equipment

The USDA-ARS-FAPRU group has received Federal money for a new building on the UK campus, which will house some of the UK forage group and other UK faculty. A location on the UK campus in Lexington has been identified, and site planning and building design processes have begun. The design process is scheduled to be completed this year (2023), with site prep and building work commencing this winter/spring. The building is currently anticipated to open in Spring 2026.

In western Kentucky, new temporary buildings are in place to house the UK faculty and staff displaced by the tornado of December 2021. Barns are being built and plans are in-place to rebuild the permanent facility, with completion projected for 2025.

3. Unique Project Related Findings

Climate change will significantly impact the world's ecosystems, in part by altering species interactions and ecological processes, such as herbivory and plant community dynamics, which may impact forage quality and ecosystem production. Yet relatively few field experimental manipulations assessing all of these parameters have been performed to date. To help fill this knowledge gap, we evaluated the effects of increased temperature (+3°C day and night, year-round) and precipitation (+30% of mean annual rainfall) on slug herbivory and abundance and plant community dynamics biweekly in a pasture located in central Kentucky, U.S.A. Warming increased slug abundance once during the winter, likely due to improving conditions for foraging, whereas warming reduced slug abundance at times in late spring, mid-summer, and early fall (from 62–95% reduction depending on month). We found that warming and increased precipitation did not significantly modify slug herbivory at our site, despite altering slug abundance and affecting plant community composition and forage quality. Climate change will alter seasonal patterns of slug abundance through both direct effects on slug biology and indirect effects mediated by changes in the plant community, suggesting that pasture management practices may have to adapt. - *Weber et al. 2023. PLOS ONE.*

4. <u>Accomplishment Summaries</u>

During 2022-2023, faculty from University of Kentucky published data from a number of forage variety trials, other on-farm work, and scientific studies and trained numerous undergraduate and graduate students. Outreach activities included leadership of the International Grasslands Congress, held in Covington, OH in May 2023, and participation in the annual AFGC meeting in Winston-Salem, NC, in January. Two students were graduates (1 PhD and 1 MS), and several other new students were started. New research in the Pyrenees of France was initiated, based on funding from NSF. A student intern was advised as part of the AFRI-SAS-CAP grant effort.

5. <u>Impact Statements</u>

*"Soil-Litter Mixing Mediates Drivers of Dryland Decomposition along a Continuum of Biotic and Abiotic Factors" - McBride et al. 2023. Ecosystems.*

*<u>Issue:</u>* Litter decomposition is a key ecosystem process that determines rates of carbon and nutrient cycling. Photodegradation and soil-litter mixing have emerged as important drivers of dryland litter decomposition, but how these processes interact with decomposing microorganisms has received less attention.

*<u>Action:</u>* In this study, we examined the effects of ultraviolet-B radiation (UV-B; 280-315 nm) and soil-litter mixing on the decomposition of litter and its associated microbial community in an arid shrubland. We performed a full factorial litter decomposition experiment using leaf litter from a dominant shrub (*Prosopis velutina*) and a dominant grass (*Eragrostis lehmanniana*) that were exposed to solar radiation with near-ambient or attenuated UV-B, and were either soil-free or soil-covered; we then quantified litter decomposition and microbial community composition over a 12 month period.

*<u>Impact:</u>* In general, shrub litter decomposed more rapidly than grass litter regardless of soil coverage, likely due to its lower C:N. Attenuation of UV-B had modest effects on decomposition but UV-B exposure did increase fungal biomass, perhaps reflecting facilitative aspects of photodegradation. Both bacteria and fungi emerged as important regulators of decomposition, and microbial decomposition was indirectly mediated by litter C:N, soil coverage, and UV-B effects on the microbial community. Bacterial colonization was inhibited in soil-free treatments but was facilitated when litter was soil-covered. These findings suggest that UV-B may plan an important role in facilitating fungal decomposition of letter, while soil-litter mixing is fundamental for promoting bacterial decomposition of litter.

*"Negative effects of nitrogen override positive effects of phosphorus on grassland legumes worldwide" - Price et al. 2022. Nature Ecology & Evolution.*

*Issue:* Ecological models predict that the effects of mammalian herbivore exclusion on plant diversity depend on resource availability and plant exposure to ungulate grazing over evolutionary time.

*Action:* Using an experiment replicated in 57 grasslands on six continents, with contrasting evolutionary history of grazing, we tested how resources (mean annual precipitation and soil nutrients) determine herbivore exclusion effects on plant diversity, richness and evenness.

*Impact:* We show that at sites with a long history of ungulate grazing, herbivore exclusion reduced plant diversity by reducing both richness and evenness and the responses of richness and diversity to herbivore exclusion decreased with mean annual precipitation. At sites with a short history of grazing, the effects of herbivore exclusion were not related to precipitation but differed for native and exotic plant richness. Thus, plant species' evolutionary history of grazing continues to shape the response of the world's grasslands to changing mammalian herbivory.

6. Published Written Works

*Refereed publications*

Bakker, J.D., J.N. Price, J.A. Henning, E.E. Batzer, T.J. Ohlert, C.E. Wainwright, P.B. Adler, J. Alberti, C.A. Arnillas, L.A. Biederman, E.T. Borer, L.A. Brudvig, Y.M. Buckley, M.N. Bugalho, M.W. Cadotte, M.C. Caldeira, J.A. Catford, Q. Chen, M.J. Crawley, P. Daleo, C.R. Dickman, I. Donohue, M.E. DuPre, A. Ebelling, N. Eisenhauer, P.A. Fay, D.S. Gruner, S. Haider, Y. Hautier, A. Jentsch, K. Kirkman, J.M.H. Knops, L.S. Lannes, A.S. MacDougall, *R.L. McCulley*, R.M. Mitchell, J.L. Moore, J.W. Morgan, B. Mortensen, H.O. Venterink, P.L. Peri, S.A. Power, S.M. Prober, C. Roscher, M. Sankaran, E.W. Seablomm, M.D. Smith, C. Stevens, L.L. Sullivan, M. Tedder, G.F. Veen, R. Virtanen, and G.M. Wardle. 2023. Compositional variation in grassland plant communities. Ecosphere. https://doi.org/10.1002/ecs2.4542

McBride, S.G., E.M. Levi, J.A. Nelson®, S.R. Archer, P.W. Barnes, H.L. Throop, K. Predick, and *R.L. McCulley*. 2023. Soil-litter mixing mediates drivers of dryland decomposition along a continuum of biotic and abiotic factors. Ecosystems. https://doi.org/10.1007/s10021-023-00837-1

Risch, A.C., S. Zimmermann, M. Schutz, E.T. Borer, A.A.D. Broadbent, M.C. Caldeira, K.F. Davies, N. Eisenhauer, A. Eskelinen, P.A. Fay, F. Hagedorn, J.M.H. Knops, J.J. Lembrechts, A.S. MacDougall, *R.L. McCulley*, B.A. Melbourne, J.L. Moore, S.A. Power, E.W. Seabloom, M.L. Silviera, R. Virtanen, L. Yahdijian, and R. Ochoa-Hueso. 2023. Drivers of the microbial metabolic quotient across global grasslands. Global Ecology and Biogeography 32(6):904-918. https://doi.org/10.1111/geb.13664

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Gill, A.L., P.B. Adler, E.T. Borer, C.R. Buyarski, E.E. Cleland, C.M. D'Antonio, K.F. Davies, D.S. Gruner, W.S. Harpole, K.S. Hofmockel, A.S. MacDougall, *R.L. McCulley*, B.A. Melbourne, J.L. Moore, J.W. Morgan, A.C. Risch, M. Schutz, E.W. Seabloom, J.P. Wright, L.H. Yang, and S.E. Hobbie. 2022. Nitrogen increases early-stage and slows late-stage decomposition across diverse grasslands. Journal of Ecology 110(6):1376-1389. doi: 10.1111/1365-2745.13878

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*Proceedings publications*

None to report.

*Extension Publications*

Allison, J., K. Burdine, and R. Smith. 2023. Economic Efficiency in Organic Dairy Operations. ID-274.

Henning, J., J. McGrath, E. Ritchey, R. Smith, and C. Teutsch. 2023. Soil Sampling and Nutrient Management in Small Ruminant Pastures. AGR-265.

Boyd, H., C. Finneseth, T. Keene, L. Schwer, and R. Smith. 2023. Prechilling Switchgrass Seed on Farm to Break Dormancy. ID-199.

Henning, J., R. Smith, and C. Teutsch. 2023. Frost Seeding Clover: A Recipe for Success. AGR-271.

Lea, K. and R. Smith. 2022. Evaluating Cool-season Perennial Grass Pastures using the UK Horse Pasture Health Score Card. AGR-268.

Arnold, M., J. Lehmkuhler, M. Romano, and R. Smith. 2022. Forage-related disorders in cattle: Nitrate poisoning. ID-217.

Henning, J., B. Sears, R. Smith, and C. Teutsch. 2022. Baleage: Frequently Asked Questions. AGR-235.

Henning, J., G. Olson, T. Phillips, R. Smith, and C. Teutsch. 2022. 2022 Timothy and Kentucky Bluegrass Report. PR-820.

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Henning, J., G. Olson, R. Smith, and C. Teutsch. 2022. 2022 Annual and Perennial Ryegrass and Festulolium Report. PR-821.

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Henning, J., G. Olson, T. Phillips, R. Smith, and C. Teutsch. 2022. 2022 Tall Fescue, Bromegrass, and Meadow Fescue Report. PR-819.

7. Scientific and Outreach Presentations

McGrail, R.K., R.C. Pearce, S.T. Lucas, L. Moe, and R.L. McCulley. 2022. The impact of industrial hemp on Kentucky's cropping rotations. ASA-CSSA-SSSA Annual Meeting, Baltimore, MD.

McGrail, R.K., J.D. Moore, A.E. Carlisle, J.A. Nelson, and R.L. McCulley. 2023. Novel fungal endophyte infection impacts grassland greenhouse gas emissions under climate stressors. AFGC Annual Meeting, Winston-Salem, NC.

Jacobs, A.A., M.D. Flythe, D.G. Ely, L. Munoz, J. May, J.A. Nelson, V. Stanton, and R.L. McCulley. 2023. Feed supplementation with natural red clover product, biochanin A, decreases trace gas emissions from soil-applied livestock waste. AFGC Annual Meeting, Winston-Salem, NC.

McGrail, R.K., A.E. Carlisle, J.A. Nelson, R.D. Dinkins, and R.L. McCulley. 2023. Plant and endophyte genetics influence vertical transmission under projected climate change scenarios. AFGC Annual Meeting, Winston-Salem, NC.

McCulley, R.L. 2023. Climatic resiliency of Kentucky forage systems. AFGC Annual Meeting, Winston-Salem, NC.

8. Collaborative Grants

McCulley, R.L. (PI). "Utilizing grass-endophyte technology to improve pasture soil health and resilience to climate change stressors and soil health." *NIFA-AFRI-Foundational – Agricultural Production Systems*. 2017-2023. $500,000

McCulley, R.L. (PI). "Determining red clover drought resistance under abiotic stress and exploring effects of clover-produced isoflavones on animal nitrogen excreta, soil-to-atmosphere trace gas production, and soil microbial communities." *USDA-FAPRU-Specific Cooperative Agreement*. 2018 – 2023. $119,942

Moe, L.A. (PI), S.T. Lucas, R.L. McCulley, R. Pearce, and G. Halich (Co-PIs). "The Hemp Effect: What impact will incorporating hemp into traditional crop rotations have on the provisioning of agroecosystem services?" *NIFA-AFRI-Foundational,* 2020 - 2024. $500,000

Welch-Devine, M. (PI), J. Thompson, A. Thompson, R.L. McCulley, T. Mote, and B.J. Burke (Co-PIs). "DISES: Co-producing knowledge to sustain pastoral socio-environmental systems: System feedbacks, future scenarios, and adaptive responses." *NSF-DISES*, 2022-2026. $1,599,000

Picasso Risso, V.D. (PI), M. Berti, K. Cassida, A. Finan, D. Hannaway, W. Lamp, and A. Stevens (Co-PIs) with many subcontracts, including one to R.L. McCulley. "Fostering Resilience and Ecosystem Services in Landscapes by Integrating Diverse Perennial Circular Systems (Resilience CAP)" *NIFA-SAS-CAP*, 2021-2026. $10M

9. Graduate students

Alayna Jacobs, PhD in Integrated Plant & Soil Sciences, graduated Dec 2022, "Manipulating species diversity: environmental impacts in row crop, livestock, and grassland agroecosystems." University of Kentucky Libraries. https://doi.org/10.13023/etd.2022.381

Echo Gotsick, MS in Integrated Plant & Soil Sciences, graduated 2023, "Comparison of botanical composition methods and change over time in Kentucky pastures." University of Kentucky Libraries. https://doi.org/10.13023/etd.2023.104

William Fleming, MS in Integrated Plant & Soil Sciences, expected graduation 2024, title - TBD.

Reilly Kaplan-Fardy, MS in Integrated Plant & Soil Sciences, expected graduation 2024, title - TBD.

Kent Pham, PhD in Integrated Plant & Soil Sciences, expected graduation 2025, title - TBD.

Jack Eaker, MS in Integrated Plant & Soil Sciences, expected grad

## Purdue University/Indiana

1. Impact Nugget

Novel cropping systems that include mulch and cover cropping offer additional economic opportities while having environmental benefits, but also require a higher level of management expertise, especially where climate/weather are variable.

2. New Facilities and Equipment

3. Unique Project Related Findings

Our work focuses on two systems: cereal rye cover cropping where rye harvest is delayed until heading resulting in higher rye yields than conventional cover cropping systems (modified relay cropping); and mulch cropping where maize is planted into an established stand of kura clover.

Biomass yield of rye harvested at heading averaged 4249 kg dry matter/ha. This is approximately four-fold higher than rye when managed as a cover crop with biomass returned to the soil. Kura clover yields have increased each year from ~2700 kg/ha in 2017 to over 9000 kg/ha in 2021. Biomass of this system is harvested twice; in mid-May prior to maize planting and a second time in October after maize grain harvest. Using the average dry matter yields of these systems, we calculated the ethanol and N fertilizer values for the rye biomass, and the milk and N fertilizer values for the kura biomass. The ethanol yield of the rye biomass (avg. 4249 kg/ha) was 659 L/a x $0.995/L resulting in $656/a gross income. The N fertilizer value of rye biomass when plowed down was estimated as 11 g N/kg DM x 4237 kg/ha biomass=47 kg/N /ha. With N valued at $2.40 /kg, the N fertilizer value of the rye biomass is $113/ha gross. The N fertilizer value of kura biomass when plowed down was estimated as $380/ha gross. The milk value of the kura biomass (5420 kg milk/ha). At $22.83 per cwt the gross value of the kura when converted to milk was estimated to be $2763/ha. Finally, the ethanol value of the maize stover left after grain harvest (6905 kg/ha) was estimated to be 1100 L/acre and had a gross estimated value of $1095.

In the continuous maize system inclusion of rye cover cropping did not impact maize grain yield which averaged ~10,000 kg/year from 2017 to 2021. This is despite a ~10% reduction in maize plant populations associate with inclusion of rye in the system. Maize grain yields were greatly reduced in the kura clover mulch system averaging ~3000 kg/ha between 2017 and 2021. Maize plant populations were reduced from 75,000 plants/ha in continuous maize to 52,000 plants/ha in the kura clover mulch system.

Preliminary analyses indicate that nitrate concentrations in tile drainflow is reduced when rye and kura clover are included in these systems. Kura clover added to continuous maize reduced nitrate to 2.5 mg/L when compared to 11.4 mg/L in continuous maize without kura clover. Adding rye to the maize component of the maize-soybean rotation reduce nitrate from 7.5 to 5.0 mg/L. Similarly, nitrate in the soybean+rye system was 4.1 mg/L when compared to 9.6 mg/L in the soybean component of the maize-soybean rotation without rye. Annual nitrous oxide emissions were reduced from 11.2 kg/ha for contiuous maize to 4.0 and 2.8 kg/ha when rye and kura clover were added to this system, respectively. similarly, addition of rye to the maize-soybean rotation reduced nitrous oxide production from 4.7 to 1.7 kg/ha. There was no impact of rye or kura clover on soil organic matter levels likely reflecting the short time frame of the study (4 yrs) and the slow rate of organic matter accrual in most systems

4. <u>Accomplishment Summaries</u>

5. <u>Impact Statements</u>

6. <u>Published Written Works</u>

*(Cite them with CSSA, ASA references format)*

*Refereed publications*

*Proceedings publication*

*Bulletins and Extension Factsheets*

Slaton, N.A., S.E. Lyons, D.L. Osmond, S.M. Brouder, S. Culman, L.C. Gatiboni, J. Hoben, P.J.A. Kleinmann, J.M. McGrath, R. Miller, A. Pearce, A. Shober, J.T. Spargo, and J.J. Volenec. 2022. Minimum dataset and metadata guidelines for soil-test correlation and calibration research. Soil Sci. Soc. Amer. J. 86:19-33. https://doi.org/10.1002/saj2.20338.

Ashworth, A.J., L. Marshall, J.J. Volenec, M.D. Casler, M.T. Berti, E. van Santen, C.L. Williams, V. Gopakumar, J.L. Foster, T. Propst, V. Picasso, and J. Su. 2023. Framework to develop an open-source forage data network for improving primary productivity and enhancing system resiliency. Agron. J. DOI: 10.1002/agj2.21441.

Brouder, S.M., and J.J. Volenec. 2023. Nutrition of plants in a changing climate. In: Marschner's Mineral Nutrition of Plants, 4th Edition. Z. Rengel, I. Cakmak, and P. White (Editors). ISBN-13: 978-0128197738; ISBN-10: 0128197730. 29 pp.

Wiersma, D., W.G. Hartman, S. Pejša, S.M. Brouder, and J.J. Volenec. (2023). Genetic and environmental variation in alfalfa forage yield from variety testing experiments conducted in North America between 1986 to 1999. (Version 2.0). Purdue University Research Repository. doi:10.4231/QS1J-6J77. (dataset)

7. Scientific and Outreach Presentations

*Abstracts , symposium and conference presentations*

dos Santos Rocha, M., J.J. Volenec, and S.M. Brouder. 2022. Nitrogen balance of maize mulch cropping with kura clover and relay cropping with rye. ASA, CSSA, SSSA International Annual Meeting, Baltimore, MD. https://scisoc.confex.com/scisoc/2022am/meetingapp.cgi/Paper/143331.

Mirbakhsh, M., S.M. Brouder and J.J. Volenec. 2022. Temporal change of carbon stocks and soil health indicators on a long-term experimental site: annual vs. perennial systems. ASA, CSSA, SSSA International Annual Meeting, Baltimore, MD. https://scisoc.confex.com/scisoc/2022am/meetingapp.cgi/Paper/143204.

Brouder, S. M., J.J. Volenec, and R. Owen. 2022. Using agricultural research to drive climate solutions. ASA, CSSA, SSSA International Annual Meeting, Baltimore, MD. https://scisoc.confex.com/scisoc/2022am/meetingapp.cgi/Paper/147605.

Abendroth, L., A.J. Eagle, T. M. Maaz, M.J. Helmers., S.M. Brouder, L. Christianson, B. Emmett, C. Drury, F. Fernandez, L. Gentry, D.B. Jaynes, J. Kovar, R.W. Malone, T. Moorman, K.A. Nelson, P. O'Brien and J.J. Volenec. 2022. Use of improved nutrient practices in maize-based agroecosystems alter allocation between leaching and denitrification loss pathways. Annu Meeting of the American Geophysical Union. Dec. 12 to 16, Chicago IL, USA.

8. Collaborative Grants

USDA-NIFA-AFRI. The NutriNet Knowledgebase for Synthesis of North American Tile Drainage Research. S.M. Brouder (PD), J.J. Volenec, M. Helmers, L. Christianson, L. Abendroth. May 1, 2019 to April 30, 2024. $500,000.

USDA-NIFA-AFRI. FACT: An Innovative Cyber-Framework Integrating Public/Private Data for Evidence-Based Recommendations. S.M. Brouder (PD), J.J. Volenec, C. Barford, W.K. Berg,

G. Bossaer, S. Brandt, C. Cai, B. Craig, N. DeLay, B. Erickson, M. Ruark, T.S. Murrell, J. Scott, N. Thompson, D. Walker, J. Zhu. Aug. 1, 2019 to July 31, 2024. $1,000,000.

USDA-NIFA-AFRI. Sustainable Ag Systems Program. Fostering Resilience and Ecosystem Services in Landscapes by Integrating Diverse Perennial Circular Systems. V. Picasso (UW-Madison, PD) and 46 co-PDs/co-PIs. Sep. 1, 2021 to Aug. 31, 2026. Total Award: $10,000,000. Purdue Share: $32,785.00

9. Graduate students

Indicate name, MS or PhD, graduation date or expected graduation date, thesis title

## The Ohio State University

1. Impact Nugget

The forage group at The Ohio State University is conducting research on 1) agroecosystems resilience to recurring short-term flooding, 2) crop-livestock diversification, and 3) carbon footprint and sequestration potential of crop-livestock agroecosystems.

2. New Facilities and Equipment
   - Gas chromatograph – Shimadzu GC2014
   - Leaf area meter – Li-Cor LI-3100C
   - NIRS Forage Analyzer FOSS DS3

3. Unique Project Related Findings

   - Recurring short-term flooding deeply modifies pasture agroecosystems, even if the effect is considered moderate. We observed effects on forage yield, botanical composition and quality, soil C content and sequestration potential, and greenhouse gas emissions from soils.

4. Accomplishment Summaries

Soil carbon inputs and storage in flooded pasture fields of Southern Ohio.

An experiment was established in May 2020 in Jackson, OH, to evaluate above and below ground inputs of organic carbon and soil carbon storage in different combinations of forage species, under flood and non-flood prone pastures for grazing, and non-flood hayfield. The treatments in flood and non-flood grazed plots were composed by: control (dominated by tall fescue, orchard grass and clover); winter cover-crops, rye and oats; iii) a mixed cool-season species, by drilling tall fescue, Kentucky bluegrass, orchard grass red and white clover; and iv) cool-season + warm-season mixed pasture. The hayfield was composed by a dominant pasture of tall fescue with random clover and orchard grass. Aboveground dry matter weights are being monitored throughout the 2021 growing season and roots were collected in mid-summer and will be collected again in late fall to determine carbon inputs. A preliminary analysis of the soil carbon stocks (0-100 cm depth) showed higher values in the grazed pastures (average of 112.2 Mg C ha⁻

[1]) relative to hayfield (102.1 Mg C $ha^{-1}$). This difference occurred mainly due to increased C content in the first 20 cm of soil in grazed plots (30.4 *vs* 23.2 g $dm^{-3}$ in the hayfield). Flooded grazed plots had decreased C storage (0-100 cm) of 8.8%, mainly due to reduced C contents on the 0-20 cm soil depth. The aboveground dry matter by mid-summer was 20% lower in the flood area compared to the non-flood pasture, and probably this lower productivity is leading to reduced carbon inputs and therefore, reduced carbon storage in flooded soils.

Effect of recurring, short-term flooding on soil, pasture and environmental characteristics of grazing and hay pastures.

A two-scenario project has been established in two different locations in OH, southern (Jackson, OH – Scenario 1) and northwestern (Jenera, OH – Scenario 2). In Scenario 1, flood-prone and non-flooded grazed and hay pastures, cultivated mainly with tall fescue, with random occurrence of red clover, and orchard grass. Three treatments were identified for this scenario at the farm in 2019: flood and non-flood pastures for grazing and non-flood hay field. In Scenario 2, hay fields and croplands will be monitored at a commercial partnering farm in the Western Lake Erie Watershed region. Croplands are predominant on flat landscapes and the establishment of forage cover on the environmentally sensitive areas is encouraged through the Ohio Working Lands Buffer Program. In both studies, a pattern of $CH_4$ emissions during periods of higher soil water content and sinks during periods with low soil water content was found. On the other hand, $N_2O$ fluxes decreased when soil water content increased. Even when the $CH_4$ sink was observed, $N_2O$ flux drove the emissions on a C-equivalent basis. $CO_{2eq}$ flux calculation that considered $N_2O$ and $CH_4$ emissions from soils was primarily determined by $N_2O$ flux. The values of $CH_4$ + $N_2O$ $CO_{2eq}$ indicate that the sink potential of $CH_4$ is overshadowed and compensated by extremely high emissions of $N_2O$. From a carbon footprint perspective, $N_2O$ drives GHG emissions and should be considered in mitigation strategies. Overall, recurring short-term soil inundation did not consistently increase GHG emissions in any location, rather a tendency to decrease emissions was observed in highly inundated soil in Jenera. At the same time, quality forage production was possible in both studies. Forage crops then represent a sustainable and productive option for areas prone to recurring short-term soil inundation.

Native warm season grasses to enhance pasture resilience to climate change

This project will focus on identifying management practices to establish native warm-season grasses (NWSG) in pastures at four different locations in Ohio, Jackson, Caldwell, Flushing and Georgetown. The objective of this study is to assess morphogenic and structural characteristics of NWSG species when there are different plant establishment strategies. This proposal has extension and research objectives. The extension objective is to determine the best management practices for establishment of the warm-season grasses species tested. The outcomes are extension publications and field days to communicate the BMP and show the demonstration plots. Four NWSG will be tested, switchgrass, indiangrass, big bluestem, and eastern gamagrass, using conventional and non-chemical practices. Big bluestem and indiangrass will be planted in combination which is the conventional practice of most beef producers. Switchgrass and Indiangrass will be planted individually. The non-chemical practices will be used to address organic producer needs. Three treatments will be tested, with different strategies of summer and winter cover crops in rotation with the NWSG.

Comparing the environmental tradeoffs and synergies of alternative modes of integrating livestock into cash grain cropping systems

The project's goal to identify pathways to improve the performance of integrated crop-livestock systems, document opportunities and barriers to the expansion of the most promising approaches, and develop recommendations for public and private interventions that can accelerate their use. To achieve these goals, we will pursue five interrelated objectives: 1. Quantify the diverse environmental outcomes associated with each approach to livestock-crop integration under working farm conditions; 2. Assess the animal welfare and human health risks and benefits associated with more widespread use of manure and greater integration of livestock in cash grain cropping systems; 3. Develop whole farm models to quantify the socioeconomic, health/welfare and environmental tradeoffs and synergies associated with each approach to livestock crop integration; and 4. Identify the social, technical, economic, and institutional constraints that limit adoption of each approach on regional livestock and cash grain farms, and 5. Use a participatory on-farm approach throughout to better integrate research and extension/outreach activities. Collaboratively develop recommendations for public policies and private supply chain programs to incentivize the most economically and environmentally beneficial approaches to livestock-crop integration.

Carbon footprint of dairy farms assessment

With the successful completion of the LCA of Fairlife products at the Coopersville, MI facility, we discussed continuing the project at the Fairlife facility in Arizona. It has been decided that the farm activities will be present as a standalone project, due to specificity of research objectives and deliverables. As done for farms in Michigan, we will complete a C footprint for a model farm in Arizona and provide insights into ways of improving the farm operation to reduce Carbon footprint. We will provide an updated and specific Farm C-footprint Tool for Arizona farms. We will also develop a soil C tool to estimate and predict C-sequestration under different soil management strategies. Finally, we are including an educational aspect to Fairlife supplier producers in both Michigan and Arizona facilities. Objectives are to 1. Perform a Carbon footprint assessment of Farilife's dairy farms suppliers to the plant processing in Goodyear, AZ. 2. Prepare and provide educational materials to supplier's farms to both processing plants n MI and AZ. Topics to be discussed and decided alongside Fairlife team. A few examples include similarities and differences between regions and facilities, sustainability and C footprint basic information and answers to frequently asked questions, information on how management practices affect GHG emissions and C sequestration.

Enhanced soil carbon farming as a climate solution – Grazing and Hay Systems

Adoption of soil-carbon-enhancing practices by farmers and ranchers requires knowledge about soil carbon sequestering practices and associated agronomic and environmental benefits. However, current knowledge on carbon (C) farming is primarily based either on simulation modelling or on data from a limited number of well-replicated field experiments. To clearly translate these findings to soil management and conservation practices for enhancing soil organic carbon (SOC) sequestration under diverse agroecosystems, large-scale on-farm data collected from croplands, grasslands and rangelands are needed. Furthermore, knowledge gaps exist on how projected climate extremes will impact SOC sequestration, crop productivity, agricultural greenhouse gas (GHG) emissions and soil health. Our objectives are to quantify different sources of C input into agroecosystems and to understand the role and the long-term impact of the animal, soil cover, soi disturbance and penalty on C input. We will evaluate farms with a long history of management either with corn-soybeans rotations or grazed and hay pastures.

5. Impact Statements

Soil carbon inputs and storage in flooded pasture fields of Southern Ohio.
The use of grazing areas with the inclusion of either winter annual grasses or cool-season species has shown the potential to increase aboveground productivity. As flood prone areas have lower soil carbon stocks, the used of more diverse pasture can be a strategy to increase soil carbon sequestration in the long run.

Effect of recurring, short-term flooding on soil, pasture and environmental characteristics of grazing and hay pastures.
Results indicate that the conversion of croplands to perennial forage crops is beneficial for farm productivity, as flooding effects on forage, although present, are not primarily negative. The Working Land Buffer Program established in Ohio to support the conversion is a sustainable alternative as GHG emissions were not increased in flood-prone pastures.

Carbon footprint of dairy farms assessment
Dairy carbon-footprint analyses were made using specific emissions factors by management strategies, climate and region. Results suggest that C-fooprint of dairy farms were reduced when compared to available online tools. Further validation is pending.

6. Published Written Works
*(Cite them with CSSA, ASA references format)*
*Refereed publications*
*Proceedings publication*
*Bulletins and Extension Factsheets*

Batalha, C.D.A*.; Congio, G.F.S.; Chiavegato, M.B.; Berdnt, A.; Frighetto, R.T.S.; Santos, F.A.P., Da Silva, S.C. 2022. Effect of timing of paddock allocation on milk yield and enteric methane emissions from dairy cows. *Animal Science Journal.* https://doi.org/10.1111/asj.13734

Ribeiro, R. H*., Ibarr, M. A., Bratti, F., Pinheiro, D., Auler, A. C., Chiavegato, M. B., Piva, J. T., Dieckow, J. 2022. Grazing intensity and nitrogen fertilization effects on biomass and morphology of black oat roots in an integrated crop-livestock system. *Agronomy Journal*. https://doi.org/10.1002/agj2.21277

Silva-Pumarada, G., Shrestha, R.K., Chiavegato, M.B., Mercer, K., Agyei, B.K., Singh, M.P., Lindsey, L.E*. Effect of biochar application on corn and soybean yield in Michigan and Ohio. *Crop, Forage & Turfgrass Management*. In press.

Barker, D.J, Sulc, R.M. Chiavegato, M.B. 2023. Chapter 9 – Pasture and Grazing Management. In Ohio Agronomy Guide. (16th Edition). *In press.*

Chiavegato, M.B. 2023. The role of roots on C sequestration in agricultural fields. *The Journal of Nutrient Management*. February 2023.

Chiavegato, M.B. 2023. The connection between nutrient management and climate change. *The Journal of Nutrient Management.* May 2023.

7. Scientific and Outreach Presentations

*Abstracts , symposium and conference presentations*

1. Mammana, F.A., Chiavegato, M.B. 2023. Identifying Grazing Targets for Improved Forge Quality in Ohio. 16th Annual Horticulture & Crop Science Research Symposium, Wooster, OH.
2. Stachler, C., Mammana, F.A., Chiavegato, M.B. 2023. Associated Effects of Grazing and Flooding on Greenhouse Gas Emissions in Southern Ohio. 16th Annual Horticulture & Crop Science Research Symposium, Wooster, OH.
3. Rodriguez, C., Chiavegato, M.B. 2023. Arbuscular Mycorrhizal Fungi a Hidden Tool to Improve Forage Growth and Quality. 16th Annual Horticulture & Crop Science Research Symposium, Wooster, OH.
4. Rodriguez, C., Rai, Q., Chiavegato, M.B. 2022. Native Warm Season Grasses – Implementation protocols and relationships with arbuscular mycorrhizal fungi. 15th Annual Horticulture & Crop Science Research Symposium, Columbus, OH.
5. Rodriguez, C., Bitler, C. Chiavegato, M.B. 2022. Cover Crops as an Alternative for Tall Fescue Pasture Renewal. ASA, CSSA, SSSA International Annual Meeting, Baltimore, MD. https://scisoc.confex.com/scisoc/2022am/meetingapp.cgi/Paper/143580
6. Rodriguez, C., Bitler, C., Chiavegato, M.B. 2022. Germination and Cultivation of Native Warm-Season Grasses Under Controlled Environment [Abstract]. ASA, CSSA, SSSA International Annual Meeting, Baltimore, MD. https://scisoc.confex.com/scisoc/2022am/meetingapp.cgi/Paper/143596
7. Miquilini, M., Ribeiro, R.H., Lyon, S., Chiavegato, M.B. 2022. Measuring Flooding in 20 Quick Steps. ASA, CSSA, SSSA International Annual Meeting, Baltimore, MD. https://scisoc.confex.com/scisoc/2022am/meetingapp.cgi/Paper/143566
8. Miquilini, M., Ribeiro, R.H., Chiavegato, M.B. 2022. Relationships Among Forage, Soil and GHG Emission on Forage Crops Under Flooding Conditions. ASA, CSSA, SSSA International Annual Meeting, Baltimore, MD. https://scisoc.confex.com/scisoc/2022am/meetingapp.cgi/Paper/143521
9. Miquilini, M., Ribeiro, R.H., Chiavegato, M.B. 2022. Perennial forages are an alternative to reduce nutrient losses to water in flooded pastures – what happens to nutrient losses to air? 15th Annual Horticulture & Crop Science Research Symposium, Columbus, OH.

10. Garcia, A.S., Bauman, S., Miquilini, M., Chiavegato, M.B. 2022. Flooding intensity effects on growth and development of tall fescue. 15th Annual Horticulture & Crop Science Research Symposium, Columbus, OH.
11. Miquilini, M., Ribeiro, R.H., Chiavegato, M.B. 2022. Effects of Flooding on Grazed Pastures – Forage Quality, GHG Emissions and C Stocks. ASAS-CSAS Annual Meeting, Oklahoma City, OK. https://www.eventscribe.net/2022/ASASAnnual/searchGlobal.asp
12. Miquilini, M., Ribeiro, R.H., Chiavegato, M.B. 2022. Balance Between Productivity and Environmental Impacts of Grazed and Hay Fields. ASAS-CSAS Annual Meeting, Oklahoma City, OK. https://www.eventscribe.net/2022/ASASAnnual/myplan.asp?mode=posters&afp=WVJWU0dFTVI6NTcyOTU4Njg6d0lXOE44NzU
13. Ribeiro, R.H., Miquilini, M., Dieckow, J., Chiavegato, M.B. (2022) Vertical Distribution of Roots and Shoot-to-Root Ratio of Diversified Pastures Under Flooding Conditions. ASA, CSSA, SSSA International Annual Meeting, Baltimore, MD. https://scisoc.confex.com/scisoc/2022am/meetingapp.cgi/Paper/142092
14. Ribeiro, R.H., Miquilini, M., Dieckow, J., Chiavegato, M.B. 2022. Forage and root production in diversified pastures under flood and non-flood conditions in Southern Ohio. 15$^{th}$ Annual Horticulture and Crop Science Graduate Research Symposium, Columbus, Ohio.
15. Rai, Q., Jackson-Smith, D., Lyon, W.S., Culman, S., Chiavegato, M.B. 2022. Effect of perenniality on soil health and greenhouse gas emissions in corn-soybeans rotations. 15$^{th}$ Annual Horticulture and Crop Science Graduate Research Symposium, Columbus, Ohio.

8. Collaborative Grants

1. 4/2021 – 12/2022. Native Warm Season Grasses to Enhance Pasture Resilience to Climate Change. Greenacres Foundation ($28,400). Research Grant.
   PI: Chiavegato, M.B. ($25,560)
   Co-I: Sulc, M. Bitler, C.
2. 2/2021 – 8/2022. Assessing the relative impact of generative agriculture versus industrial agriculture on the threat of antimicrobial resistance and zoonotic transmission of antimicrobial resistant pathogens. Greenacres Foundation ($25,000). Research Grant.
   PI: Chiavegato, M.B. ($23,750)
   Co-I: Pettigrew, M. Tanner, W; Parker, A.
1. 03/2022 - Present. Enhanced soil Carbon farming as a climate solution. FFAR ($5,000,000). Research Grant.
   PI: Lal, R.

Co-I: Lorenz, K., Demyan, S., Chiavegato, M.B. ($310,749), Williams, R., Wilkins, J., Rich, V., Carlarne, C., Ciganda, V., Franzluebbers, A., Mishra, W., Pravia, V., Singh, M., Snapp, S., Tomilinson, P., Yost, M., Presley, D., Reeve, J.

9. Graduate students

Indicate name, MS or PhD, graduation date or expected graduation date, thesis title

Verhoff, Kyle. MS. Graduation date March 2023. A rotational stocking strategy to maintain pasture sward heights for optimizing sheep and forage responses.

Ribeiro, Ricardo Henrique. PhD. Graduation date February 2023. Soil carbon inputs and storage in flooded pasture fields of Southern Ohio.

Miquilini, Marina. MS. Graduated December 2022. Effect of recurring, short-term flooding on soil, pasture and environmental characteristics of grazing and hay pastures.

Rodriguez, Chelsie. MS. Expected graduation date December 2023. Native warm-season grasses in Ohio – Implementation protocol and productive response to arbuscular mycorrhizal fungi.

Mammana, Alexandre F. PhD. Expected graduation date: April 2025. Planned species diversification and strategic grazing management to increase system resilience and productivity.

Salsbury, Lydia. Expected graduation date December 2026. Carbon inputs from manure, plants, and roots to Carbon soil stocks in grazed pastures and hayfields.

## Michigan State University

1. Impact Nugget

none

2. New Facilities and Equipment

None

2. Unique Project Related Findings

none

4. Accomplishment Summaries (limited to projects with direct multi-state involvement)

Fostering resilience and ecosystem services in landscapes by integrating diverse perennial circular systems. Michigan has four roles in this project: 1) Farm Network-lead development of a nationwide farmer network, 2) Extension - lead development of a nationwide Extension effort, 3) Collaborative Research - participate in a multi-state network of field experiments evaluating soil improvement by resilient cropping practices, and 4) Education - participate in educational activities. *Key Outcomes and other accomplishments realized*: We led recruitment of 93 farmers nationwide, including 13 in Michigan, and began data collection. We designed a website for the project and initiated planning for other Extension assessments and outputs. We leveraged additional funding to support materials and supplies for two collaborative experiments: 1) intercropping corn and alfalfa and 2) nitrogen fixation in alfalfa-grass mixtures. Two MS graduate students were recruited and enrolled in 2023 and yield, quality, and soil samples were collected. Resilience principles were incorporated into presentation for FFA students and STEM teachers.

Commercial Variety Testing. Michigan State University conducted variety trials on alfalfa, red clover, orchardgrass, fescues, perennial and Italian ryegrass, timothy, Kentucky bluegrass, and forage sorghum. *Key Outcomes and other accomplishments realized:* These data were distributed to farmers and industry.

5. Impact Statements

none

6. Published Written Works

*Refereed publications*

none

*Proceedings publication*

1. K. Cassida, B. Lamp, and S. Gruss. 2023. Developing extension and educational and tools for resilience and sustainability. *Proc. XXV Internat. Grassl. Congr.* May 14-19, 2023, Covington, KY.
2. Gruss, S., & KA. Cassida. 2023. Comparing resiliency for different agricultural production systems in the US. Proc. American Forage & Grassl. Conf, Winston-Salem, NC. Jan. 8-11, 2023. (poster)

*Bulletins and Extension Factsheets*

1. Cassida, K., J. Paling, J. Dedecker, & C. Kapp. 2023. *2022 Michigan Forage Variety Test Report.* MSU Forage Factsheet 23-01, 32 pages. Online Mar 1, 2023. https://forage.msu.edu/wp-content/uploads/2023/04/2022-MichiganForageVarietyTestReport-Web.pdf

7. Scientific and Outreach Presentations

*Abstracts , symposium and conference presentations*

1. K. Cassida, B. Lamp, and S. Gruss. 2023. Developing extension and educational and tools for resilience and sustainability. *Proc. XXV Internat. Grassl. Congr.* May 14-19, 2023, Covington, KY.
2. Gruss, S., & KA. Cassida. 2023. Comparing resiliency for different agricultural production systems in the US. Proc. American Forage & Grassl. Conf, Winston-Salem, NC. Jan. 8-11, 2023. (poster)

8. Collaborative Grants *(NCCC31 members bolded)*

- Cassida, K, and S. Gruss. Nitrogen cycling in biodiverse perennial forage mixtures. Project GREEEN, $98,176. FUNDED.

9. Graduate students

Indicate name, MS or PhD, graduation date or expected graduation date, thesis title

- Jonathan King (MS, expected Dec 2023)
- Paige Baisley (PhD, expected May 2026)
- Jasmine Bontrager (MS, expected May 2025)
- Brandon Scott (MS, expected May 2025)

## Utah Report 2023

1. Impact Nugget

Beef production is the major agricultural pursuit in rural Utah. A study of sainfoin cultivars completed in 2022 demonstrated that sainfoin could be highly productive in dense stands under dryland conditions. These results provided valuable preliminary data for the current NIFA-funded CAP grant "Using Smart Foodscapes to Enhance the Sustainability of Western Rangelands" which is using sainfoin as the key plant species in rangeland resource islands that will be used to supplement pregnant cows in late summer and early autumn. This standing supplementation will replace hay or protein cakes that are costly for ranchers., so this project has the potential to benefit individual ranchers and the communities where they live.

2. New Facilities and Equipment

NA

3. Unique Project Related Findings

NA

4. Accomplishment Summaries

Using Smart Foodscapes to Enhance the Sustainability of Western Rangelands

Approximately six million beef calves are produced annually in the western U.S. alone, and ranchers must maintain profitable operations while addressing the growing number of consumers seeking environmentally, economically, and socially sustainable food. In response to these concerns, we propose the development of smart foodscapes as a transformative paradigm for western U.S. beef production. Our hypothesis is that a diversity of deep-rooted perennial legumes and forbs with high nutrient content and the presence of functional biochemicals can be grown and stockpiled in "islands" across the landscape to be used as low-cost supplementation for beef cattle to enhance productivity and biodiversity while reducing environmental impacts. Thus, our long-term goal is to improve the sustainability of beef production through the establishment of islands of multifunctional diversity in rangelands, in line with the NIFA Program Area Priority long term goals of Land Stewardship, Food and Agricultural Production and Agricultural Climate Adaptation. We will screen a wide selection of plants for synergisms that will be tested for their impacts on beef cattle performance, health, nutrient losses to the soil and atmosphere, habitat for pollinators, wildlife, and economic viability. Research will be integrated with grazing schools, assessments of adoption, and producer engagement. We will integrate garden-based learning and smart foodscapes into Science Technology Engineering Arts Mathematics (STEAM) teaching and learning, and all objectives into a comprehensive outreach program. This transdisciplinary project will contribute to create more sustainable beef production systems while engaging and educating current and future land stewards.

5. <u>Impact Statements</u>

The MacAdam et al. (2022) paper published in *Animals* demonstrated that different classes of beef cattle grazing legume pastures retained more nitrogen and emitted less enteric methane per kg intake than cattle grazing grass pastures, and that cattle grazing legume pastures emitted no more methane than cattle fed a total mixed ration.

6. <u>Published Written Works</u>

*Refereed publications*

MacAdam, J. W., Pitcher, L. R., Bolletta, A. I., Guevara, R. D. B., Beauchemin, K. A., Dai, X., & Villalba J. J. (2022). Increased nitrogen retention and reduced methane emissions of beef cattle grazing legume vs. grass irrigated pastures in the Mountain West USA. *Agronomy, 12*, 304.

Pitcher, L. R., MacAdam, J. W., Ward, R. E., Han, K.-J., Griggs, T. C., & Dai, X. 2022. Beef steer performance on irrigated monoculture legume pastures compared with grass- and concentrate-fed steers. *Animals, 12*, 1017.

*Proceedings publication*

*Bulletins and Extension Factsheets*

MacAdam, J. W., & Bohle, M. (2022). Altitude adds energy value to alfalfa hay. Hay and Forage Grower (August).

7. Scientific and Outreach Presentations

*Abstracts , symposium and conference presentations*

MacAdam, J. W. (2022). Differential responses of irrigated grasses and legumes in the Mountain West USA to mob stocking compared with clipping. In Annual Meetings Abstracts. ASA, CSSA, and SSSA, Madison, WI.

Villalba, J. J. (2022). Smart Foodscapes: Developing functional landscapes to enhance the sustainability livestock production systems. Journal of Animal Science, 100 (Supplement 3), 89-90.

8. Collaborative Grants

NIFA Sustainable Agriculture Systems CAP Grant, 10/01/21 to 09/30/26. Using smart foodscapes to enhance the sustainability of western rangelands. PD J. J.Villalba; multiple Co-PDs including J. W. MacAdam, $6,800,000.

9. Graduate students

Surbhi Verma, Master's student, expected graduation August 2024. Screening of multiple legume and non-legume forb forage species for optimizing ruminant nutrition and reducing environmental impacts during late season grazing on semi-arid rangelands.

## Virginia/ Virginia Tech

1. Impact Nugget

A major research effort at Virginia Tech is testing the idea that ecosystem services provided by tall fescue-dominated grasslands can be improved by increasing the plant biodiversity available to beef cattle and bees. We do this my creating grazed grasslands that contain native warm-season grasses mixed with diverse wildflowers. We have termed this land sharing approach, where beef cattle and bees share the same land replete with warm-season grasses and wildflowers, "Bee-Friendly Beef". Our goal seeks to improve the output of ecosystem services by providing improved beef cattle production (provisioning service) and generating valuable pollination resources (regulating service) compared with tall fescue-dominated grassland.

2. New Facilities and Equipment

N/A

3. Unique Project Related Findings

We have learned several unique things from this work. We have shown that biodiverse pasturelands made up of native grasses and wildflowers can be integrated into tall fescue pastures to improve beef cattle production and pollinator abundance. In a three-year grazing trial beef cattle performance was consistently greater on biodiverse pastures compared with control pastures. Pollinator abundance was also consistently greater in biodiverse pastures. We also have found that non-native honeybees seldom use native wildflowers as pollen/nectar resources – even when wildflowers are planted near active hives. The native wildflowers appear to favor native bees instead. A socioeconomic survey recently completed showed that consumers may pay as much as $1/lbs more for ground beef that come from a 'Bee-Friendly Beef' farm.

4. Accomplishment Summaries

With cooperators at the University of Tennessee, we have initiated many studies across our two states starting in 2020. Studies include: 1) grazing experiments to evaluate beef cattle performance and pollinator abundance on biodiverse pastures. 2) on-farm trials where biodiverse pastures have been created on private land to enhance pollinators and honey bee production, and 3) various small-plot experiments where we are trying to determine the most effective way to establish native grasses and wildflowers. Several socio-economic surveys are also on going to evaluate consumer and producer acceptance of these approaches to enhance pasture biodiversity.

5. Impact Statements

6. Published Written Works

Larcom, R. (2023). Honey Bee Colony Resource Acquisition, Population Growth, and Pollen Foraging in Diversified Native Grass-Wildflower Grazing System. School of Plant and Environmental Sciences, Virginia Tech. MS Thesis: 119.

Kubesch, J. (2023). Evaluating native warm-season grass and wildflower mixtures for beef cattle production in the Mid-Atlantic, Virginia Tech. Ph.D. Dissertation: 244.

Kietzman, P., M. O'Rourke, B. Tracy. 2023 Bee-Friendly Beef: Diversified Pastures Offer Rehabilitated Habitat to Native Pollinators. Basic and Applied Ecology (In Review)

Larcom, R., P. Kietzman, M. O'Rourke, B. Tracy 2023. Do pastures diversified with native wildflowers benefit honey bees (Apis mellifera)? Agriculture Ecosystems and Environment (In Review)

*Bulletins and Extension Factsheets*
*N/A*

7. Scientific and Outreach Presentations

Kubesch, J., B. Tracy 2023. Biodiverse Forage Mixtures for Bees and Beef Cattle-- Proceedings XXV International Grassland Congress, May 14-19, 2023, Northern Kentucky Convention Center in Covington, Kentucky USA (In Press)

8. Collaborative Grants

9. Graduate students

Jonathan Kubesch PhD – expected graduation date Dec 2023
Harrison Stewart MS – expected graduation date Dec 2024

## University of Wisconsin – Madison

1. Impact Nugget

The forages and perennial grains program at UW-Madison consistently grew this year. A Forage systems agroecologist was hired (Dr. Martha Kohman) and joined the NCCC31 group. The NIFA-AFRI-SAS RESILIENCE CAP grant is a collaborative effort of the NCCC31 members and invited colleagues in areas of sociology, economics, and policy. This project is expanding the research, teaching, and extension on forages across Wisconsin and the US.

2. New Facilities and Equipment

None

3. Unique Project Related Findings

A paper from the Resilience CAP was published (Picasso et al 2022) describing the conceptual framework of the project: diverse, perennial, circular forage systems are needed to foster resilience and ecosystem services across landscapes.

4. Accomplishment Summaries

Papers in high impact peer reviewed Journals, including a synthesis paper on a new framework to foster resilience in agriculture by integrating diverse perennial circular systems product of the 10 million $ NIFA SAS CAP grant.

5. Impact Statements

Prevailing agricultural systems dominated by annual crop monocultures, and the landscapes that contain them, lack resilience and multifunctionality. They are vulnerable to extreme weather events, contribute to degradation of soil, water, and air quality, reduce biodiversity, and negatively impact human health, social engagement, and equity. To achieve greater resilience, stability, and multiple ecosystem services therein, and to improve socio- economic outcomes, we propose a practical framework to gain multi- functionality at multiple scales. This framework includes forages within agroecosystems that have the essential structural features of diversity, perenniality, and circularity. These three structural features are associated with increased resilience, stability, and provision of several ecosystem services, which in turn improve human health and socioeconomic outcomes. This framework improves understanding of, and access to, tools and materials for promoting the adoption of diverse circular agroecosystems with perennial forages. Application of this framework can result in land transformations that solve sustainability challenges in agriculture if policy, economic, and social barriers can be overcome by a transdisciplinary process of equitable knowledge production.

6. Published Written Works

*Refereed publications*

*Shoenberger, E.D., Jungers, J.M., Law, E.P., Keene, C.L., DiTommaso, A., Sheaffer, C.C., Wyse, D.L., Picasso, V.D., Stoltenberg, D.E.#. Synthetic auxin herbicides do not injure intermediate wheatgrass or affect grain yield. Weed Technology (accepted).

Poudel, K., Sheaffer, C.#, Jungers, J.M., Weihs, B.J., Lamb, J.F.S., Bauder, S., Picasso, V., Heuschele, J., Xu, Z.#. 2023. Quantifying winter survival of Alfalfa (Medicago sativa L.). Agronomy Journal (accepted).

Ashworth, A.J.#, Marshall, L., Volenec, J.J., Casler, M.D., Berti, M.T., van Santen, E., Williams, C.L., Gopakumar, V., Foster, J.L., Propst, T., Picasso, V.D., and Su, J. 2023. Framework to Develop an Open-Source Forage Data Network to Improve Primary Productivity and Enhance System Resiliency. Agronomy Journal. https://doi.org/10.1002/agj2.21441

DeHaan, L.R.#, Anderson, J.A., Bajgain, P., Basche, A., Cattani, D.J., Crain, J., Crews, T.E., David, C., Duchene, O., Gutknecht, J. and Hayes, R.C., Hui, F., Jungers, J.M., Knudsen, S., Kong, W., Larson, S., Lundquist, P.O., Luo, G., Miller, A.J., Nabukalu, P., Newell, M.T., Olsson, L., Palmgren, M., Paterson, A.H., Picasso, V.D., Poland, J.A., Sacks, E.J., Wang, S., Westerberg, A. 2023. Discussion: Prioritize perennial grain development for sustainable food production and environmental benefits. Science of The Total Environment, p.164975. https://doi.org/10.1016/j.scitotenv.2023.164975

Culman, S.#, Pinto, P., Pugliese, J., Crews, T., DeHaan, L., Jungers, J., Larsen, J., Ryan, M., Schipanski, M., Sulc, M., Wayman, S., Wiedenhoeft, M., Stoltenber, D., & Picasso, V. 2023. Forage harvest management impacts “Kernza” intermediate wheatgrass productivity across North America. Agronomy Journal, 00, 1–15. https://doi.org/10.1002/agj2.21402

*Locatelli, A., Gutierrez, L., Duchene, O., Speranza, P. R., & Picasso, V. D. 2023. Agronomic assessment of two populations of intermediate wheatgrass—Kernza® (Thinopyrum intermedium) in temperate South America. Grassland Research, 1– 17. https://doi.org/10.1002/glr2.12032

*Pinto, P.#, Cartoni-Casamitjana, S., Cureton, C., Stevens, A.W., Stoltenberg, D.E., Zimbric, J. and Picasso, V.D. 2022. Intercropping legumes and intermediate wheatgrass increases forage yield, nutritive value, and profitability without reducing grain yields. Frontiers in Sustainable Food Systems 6:977841. https://www.frontiersin.org/articles/10.3389/fsufs.2022.977841/full

Price, J. H., Van Tassel, D. L., Picasso, V. D., & Smith, K. P. 2022. Assessing phenotypic diversity in silflower (Silphium integrifolium Michx.) to identify traits of interest for domestication selection. Crop Science, 62, 1443– 1460. https://doi.org/10.1002/csc2.20748

*Picasso, V. D.#, Berti, M., Cassida, K., Collier, S., Fang, D., Finan, A., Krome, M., Hannaway, D., Lamp, W., Stevens, A. W., & Williams, C. 2022. Diverse perennial circular forage systems are needed to foster resilience, ecosystem services, and socioeconomic benefits in agricultural landscapes. Grassland Research, 1( 2), 123– 130. https://onlinelibrary.wiley.com/doi/full/10.1002/glr2.12020

Wiesner, S.#, Duff, A.J., Niemann, K., Desai, A.R., Crews, T.E., Picasso, V.D., Riday, H., Stoy, P.C. 2022. Growing season carbon dynamics differ in intermediate wheatgrass monoculture versus biculture with red clover. Agricultural and Forest Meteorology 323 (2022) 109062. https://doi.org/10.1016/j.agrformet.2022.109062

*Locatelli, A., L. Gutierrez, & V.D. Picasso#. 2022. Vernalization requirements of Kernza intermediate wheatgrass. Crop Science, 62, 524–535. https://doi.org/10.1002/csc2.20667

*Book Chapters:*

**Orcasberro, S., Astigarraga, L., Kohmann, M.M., Modernel, P., and Picasso, V.D. 2022. Ecological Intensification in Grasslands for Resilience and Ecosystem Services: the Case of Beef Production Systems on the Campos Grasslands of South America. Chapter 7. In. Rastandeh, A., and Jarchow, M. (Eds.) Creating Resilient Landscapes in an Era of Climate Change: Global Case Studies and Real-World Solutions https://doi.org/10.4324/9781003266440*

7. Scientific and Outreach Presentations

*Abstracts, symposium and conference presentations*

*Picasso, V.*; Williams, C.*. 2023. A transdisciplinary approach to landscape transformation towards perennial, diverse, circular systems: why and how. XXV International Grasslands Congress, Covington, KY, USA, May 14-19, 2023.

Jungers, J. M., Anderson, J. A., Bajgain, P., Cureton, C., DeHaan, L., Gutknecht, J. L., Hartman, A., Meier, E., Peters, T., Picasso, V. D., Reser, A., Ritter, T., Streit Krug, A., & Tautges, N. 2022. Developing and Deploying Kernza, a Perennial Grain Crop. ASA, CSSA, SSSA International Annual Meeting, Baltimore, MD.
https://scisoc.confex.com/scisoc/2022am/meetingapp.cgi/Paper/143433

*Olugbenle, O., & Picasso, V. D. 2022. Does Spring and Fall Nitrogen Fertilization Affect Kernza Intermediate Wheatgrass after Five Years? [Abstract]. ASA, CSSA, SSSA International Annual Meeting, Baltimore, MD.
https://scisoc.confex.com/scisoc/2022am/meetingapp.cgi/Paper/142490

*Shoenberger, E., & Picasso, V. D. 2022. Managing Inter-Row Spacing and Nitrogen Fertility in Dual-Use Kernza Intermediate Wheatgrass (Thinopyrum intermedium) to Sustain Grain Yield over Time. ASA, CSSA, SSSA International Annual Meeting, Baltimore, MD.
https://scisoc.confex.com/scisoc/2022am/meetingapp.cgi/Paper/142654

Bianchin Rebesquini, R., Basche, A., Picasso, V. D., Jungers, J. M., & Culman, S. 2022. The Impact of Nitrogen Rates across Sites and Years on Intermediate Wheatgrass Grain Yields: A Meta-Analysis. ASA, CSSA, SSSA International Annual Meeting, Baltimore, MD.
https://scisoc.confex.com/scisoc/2022am/meetingapp.cgi/Paper/143883

Pizarro,D.M., Akins,M.S., Picasso, V.D., and Wattiaux, M.A. 2022. Methane and carbon dioxide production of dairy heifers fed Kernza Intermediate wheatgrass straw mixed with alfalfa haylage and corn silage. American Dairy Science Association (ADSA) conference June 19-22, 2022, Kansas City, MO, USA.

Pizarro, D.M., Akins, M., Picasso, V.D., Wattiaux, M. 2022. Effect of Including Kernza Straw in Forage-Based Heifer Diet on Methane Production, Yield and Intensity. 8th International Greenhouse Gas & Animal Agriculture Conference DOI: 10.13140/RG.2.2.10151.21924. Orlando, FL, USA, June 5-9, 2022.

*Pinto, P., and V.D. Picasso. 2022. Planting season and legume species affect grain and forage yield in Kernza intermediate wheatgrass perennial intercrops. European Sociecty for Agronomy meeting. Postdam, Germany, August 29-Sept 2, 2022.

*Bhandari, K.B., and V. D. Picasso. 2022. Assessing resilience of alfalfa cultivars to drought stress in Wisconsin, United States. 29th General Meeting of European Grassland Federation. June 26-30, 2022, Caen, France
Invited talks:

2023. Increasing resilience of agricultural systems with perennial crops. ICRISAT's Institutional Learning Seminars. Feberuary 1, 2023. Hyderabad, India.
2022. Perennial grain poycultures: current highlights from USA. North European meeting on Perennial Grains, Lund, Sweden, December 5-6, 2022.
2022. Diversity and perenniality for resilience and ecosystem services in agroecosystems. Tamm Ecology Seminar Series, Uppsala, Swedish Agricultural University, November 29, 2022.
2022. The perennial grains agricultural revolution. Bydgoszcz University, Poland, October 24, 2022.
2022. Planting season and legume species affect grain and forage yield in Kernza intermediate wheatgrass perennial intercrops. European Socioecty for Agronomy meeting. Postdam, Germany, August 29-Sept 2, 2022.

8. Collaborative Grants

Current grants:

Fostering Resilience and Ecosystem Services Across Landscapes by Integrating Diverse Perennial Circular Systems. USDA NIFA SAS CAP. $10,000,000 (PI: Picasso – UW-Madison)

Breeding Alfalfa for Intercropping with Intermediate Wheatgrass: Towards perennial grain-forage systems. USDA-NIFA- AFRP. $800,000 (PI: Moore- Cornel U)

Developing and deploying a perennial grain crop enterprise to improve environmental quality and rural prosperity. USDA NIFA SAS CAP. $10,000,000 (PI: Jungers -UMN)

Closing the alfalfa yield gap while improving soil health. NAFA: $ 98,002 (PI: Tautges -MFAI)

Intercropping the perennial grain Kernza with legumes for sustained economics and environmental benefits. USDA NIFA SARE$ 199,946 (PI: Jungers -UMN)

9. Graduate students and postdocs

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| Olugakorede Olugbenle | PhD Agronomy | Kernza agronomic management |
| Dante Pizarro | PhD Dairy Science | Kernza feed value & silvopasture |
| Soledad Orcasberro | PhD Agronomy | Alfalfa in dairy and soil health |
| Erica Shoenberger | MSc/PhD Agronomy | Kernza soil health and farmers |
| Angad Dhariwal | MSc Agroecology | Intercropping perennial grains |
| Priscila Pinto | postdoc | Kernza fertility and agronomy |