FFAR Annual Progress Report

As part of the Grant Agreement, grantees must complete an Annual Progress Report. Please use the template below to complete the programmatic report. The requirement must be submitted to FFAR within 30 days after the end of each annual funding period. All questions about this form should be directed to grants@foundationfar.org.

The Annual Progress Report communicates the annual results and accomplishments of the funded grant research, including accomplishments and tentative completion of specific annual goals and objectives. Disbursement of next year's funds for this grant are contingent on the receipt and approval of the Annual Progress Report to include a programmatic and financial piece as well as availability of matching funds, if applicable.

Grant Information	
Grant ID	DSnew-0000000028
Award Program	
Project Title	Metrics, Management and Monitoring: An Investigation of Rangeland and Pasture Soil Health and its Drivers
Reporting Period	10/01/2023 – 9/30/2024
Period Budget	**Year 3**
Project Director/Principal Investigator Information	
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ASO Title	
Email	

Phone	

1. General Information

1.1. Please list the geographic location(s) – city, state, congressional district - where the work was conducted. If the work was conducted outside of the U.S., please list the city and country.

Ardmore, OK-4
Burneyville, OK-4
Marietta, OK-4
Mannsville, OK-4
Sulphur, OK-4
Mountain View, OK-3
Waukomis, OK-3
Snyder, OK-3
Chandler, OK -5
Konawa, OK-5
Sherman, TX-4
Gainesville, TX-26
Powderly, TX-4
Decatur, TX-26
Muenster, TX-26
Rosston, TX-26
Blooming Grove, TX-6
Valley Mills, TX-31
Graford, TX-25
Bowie, TX-13
Elbert, TX-19
College Station, TX-10
East Lansing, MI-7
Lake City, MI-4
Merrit, MI-2
Alden, MI-1
Trenary, MI-1
Chatham, MI-1
Hersey, MI-2
Remus, MI-2
Evart, MI-2
Homer, MI-5
Coopersville, MI-3
Middleville, MI-2
Dexter, MI-6
Reed City, MI-2
Alpena, MI-1

Drafter, MI-1
Mount Pleasant, MI-2
South Haven, MI-4
Lowell, MI-2
Marne, MI-3
Laramie, WY-at large
Ranchester, WY-at large
Newcastle, WY-at large
Gillette, WY-at large
Moorcroft, WY-at large
Sheridan, WY-at large
Saratoga, WY-at large
Cheyenne, WY-at large
Arvada, WY-at large
Rock River, WY-at large
Medicine Bow, WY-at large
Kim, CO-3
Nathrop, CO-7
Alamosa, CO-3
Fowler, CO-3
Gunnison, CO-3
Woodrow, CO-4
Craig, CO-3
Lamar, CO-4
Rush, CO-5
Fort Collins, CO-2
Beltsville, MD-4
Missoula, MT-1
Corvallis, OR-4
Minneapolis, MN-5
Phoenix, AZ-5
Exeter, United Kingdom
Woodhouse, Leeds, United Kingdom
Australia

1.2. How many new jobs were created by the grant during this reporting period? 20

2 from UW (University of Wyoming)
4 from MSU (Michigan State University)
12 from CSU (Colorado State University)
2 from USDA MD

1.3. How many jobs were maintained by the grant during this reporting period?56

4 from Noble - 1 Post doc, 1 Research associate, 1 Research assistant, 1 project coordinator
3 from MSU hub - 1 Post doc, 1 Research assistant, and 1 project coordinator
3 from UW - 1 Research Associate and 2 Ph.D. graduate research associate
3 from MSU ecological outcomes verification (EOV) – 1 Post doc, 1 Research tech, and 1 Faculty member
3 from MSU Economic team – 2 graduate students, and 1 part-time Faculty member
5 from Wellbeing module – 2 Postdoctoral Researchers and 3 research Assistants
9 from MSU water module team
17 from CSU - 3 undergraduate research assistants, 2 Ph.D. students, 3 Research scientists, 4 Research associates, 2 Graduate research assistants, and 3 Faculty
1 from USDA MD
2 from USDA WY – 1 post doc research associate and 1 Remote Sensing Specialist
2 full time Quanterra
2 from TAMU (Texas A&M University)
2 from TNC (The Nature Conservancy)

2. Accomplishments

What were the goals/specific aims of the project for this reporting period? If the approved application lists milestones/target dates for important activities or phases for this reporting period, identify these milestones and dates, as well as show actual completion dates or the percentage of completion of milestone targets.

The goal of the project for this reporting period (10/01/2023 – 9/30/2024) was to continue project activities, including intensive monitoring of hubs and producers' sites, as well as model development. Specific objectives of the project for this period were:

1 – Model development

Intensive monitoring sites have collected and sent data to module teams for model development. Data includes:

- Remote sensing (RS) measurements
- Grazing measurements
- Water module

Model Development to represent the effects of adaptive and prescriptive grazing management on grazingland plant productivity and soil C pools in the MEMS (Microbial Efficiency – Matrix Stabilization) model, initialize hubs sites, and run simulations.

Development and evaluation of remotely-sensed evapotranspiration (ET) and leaf area index (LAI) image timeseries at intensive sites, assessment of historical response of ET, LAI, biomass and grassland phenology to climate drivers (e.g., drought) at intensive sites, and development and evaluation of regionalized U.S. grazingland biomass estimation techniques based on multi-sensor RS and machine learning techniques.

2 – Implement intensive producer sites

Intensive monitoring sites coordinated sampling at 30 producers' sites with the support of other modules (soil, water, and EOV). Remote sensing protocol, including measuring vegetation structure and biomass, was performed. OK/TX producers were completed on October 17th 2024.

For the WY intensive monitoring hub, all instrumentation and sampling at the McGuire Ranch was completed and grazing management installed (6 herds in 2 different management schemes).

Quantitative and qualitative wellbeing data collection in Winter/Spring 2023/24 from participant producers, along with data analysis from 2022/23 data and publications.

3 – Soil and EOV on producers' sites

We have done EOV on 58 producers' sites. Soil sampling was completed at the remaining producers' sites for each hub (28 producers – total of 1080 cores collected) for the baseline data. We also measured infiltration rates at the same producers' sites.

- Producer sampling on 09 Michigan sites, completed in August 2024.
- Producer sampling on 09 Colorado and Wyoming sites, completed in September 2024.
- Producer sampling on 10 Oklahoma and Texas sites, completed in October 2024

4 – Producer meeting (3 sites)

Scheduled for Nov 13st (MI hub), Nov 19th (CO/WY hub), and Nov 21st (OK/TX hub) of 2024.

- Regional meetings had to be pushed to the end of the year (beginning of YR4 of the project) based on producers' availability.
- Meeting agenda includes presentations from three modules: EOV, data scaffolding, and producer feedback tool. The meetings will be delivered in person and virtual in OK, MI and WY.

2.1 Have any of the major goals/specific aims or milestones for this reporting period changed since the award or previous report? If so, please list the goal(s) that have changed and provide justification for the change from the approved goals. (Up to 300 words)

- The second producer meeting will be held in November 2024 for all hubs, which falls into Y4. Planning for the producer meetings occurred during Y3.
- OK and TX producers' baseline sampling (soil cores sampling and soil water infiltration measurements) fell into Y4 due to availability of producers (completed on October 17th, 2024). MI and WY have already completed baseline sampling for the remaining producers.
- Added control towers in OK and MI intensive sites to enable consideration of ungrazed sites. It did not impact the milestones for this reporting period.
- Economic team: There was some delay on data collection and analysis (due to the departure of PI McKendree and due to some producers providing incomplete or missing financial data). The financial and economic data cleaning and processing fell behind schedule for the first half of the year, and the rest of the year was spent on efforts to get things back on track.
- By bringing Dr. Nathan DeLay onto the team, the CSU group will contribute more significantly to producer economic, financial, and well-being analyses.

2.2 What was accomplished under the goals/specific aims or milestones for this reporting period? For this reporting period describe: 1) major activities; 2) specific objectives; 3) significant results, including major findings, developments, or conclusions (both positive and negative); and 4) key outcomes or other achievements. Include a discussion of stated goals not met. As the project progresses, the emphasis in

reporting in this section should shift from reporting activities to reporting accomplishments. In the response, emphasize the significance of the findings to the scientific field. Include approaches taken to ensure robust and unbiased results. (Up to 2000 words)

1. Major activities

a) Intensive sites

- Intensive site monitoring and data collection continued.
- Assistance with data inputs for data scaffolding and model development.
- Selected and onboarded final producer in MI.
- Planned for and hosted 3M Project Team meeting at MSU.

b) Soil Module

- Completed soil sampling at producers' sites.
- Completed soil processing and continued analyzing 2022 samples.
- Started soil processing, archiving, and analyses from 2023 samples.
- Developed framework to conceptualize effects of grazing management levers on grazingland ecophysiology and soil outcomes.
- Developed new version of MEMS process-based ecosystem model (MEMS v2.34) to represent effects of adaptive grazing management levers on grassland productivity and soil C storage.
- Initiated development of MEMS v3, goal of which is to improve representation of spatial heterogeneity on grazinglands and grazing dynamics.
- Development of RS data and tools to support regional scale modeling.
- Integrated model components have been better clarified.

c) Flux Module

- Undertake analysis to identify optimal tower locations for ungrazed areas in OK and MI.
- Undertake maintenance and routine data collection at 58 flux systems.
- Continue data analysis and processing.

d) Water Module

- Continue water content and saturated hydraulic conductivity monitoring.
- Soil samples analyzed for NH_4-N, NO_3-N, total carbon and total nitrogen content.
- Central database developed and populated for data on MSU cloud.
- New water samples collected at observation wells at MI site to support modeling efforts.
- Hydrological models calibrated for MI site and model input preparations started for OK sites.
- Producer feedback team held initial meeting with other modules to start discussions about design of the tool. Additional meetings held with project's economists and developers of MEMS model to discuss how the tool will function and what modeling activities will be needed to support it.

e) EOV Module

- Sampled intensive and producer sites for various ecological outcomes.
- Launched online ecological monitoring training.
- Distributed ecological monitoring reports to producers detailing findings of their ecological monitoring.

f) *Remote Sensing Module*

- Continue development and evaluation of remotely-sensed ET and LAI image timeseries at intensive sites.
- Continue assessment of historical response of ET, LAI, and grassland phenology to climate drivers at intensive sites.
- Remote sensing protocol updated to address sampling issues recognized by field crews in MI, OK, and WY.
- Supported a NASA DEVELOP project in which students applied RS analysis techniques to satellite-based biomass production estimates using OK intensive site as a case study.

g) Socio-Economic Wellbeing/Resilience Module

- Data collection (quantitative and qualitative) completed with participants producers.
- Data analysis completed:
    - Relational values review paper analysis;
    - Monitoring paper "Formal and Informal Monitoring on Pasture and Rangelands in the U.S.: Bridging Two Knowledge Paradigms";
    - Intake interview data analysis (coding using MaxQDA software) from 2023;
    - Wellbeing survey analysis.
- Initiated new collaborative case study project with other modules.
- Refinement of economic wellbeing framework.
- Continued implementation of financial survey with social science team.
- Refine and improve economic data collection instruments, financial statement templates and enterprise budget templates.
- Tool development for reporting financial data to producers (and which producers can use to manage their financial data).

h) Grazing Module

- Organized regional meetings in OK, MI, and WY.
- Set up 53 of 59 producers with PastureMap subscriptions to record grazing management.
- Collected monthly, pasture-level producer grazing management data.
- Grazing management data reported in many forms including software platform reports, Excel, or alternative spreadsheets already in use by producers.
- Aggregated grazing management data into one spreadsheet to facilitate analysis.

i) *Data Scaffolding Module*

- Offered first user feedback session.
- Analyzed data from other modules.
- Developed user management features for IRB datasets and backend data structure for producers' datasets.

2. Specific Objectives

a) *Intensive sites*

- Continue data collection for grazing, water infiltration, EOV, and RS modules.

- Maintain instrumentation through on-site maintenance and coordination when additional work needed.

b) Soil Module

- Completed producer baseline soil collection.
- Completed FTIR scans, spectral model building, and following analyses on 2022 samples: bulk density, water stable aggregates, pH, texture, inorganic C, and bulk soil C, N, and isotopic composition. Completed fractionating samples by size and density on ~¾ of samples.
- MEMS Model and grazing Framework Development: two manuscripts published: Stanley et al. (2024) and Santos et al. (2024).
- Evaluated spatial and temporal trends with remote sensing team in net primary productivity and aboveground biomass.
- Integration of model components, such as producer choices and well-being, animal growth, grazing behavior, etc.

c) Flux Module

- Analysis and site selection for ungrazed areas in OK and MI.
- Building and installing 3 flux systems for ungrazed areas.
- Maintaining and collecting data from 58 flux systems.
- Preliminary processing and data analysis for intensive sites.
- Continued development of portal to enable routine access to flux data.
- Discussion with modelling teams following analysis of v1 dataset.

d) Water Module

- Completed infiltration measurements at 30 new producers' sites.
- Completed measurements of NH_4-N and NO_3-N in soil samples taken in 2022-2023.
- Shared initial cloud-based water monitoring data with data scaffolding team.

e) EOV Module

- Launched and promoted asynchronous online ecological monitoring training among participants producers.
- Producers received a report detailing findings of ecological monitoring completed in 2023.
- Producers surveyed by monitoring teams to discuss engagement with online monitoring training and reports.

f) Remote Sensing Module

- Extended development of multi-year 30-m resolution ET timeseries (2019-2023) for intensive sites.
- Continued evaluation of regression relationships between visual obstruction recordings (VOR) in field-to-field clipped biomass and biomass estimates.
- Refined satellite models using field clipped biomass and biomass estimates.
- Integrated RS, qualitative interview data, and grazing management data to understand how decision-making on grazinglands impacts ecological outcomes over time.

g) Socio-Economic Wellbeing/Resilience Module

- 2024 Interview protocol completed.
- 2024 Resilience assessment data collection activity protocol.
- 59 producer interviews completed.
- Wellbeing survey completed by 53 participating farms (81 surveys submitted).
    - 18 producers in MI, 19 in WY and CO, and 16 in OK and TX. Responses per ecoregion were 29, 29, and 23 respectively.
- Continued implementation of survey along with social and economic science teams.
- Continued economic data collection, financial statement templates and enterprise budget templates.
- Continued data analysis.

h) Grazing Module

- First annual regional producer meetings hosted in Oct-Nov 2023 in Marion, MI, Laramie, WY, and Ardmore, OK. Producer attendance at meetings was ≥85%.
- Three regional producer meetings scheduled for late November 2024 and are being planned by Grazing Module team with support of other modules. Meetings will focus on data sharing, getting feedback on a decision support tool, and reviewing EOV reports.

i) Data Scaffolding Module

- First user feedback session presented during annual project meeting in MI.
- Integrated first datasets analyzed from modules, including soil, water, flux, and EOV datasets.
- Developed user management features for IRB datasets. Currently, core privilege management is available for researchers.

3. Results

a) Intensive sites

- In progress.
- OK native rangeland is showing greater animal unit days in adaptive compared to prescriptive grazing.

b) Soil Module

- Results of MEMS model and grazing framework development presented in two manuscripts: Stanley et al. (2024) and Santos et al. (2024).
- Integration of model components will provide input to MEMS simulations.

c) Flux Module

- Use of v1 flux dataset by ET and biogeochemical modelling teams indicated good utility and reinforced need to address known weaknesses in flux processing methodology. V2 dataset should be available by end of 2024.

d) Water Module

- Preliminary analysis of infiltration data with EOV scores indicate a positive relationship both within and across three study regions. Further analysis with remaining producer sites sampled in 2024 will be necessary to better understand these relationships.

e) *EOV Module*

- Preliminary observations suggest low engagement with training and reports by producer-partners. These results will be formalized, and findings used to improve training and reporting material through remainder of project.

f) *Remote Sensing Module*

- Models for predicting standing biomass in OK and MI have moderate to low accuracy. Improvement expected with additional years of data and additional data quality control.
- Incorporated standing biomass data from multiple sites in Long-Term Agroecosystem Research (LTAR) network to investigate possibility of site-to-site model transfer.
- Case study ranch chosen and collected and summarized RS data at pasture and pixel level. Results show detectable changes in biomass productivity (an indicator of rangeland health) after a major management shift.
- Remote sensing LAI compared to ground LAI showed bias of -0.07 to -0.48 and 0.58 to 1.28 in OK and MI sites, respectively.
- RS phenological metrics from 2018 to 2023 produced for surrounding areas using HLS data. Results are under assessment.
- Flux data from 2022-2023 used to quantitatively evaluate 30m remotely-sensed ET timeseries extracted within tower footprints. Quantitative performance assessed at each site with available flux data, with typical errors of 0.6-0.8 mm d-1, and site-to-site variability (due to soils, topography, vegetation composition, and management) evaluated.

g) Socio-Economic Wellbeing/Resilience Module

- Relational Values review paper analysis:
    - Explored six salient articulations of relational values.
    - Identified important role of valuing sustaining conditions for relational values, and valuing life supporting processes, especially social and ecological health;
    - Findings highlight important values distinction between relational and productive regenerative agriculture, which we propose is more significant to regenerative agriculture's transformative potential than process-outcomes distinction;
    - Findings suggest that regenerative agriculture definitions are more likely to contribute to sustainability transformations if they mobilize relational values evident in regenerative agriculture literature.
- Paper "Formal and Informal Monitoring on Pasture and Rangelands in the U.S.: Bridging Two Knowledge Paradigms".
    - Explores how ranchers define and utilize both formal and informal monitoring methods.
    - The findings revealed that reported financial and subjective wellbeing of producers is above the average of our reporting scale.

- Findings suggest that characteristics like producer age, herd size, economics-related degree, off-farm job, and household income impact rancher's reported financial wellbeing. The older a producer is, the higher are their household, farm.
- There is a negative relationship between herd size and household financial wellbeing; it might be that ranch households with fewer cattle usually have more off-farm income to support household finances that could alleviate stress.
- Ranchers who consider their major occupation as a farmer/rancher have higher financial wellbeing scores.

h) Grazing Module

- Nothing to report.

i) Data Scaffolding Module

- Ingested newly acquired data collections, encompassing soil carbon, water, EOV, and heat-flux data recorded during 2022-2023.

4. Outcomes

a) *Intensive sites*

- PhD students and post docs in progress and a stream of data flowing that will inform large modeling questions and specific applied questions.

b) *Soil Module*

- With improvements of MEMS model, it can estimate amount of plant biomass removed by animals, loss of carbon and nitrogen in animal digestion, and return of feces and urine to soil.

c) *Flux Module*

- Exploration of temporal trends due to management interventions or meteorological influences.
- Analysis highlighted potential benefit in establishing flux systems on ungrazed pastures.

d) *Water Module*

- Identified approach to drive producer feedback tool with pre-simulated data from multiple models of range management scenarios across various study areas.

e) *EOV Module*

- Ecological Outcomes Verification reports sent to all producers.

f) *Remote Sensing Module*

- Biomass production predictions will help understand key issues of predicting net primary production from satellites.
- Developed prototype methodology for determining local representativity of each flux measurement, beyond the physical tower footprint. Dependency on soil type, microtopography, and proximity to edge forest and grazing by wildlife was identified.

g) Socio-Economic Wellbeing/Resilience Module

- Conceptual framing of grazing typology/spectrum underway along with other modules.
- Interviews provided insight into how two types of monitoring, observational (informal) and formal (e.g., soil tests), are used in management. Informal monitoring tended to drive management decision-making, whereas formal monitoring was less directly connected to management decisions, but used for other purposes
- Data analysis showed that formal, "scientific," monitoring methods are often underutilized due to time constraints, labor demands, perceived irrelevance, and inadequacy of data to capture localized variability that ranchers observe and manage for.
- Ranchers predominately use informal monitoring methods to develop local knowledge, track changes, and make management decisions tailored to their specific conditions.
- Our findings highlight importance of informal monitoring methods ranchers use that may be outside the scientific paradigm.

h) Grazing Module

- The first annual regional producer meeting was received very well by all producers.

i) Data Scaffolding Module

- *Web-Based User Interface:* Equipped with actual data from modules.
- *Data Visualization Features:* Encompasses data filtering, map-based visualization, and plotting functionalities.

2.2.1 *Aside from the accomplishments outlined above, have there been any other significant impacts resulting from the work under this grant? Please describe any broader impacts such as:*

- *Tools developed*

- MEMS v2.34 of process-based ecosystem model.
- Data framework with intensive site datasets. Includes backend data structure for intensive site datasets and curated data product. Also, data visualization capabilities such as site comparison, and time series graphing are included. More recent datasets have been actively integrated from 3M teams. See the attached status of data integration.
- A conceptual framework for assessing impacts of grazing on grazingland ecophysiological and soil outcomes (see citation in *3. Informational Products*). Will help researchers both internal and beyond the project in improving research outcomes on these systems.
- A standard operating procedure, protocol, and automated spreadsheet calculations to improve bulk density calculations to include rock volume corrections for rangeland soils.
- Refined economic wellbeing framework and economic data collection tools for enterprise budget and farm financial statements.
- Developed tool for reporting summarized financial data to ranchers that can also be used by farmers to manager their own financial and enterprise data.
- Recruitment survey tool (2023).
- Wellbeing survey tool.
- Intake interview protocols.
- Resilience protocols.
- Prototype to assess near-real time biomass for pastures developed. https://cperviewer.com/

- *Benefits to policy*

- MEMS v2.34 has potential for improved policy making outcomes, as tool can be used to both assess and predict SOC outcomes from various grazing management strategies on grazinglands.

- *Benefits to future research*

- Soils team met with other research efforts to advise on measurement methods and approaches. Lessons learned and experiential knowledge gained from soils work on this project has broad ranging effects on outside research aiming to examine effects of grazing on SOC and other ecosystem outcome.
- Preliminary findings as part of this project presented at Society for Range Management Annual Meeting in Jan. 2024. There were questions and engagement from audience concerning the role of monitoring in protecting rangelands.
- Informal blog post written for Center for Regenerative Agriculture at MSU outlined what ecological monitoring is and how it has been used within 3M research project at MI producer-partner properties during summer of 2024.
- Based on results from the project, focus on new grazingland applications is being promoted within OpenET (etdata.org) project. 3M work is inspiring new collaborative investigations of remotely-sensed biomass estimation within USDA-ARS LTAR Grazing Land Working Group.

- *Benefits to food, the food system or agriculture*

- Research project recognition & recipient of MSU College of Agriculture & Natural Resources Excellence in Research Awards, Impact Award.
- Seeing a growing interest in project with applicability to producers dealing with interest from carbon project developers.

- *Broader economic or health benefits*

- Nothing to Report

2.3 *Describe challenges or delays encountered during the reporting period and actions or plans to resolve them. Only describe significant challenges that may impede the research and emphasize their resolution.* (Up to 500 words)

- Wildfire risk and activity at one producer site has delayed work on the 20th ranch in WY-CO hub.
- MSU team had a major staffing change with the departure of former PI Melissa McKendree (Economic module).
- Economic team continued to have some issues with producers not being able or willing to provide economic data. We are being flexible and still working with them to get information.
- CSU team: Dale's move to UTK has delayed integrated modeling efforts, though his plan to hire a post doc instead of grad student should allow the integrated model to catch back up after the post doc is hired.
- It has been challenging to gather grazing management records from some producers. Some producers upload reports directly to their respective Google Drive folders, but many do not. We have gained access to PastureMap accounts for 28 producers. For those that we have account

access to, we pull reports for them monthly. To overcome the challenge of receiving regular reports from others, we send out email reminders and call producers when necessary.

- Laboratory infrastructure issues (both physical and personnel) stemming from building closure in 2023 (see 2023 report) had caused delays in hiring and spending leading up to 2024. As of now, we are full force and on track to spend down existing funds. Despite these challenges, we have accomplished the goals we established for this year and have made significant progress in our analyses.
- The regression relationships between the field-collected VOR and field-clipped biomass continued to be poor for most sites. This was unexpected. After additional investigation, discussions with the field crews and a site visit to OK, we hypothesize that the cause may be due to the way the VOR were collected in the presence of significant amounts of 'standing dead' (i.e., senesced) vegetation. We worked with field crews to revise the protocol and clarify how to address this issue. We are awaiting data from year 3 to determine whether this has resolved the issue. In the meantime, we have been working only with the clipping data to train satellite-based models and decided to collect clipped biomass at producer ranches to further investigate the issue and to have appropriate validation data (the original plan was to only collect the rapid VOR data on producer ranches). This has caused some minor delays, but we anticipate our approaches will resolve any problems caused by this issue.

2.4 Have there been any changes in scientific approach or reasons for change? If so, what are the changes? Remember, changes to the approved scientific approach must be pre-approved by FFAR. (Up to 500 words)

- Intensive sites: MI and OK hubs had decided to implement a non-grazing area to serve as a control. Flux tower and soil moisture sensors have been installed and soil cores has been collected as baseline data. Scientific approach hasn't changed.
- Water module: shift sampling from 2 times on half of the producer sites to sampling once on all the producer sites. This decision was made based on preliminary results from the 2023 producer infiltration data which indicated that spatial coverage of all producer sites would be more beneficial to the project than monitoring any change through time on half of the producer sites.

2.5 *What opportunities for training and professional development has the project provided during this reporting period? If the research is not intended to provide training and professional development during this period, state "Nothing to Report." For all projects reporting graduate student and/or post-doctoral participants, grantees are encouraged to describe how Individual Development Plans (IDPs) are used to help manage the training for those individuals.* (Up to 500 words)

- Intensive monitoring and on-site producer sampling allowed personnel to participate in data collection and engage with producers throughout the states.
- PhD students funded by project from University of Wyoming have received hands-on training related to rangeland and ranch management decision making, and attended the Society for Range Management conference in Reno, NV.
- Postdoc from Noble Research Institute attended the 2024 American Society of Animal Science conference in Calgary, Canada.
- Post doc from MSU gave an overview of the project on a pasture walk in Lake city Research Center three time throughout the year. Attendees were from Kentucky and Michigan Cattlemen

Association, Michigan Agriculture Environmental Assurance Program technicians, and USDA-NRCS conservationists.

- Postdoc of EOV module has been writing grant proposals to extend the monitoring work to populations beyond this grant. Additionally, promoting the work within MSU College of Ag and Natural Resources has been part of the IDP for the researcher. The researcher has engaged in learning communities and communities of practice related to integrating DEIJ into agricultural research, place-based scholarship, community collaborations/community engaged research, and resilient agroecology.
- Ph.D students from Economic module attended Society for Range Management conference and other professional development activities at the conference.
- Staff/students from Economic module learned more about beef cattle industry by working on project.
- IDPs revisited for Ph. D students from Wellbeing module during annual review and opportunities sought accordingly. Students assisted in mentoring graduate students working on related topics. Continued group learning in collaborative data analysis using MAXQDA software.
- Water module: Undergraduate research assistants received training in soil extractions for nitrate measurements and plating for total carbon and total nitrogen and in operating the SATURO Infiltrometers. All research staff have received training for chemical hygiene, hazardous waste, worker protection standard, and site-specific safety for working in the laboratory.
- Soil module: Two, one-week long training sessions for internal and visiting graduate students and post docs. Hosted visiting undergraduate student from Tanzania Fall 2023, who we trained on various soil processing and analytical techniques. Developed IDP for soils team master's student who is working on water stable aggregates data for thesis research. IDP has helped guide her analytical training, data analysis education, formation of thesis committee, and initial plans for thesis.
- PhD from CSU developed IDP as FFAR Professional Development Fellow. IDP is used to set personal and professional goals for the year, with scheduled points of connection with group of mentors. IDP creates framework which formalizes goals into reasonable action items and deliverables, while mentors provide guidance and advice, and hold the student accountable to IDP.
- Remote sensing supported one postdoc since February 2024, with another joining project full time in July 2024. A third postdoc is participating with partial support from other projects. Postdocs are encouraged to attend scientific meetings and present their work, and to travel for site and collaboration visits.
- Workflow enhancements in RS data incorporated into our efforts and we are anticipating training/professional development opportunities in Python and R to be part of the IDPs for both the postdoc research associate and RS specialist in performance year 2025.

2.6 Please indicate the number of undergraduate and graduate students, post-doctoral scholars, or other educational components involved during this reporting period. If other education components are involved, please describe them in detail. (Up to 300 words)

- 1 post Doc from intensive site in OK (Noble Research Institute)
- 1 Post Doc from Intensive site in MI (MSU)
- 2 PhD and 2 undergraduate students from Intensive site in WY (University of Wyoming)
- 1 Post Doc, 1 research tech and 1 undergraduate summer intern from EOV module (MSU)

- 3 graduate students from Economic module (MSU)
- 2 Post Doc, 1 undergraduate research assistant; 1 graduate research assistant from OSU/MSU (Wellbeing/Resilience module)
- 1 Post doc and 2 undergraduate students from water module (MSU).
- CSU:
  - Soil team: 10 undergraduates, 2 graduate students, and 1 visiting scholar.
  - MEMS modeling team: 2 graduate students, 1 postdoc, and 1 research scientist.
  - Data framework team: 2 graduate students.
- 3 Post Doc from USDA Maryland
- 1 Post Doc from USDA Wyoming

2.7 How have the results of this reporting period been disseminated to communities of interest? Describe how the results have been disseminated to communities of interest. Include any outreach activities that have been undertaken to reach members of communities who are not usually aware of such activities, to enhance public understanding and increase interest in learning and careers in science, technology, and the humanities. Reporting the routine dissemination of information (e.g., websites, press releases) is not required. For awards not designed to disseminate information to the public or conduct similar outreach activities, a response is not required; the grantee should write "nothing to report." A detailed response is only required for awards or award components that are designed to disseminate information to the public or conduct similar outreach activities. Note that scientific publications and sharing research sources will be reported under Information Products. (Up to 500 words)

- Project goals and preliminary results mentioned in several scientific presentations given during this reporting cycle (Sec 3.1 under Information Products).
- Initial data presented at Annual Producer meeting, at staff Project Team meeting, and to project Advisory Board Committee.
- Intensive sites data has been collected for almost 3 years and we have worked with respective teams to assist with processing, analysis, and interpretation. Some data sets are continuous and will result in an on-going collaboration with teams, whereas discrete samples (e.g., soils) are still being processed. Some data will be presented at Annual Producer Meetings throughout the states in Y3.
- WY intensive sites data presented to Wyoming Stock Growers Association and University of Wyoming Trustees over the past year.
- Flux team demo for data with select participants for feedback with future dissemination of data
- Social wellbeing reports shared with producers in 2023.
- PI Cotrufo gave an invited presentation at Webinar SPP2322 Soil Systems, with presentation entitled: Identifying mechanisms and controls of POM and MAOM formation and persistence, where content from this project was presented. June 6th, 2024
- PI Cotrufo led Soil Carbon Solution Center 1 credit course for high school teachers entitled: Soil Based Intervention to Climate Change, where content from this project was presented. In February 2024, Research Scientist Dr. Stanley co-organized a session at Society for Range Management conference in Reno, NV for module presentations. The session was titled, "Metrics, Management, and Monitoring: Linking grazing management, soil health, and producer wellbeing." Dr. Stanley

presented soils results in this session, along with presentations from other modules. Dr. Stanley also gave an invited presentation on conceptual framework developed as a result of this work in a talk entitled, "Ruminating on soil carbon: applying current understanding to inform management". In Spring 2024, Dr. Stanley organized and led event entitled "3M science office hours," which was meant to serve as an opportunity for producer collaborators to ask questions related to measurements conducted on their lands for this project. More than 30 individuals joined the 2-hr online event, including majority of producers involved in the project. In July 2024, Dr. Stanley presented content from the 3M project in an invited talk by FFAR and US Roundtable for Sustainable Beef intended to guide their research roadmap (https://www.usrsb.org/news-events/2024-sustainable-beef-research-roadmap-workshop).

- PhD candidate Erica Patterson launched professional social media accounts (Instagram and Threads: @rangesoil.sciart; X: @rangesoils) with goal of disseminating her research and related work to a broader audience. The accounts went live in September 2024 and have accumulated a steady stream of followers and activity.
- USDA-ARS in Fort Collins hosted a day of activities related to agriculture with hands-on activities for local science-focused high school, with our unit focusing on sustainable rangeland management practices.
- Two manuscripts are in preparation on LAI and ET product generation and evaluation. We anticipate these will be submitted in the next funding year.

2.8 What do you plan to do during the next reporting period to accomplish the goals of the approved project? Briefly describe what you plan to do during the next reporting period to accomplish the project goals and objectives. Discuss efforts to ensure the approach is scientifically rigorous and results are robust and unbiased. Remember that significant changes to the approved goals and objectives and project scope require prior FFAR approval. Include any important modification to the original goals and provide justification for the change. (Up to 500 words)

No significant changes to original goals, objectives and plans.

Intensive Sites Module

- Continued monitoring and data collection.
- Assist with data processing, analysis and interpretations, support integration of module data, advance model outputs and feedback tools, and engage with producers.

Soil/MEMS Module

- Complete development of MEMS v3.0.
- Complete fractionation analyses on 2022 samples.
- Continue processing samples from producer sites in 2023 and begin analyses.
- Start processing samples from producer sites in 2024.
- Remote sensing data products for multi-year time series of aboveground biomass and grassland productivity will be further developed.

Flux Module

- Maintenance and data collection from 61 flux systems.
- Advancing processing of data and supporting interpretation.

- Advancing collaborative analysis with other data sources.
- Advancing mechanisms for data sharing across project team and with producers.

Water/Producer Feedback Modules

- Continue water content and infiltration monitoring and developing workflow to share data on data scaffolding platform
- Continue data analysis to develop relationships in biophysical characteristics of sites.
- Continue hydrological model development to support integrated model and producer feedback tool.
- Producer Feedback team will engage producers to gather input on tool's design and function.

EOV Module

- Send monitoring-outcome reports to producers.
- Hold online "office hours" to engage with producers.
- Conduct annual ecological monitoring at all sites.

Remote Sensing Module

- High resolution ET image timeseries will be extended into 2025, and back to 2017.
- Model evaluation will be expanded to all intensive sites and include 2024.
- LAI data products at 30m resolution will be produced, and LAI validation will continue.
- Refit models for evaluating regression relationships between VOR in field to field clipped biomass and RS biomass estimates.
- Incorporate new satellite data to attempt to improve RS models for predicting biomass.
- Explore transferability of models across sites.
- Continue working with other modules to understand how RS can be used in decision-making.

Socio-Economic Wellbeing/Resilience Module

- Continued quantitative and qualitative data collection and analysis.
- Work with other modules to create first draft of typology/spectrum of grazing management.
- Dissemination of findings at conference session/s – SRM, IASNR.
- Finish collecting and processing Fiscal year 2023 financial data.
- Report to producers on cow-calf enterprise budget and whole farm financial statements (balance sheet, income statement, and cash flow statement).

Grazing Module

- Continue collecting grazing management data. Grazing management records will be evaluated for completeness.
- Begin development of grazing management "spectrum" using grazing management data.
- Provide producers with annual reports of grazing management data, at ranch and paddock-level.
- Plan, organize, and facilitate third annual regional producer meetings.

Data Scaffolding Module

- *Data Framework:* Integrate producers' datasets with appropriate IRB-based data access. Extend intensive site dataset with new datasets collected in 2024 and grazing management data collected in intensive sites. Integrate flux datasets. Refine visualization capabilities based on feedback during project meeting in March.
- *Integrated Modeling:* Hire a postdoc, work with MEMS team to integrate economic decisions with physical processes modeled. Work with MSU colleagues to develop and administer producer survey.

Outreach

- TNC to continue to engage in activities supporting grant topics, advising on study design, findings interpretation, implications, and broadly connecting with research team.

3. Information Products

3.1 Please list the type(s) of information products (e.g., scholarly publications, reports or monographs, workshop summaries or conference proceedings, video, audio, images, models software, curricula, instruments or equipment, intervention, etc.) produced during this reporting period resulting directly from the FFAR award. If there are no information products to date, state "Nothing to Report."

- Video, images, reports from intensive sites and producers.
- Posters/abstracts presented in conferences.
- Meetings.

3.2 *Please provide a list of citations for the information products produced during this period.* If there are no citations to date, state "Nothing to Report."

- Video, images, reports from intensive sites and producers
    - Producers' Report
        - Social wellbeing report
        - EOV report
    - 3M Data framework: https://cs.colostate.edu/3M-FFAR/
    - Collection, each of the 3M/FFAR galleries: https://www.flickr.com/photos/137252487@N06/collections/72157721064412897/

- Posters/abstracts:
    - Gergeni, T., J. Rowntree, F. Cotrufo, J. Goodwin, J.D. Scasta. 2024. Infrastructure development at the University of Wyoming's McGuire Research Ranch: Rangeland grazing innovations in high-elevation sagebrush. Society for Range Management 77th Annual Meeting. Sparks, NV.
    - Norton, A., T. Gergini, S. Hook, J. Goodwin, J.D. Scasta. 2024. Foraging behavior of beef cattle in an adaptive multi-paddock grazing system on a sagebrush steppe ranch in Wyoming. Society for Range Management 77th Annual Meeting. Sparks, NV.

- Norton, A., T. Gergini, J.D. Scasta. 2024. Songbird community response to grazing and infrastructure on a sagebrush steppe ranch. 77th Society for Range Management 77th Annual Meeting. Sparks, NV.
- Scasta, J.D., N, Nimlos, J., Goodwin. 2024. Project Overview: Metrics, Management, and Monitoring. Special Symposium. Society for Range Management 77th Annual Meeting. Sparks, NV.
- Congio, G.F.S., Hale, T., James, T., Araujo, E.M., Sparks, M., Chi, M., Maciel, I.C.F. PSXII-6 Canopy height as a predictor of forage biomass in native rangelands and bermudagrass pastures, Journal of Animal Science, Volume 102, Issue Supplement_3, September 2024, Pages 605–606, https://doi.org/10.1093/jas/skae234.680.
- Mathisonslee, M. et al., 2024. Applied landscape monitoring and education. Society for Range Management 77th Annual Meeting. Sparks, NV.
- Dong, Z. et al., 2024. Producer profitability and Financial Well-being. Society for Range Management 77th Annual Meeting. Sparks, NV.
- Likins, J. et al., 2024. A framework for defining a continuum of grazing management strategies. Society for Range Management 77th Annual Meeting. Sparks, NV.
- Smith, Ada. 2024. Producer wellbeing and resilience. Society for Range Management 77th Annual Meeting. Sparks, NV.
- Stanley, P., Patterson, E., Machmuller, M., Cotrufo, F. 2024. Soil health indicators and modeling. Society for Range Management 77th Annual Meeting. Sparks, NV.
- Smith, A. P. et al., (2025). Formal and Informal Monitoring on Pasture and Rangelands in the U.S.: Bridging Two Knowledge Paradigms. Rangeland Ecology & Management, In Review.
- Gordon et al., 2025, A systematic review of relational values in regenerative agriculture, Agriculture & Human Values, In Review.
- Kuhl, A., Kelley, C., Merrill, Q., O'Neil, G., Guber, A., Asher, J. 2024. Linking water flux dynamics to the grazingland ecosystem. Society for Range Management 77th Annual Meeting. Sparks, NV.
- Pierce, E. 2024. What is truth? Comparing different rangeland biomass estimation methods to inform remote sensing products. Society for Range Management 77th Annual Meeting. Sparks, NV.

- Meetings:
  - Project aims and preliminary results have been reported at meetings of OpenET Science Team, the Landsat Science Team, USDA ARS Remote Sensing and GIS Working Group, AGU Hydrology Days, and in keynotes at an international workshop on Agro-Geoinformatics.

3.3 *Are there publications or manuscripts accepted for publication in a journal or other publication (e.g., book, one-time publication, and monograph) during the reporting period resulting directly from the FFAR award? If yes, please provide citation.* If no, state "Nothing to Report."

- Stanley, P.L., Wilson, C., Patterson, E., Machmuller, M.B., Cotrufo, M.F. 2024. Ruminating on soil carbon: Applying current understanding to inform grazing management. *Global Change Biology*, 30, e17223 https://doi.org/10.1111/gcb.17223
- Santos, R.S., Hamilton, E.K., Stanley, P.L., Paustian, K., Cotrufo, M.F., Zhang, Y. 2024. Simulating adaptive grazing management on soil organic carbon in the Southeast USA using MEMS 2. *Journal of Environmental Management*, *365*, p.121657. https://doi.org/10.1016/j.jenvman.2024.121657
- Peirce, E.S., Kearney, S.P., Santamaria, N., Augustine, D.J. and Porensky, L.M., 2024. Predictions of Aboveground Herbaceous Production from Satellite-Derived APAR Are More Sensitive to Ecosite than Grazing Management Strategy in Shortgrass Steppe. Remote Sensing, 16(15), p.2780. https://doi.org/10.3390/rs16152780
- Dong, Z.S., M.G.S. McKendree, and F. Lupi. "Financial Well-Being of Farm Households: A Theoretical Framework and Application." Paper under review at Journal of Rural Studies.

3.4 Website(s). List the URL for any internet site(s) that disseminates the research activities. A short description of each site should be provided. It is not necessary to include the publications already specified above. If not available, state "Nothing to Report."

- The 3M project web page. This webpage serves as a publicly accessible interface for the project, enabling users to access the data framework directly from this platform: https://www.noble.org/3m/
- The 3M data framework. This serves as the gateway to the 3M data framework, requiring users to get a valid account from the project. With such credentials, users gain the capability to access, visualize, and download datasets of the 3M project: https://cs.colostate.edu/3M-FFAR/

3.5 *Have inventions, patent applications, and/or licenses resulted from the award during this reporting period? If yes, indicate the invention, patent application(s), and/or license(s).* If no, state "Nothing to Report."

Nothing to report

3.6 *Are any of the information products produced during this reporting period confidential, proprietary, or subject to special license agreements? If so, please list them below and describe why they must remain confidential. Also, note if (and when) you plan to make these data publicly available in the future or if they must remain confidential indefinitely.* If no, state "N/A." *(up to 500 word)*

- Video - contains producers and should remain confidential at this time.
- We collected survey responses across OK, TX, MI, WY, and CO ranchers, where some information contained confidential and/or identifiable information (e.g., economic data, phone numbers, addresses, etc.). All this information is protected in private-access folders which are only accessible to IRB trained team members
- Individual reports on social wellbeing are confidential as per our ethical agreement and will not be shared publicly.

3.7 *Beyond depositing information products in a repository, what other activities have you undertaken to ensure that others (e.g., researchers, decision makers, and the public) can easily discover and access the listed information products? What other activities have you undertaken to ensure that others can access and re-use these data in the future?*

- We provided Presentation to Wyoming Legislators, the Wyoming Stock Growers Association, and the University of Wyoming Trustees highlighting our research.
- All data utilized for the publications (Soil module) have been made available upon request.
- Remote sensing datasets will be finalized and verified, and then they will be shared with the full project team via Box. Remote sensing data can also be hosted at the USDA National Agricultural Library if this is deemed advantageous to the project team.
- Since RS data products are currently provisional, we have not yet deposited them in an accessible and discoverable location. Our cleaned and quality assured ground data are deposited on the MSU Teams channel for easy access within the 3M project. As we develop final data products, we will work with the rest of the RS team and other modules to identify the best ways to share final dataset and products. We are also exploring mechanisms for hosting interactive tools/dashboard that could be accessible to decision-makers.

4. Data Management

4.1 During this period, did the project generate any data? Data generation includes transformation of existing data sets and data from existing resources (e.g., maps and imageries). Please list the data generated in this reporting period.

Datasets have been generated from all intensive monitoring sites.

- Intensive sites/Grazing Modules Datasets
  - Grazing management data from each intensive monitoring site include:
    - Stocking rate
    - Stocking density
    - Rest/Recovery period
    - Days of grazing
    - Forage biomass
  - Grazing module is currently developing the grazing management datasets that include ranch- and pasture-level grazing management metrics from producers' data.
  - Additional data from UW:
    - Bird Community Data from the Intensive Hub
    - Cattle Foraging Data (Behavioral and Spatial) from the Intensive Hub
  - Additional data from OK-TX Producers:
    - Grassland Bird community data
    - Surface water quality from ponds

- Soil Module Datasets
  - Soil and EOV data: EOV measures and trends key indicators of ecosystem function, which in the aggregate indicate positive or negative trends in the overall health of a landscape.
  - Soil water content data: This collection has soil sites ID along with its point location and soil moisture properties

- Soil carbon data: This collection has soil sites ID and its point location along with its soil properties data.
- Grazing management per ranch: This collection covers the properties of Grazing management per region (WY-CO, OK-TX, MI). This data is averaged per month. The aggregated values are per region and per month.

- Flux Module Datasets
  - The installed flux systems are undertaking continuous measurement which will enable generation of data subsequently, including 30 min means value for:
    - Net Ecosystem Exchange
    - Gross Primary Productivity
    - Ecosystem Respiration
    - Latent Heat Flux
    - Sensible Heat Flux
    - Evapotranspiration
    - Wind Speed
    - Wind Direction
    - Air Temp
    - Relative Humidity
    - Net Radiation
    - Precipitation
    - Atmospheric Pressure
    - Vapor Pressure Deficit
    - Soil Moisture
    - Soil Heat Flux
    - Soil Temperature

- Water Module Datasets
  - Soil moisture
    - Tabular data of soil moisture content dynamics at three depths and three locations within each pasture.
    - Visual data containing charts and graphs of soil moisture dynamics.
  - Saturated hydraulic conductivity.
    - Tabular data of Ksat at three locations in each pasture with three different infiltration measurements at each of the three locations; 2x annually at hub sites and 1x at new producer sites.
  - Observation well water depth
    - Tabular data of perched water depth in selected locations of the Michigan Lake City research site only currently.
  - Soil samples
    - Tabular data containing analysis of volumetric water content of soil samples.
    - Tabular data of soil NH_4-N and NO-N measured in 2022-2023 monitoring seasons at all monitoring sites including recently equipped producer sites.
  - Tabular data of total carbon and total nitrogen in soil taken in 2023. GIS maps containing point locations of the sampling sites where the data was collected.

  - Relational database of sensors, hardware, and data being collected in the field to be used with data analysis and the producer feedback tool later in the project.

- EOV Module Datasets
  - Short-term monitoring data
  - Long-term monitoring data (from remaining WY-CO producers.

- Remote Sensing Module Datasets
  - 30m daily timeseries of ET for 2019-2023 over domains including the OK, WY and MI intensive sites.
  - 30m daily and monthly timeseries of LAI for 2013-2023 over domains including the OK, WY and MI intensive sites.
  - 30m RS phenology from 2018-2023 over CONUS including the OK, WY and MI intensive sites.
  - 500m regionalized cluster map for grazing lands across CONUS, with distribution of key environmental variables (including precipitation, elevation, land surface temperature, vegetation cover, and soil texture).
  - Provisional maps of daily standing biomass for MI and OK intensive monitoring sites.
  - Annual and 20-year trend maps of biomass production, productivity and cover for a case study ranch (3M participating producer).
  - A clean data set for ground clipped biomass at the intensive monitoring sites that is located on Teams, the MEMS team is currently using this.

- Socio-Economic Wellbeing/Resilience Module Datasets
  - Quantitative dataset from 2024 wellbeing survey
  - Qualitative dataset from 2024 interviews
  - Qualitative and image data from 2023 producer meetings
  - Financial data

- Data Scaffolding Module Datasets
  - Data dictionary
  - Information about the experimental sites
  - Data schema for soil water, carbon, EOV, and heat flux tower datasets

4.2 *If you list multiple data sets, are these data sets related? If so, please provide a short description of how they are related.*

- Datasets are related.
- The datasets have been acquired based on the collaborative planning performed by the 3M researchers based on the close collaboration with the Noble Research Institute and other partners.
- The datasets are aligned with the uniformed spatial identifications and temporal ranges.
- The datasets share the interoperable metadata scheme that connects the observations and enables a wide range of data search and retrieval.
- Data were collected by each respective monitoring team, cleaned, QA/QC'd, and subsequently transformed for a variety of purposes, including query by other teams.

- There is overlap between flux metrics and remaining metrics.
- Ecosystem Respiration and Gross Primary Productivity are derived from Net Ecosystem Exchange (Flux module data).
- Water datasets are related by sensor ids and ports.
- Datasets from soil sites are related to water, and EOV monitoring sites.
- Ground clipped biomass data were used to train a model to create the provisional biomass maps for the intensive monitoring sites.
- LAI and ET are physically related biophysical variables. The transpiration component of ET is directly dependent on the transpiring leaf area. In addition, LAI is an input to the surface energy balance model used to estimate ET.
- Datasets from Socio-Economic Wellbeing/Resilience Module are related to 59 producers' participants.

4.3 Please provide copies of relevant metadata records to support FFAR's mission of enhancing the discoverability of FFAR funded project data and information products. Upload copies of records and a simple file inventory, if necessary, in a compressed folder.

Metadata records will be provided once the data has been generated, uploaded, and organized. Ground data have been deposited on the MSU Teams channel for easy access within the 3M project. This includes code used for cleaning the data and several README files for data cleaning transparency.

Producers' data is still being cleaned and de-identified, records for sharing in preparation.

Producers' data cannot be shared yet as the data is still identifiable.

Data is still being cleaned, de-identified, records for sharing in preparation.