FOUNDATION FOR FOOD & AGRICULTURE RESEARCH

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	10/01/2022 – 09/30/2023
Period Budget	**Year 2**
Project Director/Principal Investigator Information	
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FOUNDATION FOR FOOD & AGRICULTURE RESEARCH

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
Exeter, United Kingdom
Woodhouse, Leeds, United Kingdom

1.2. How many new jobs were created by the grant during this reporting period? 22

CSU (Colorado State University): 11
- 5 undergraduate research assistants
- 1 international exchange undergraduate intern
- 2 research associates
- 3 PhD students

UW (University of Wyoming): 2
- 2 PhD students

USDA Wyoming: 2
- Postdoc research associate
- Remote sensing Specialist)

OSU (Oregon State University): 2
- 2 Postdoc Researchers

MSU (Michigan State University): 5
- Economic Module
  - 2 PhD students
-Water Module
  - 1 Postdoc
  - 2 Researchers

1.3. How many jobs were maintained by the grant during this reporting period? 40

NRI (Noble Research Institute): 4
- 1 Postdoc
- 1 Research Associate
- 1 Research Assistant
- 1 Project Manager

CSU: 9
- 1 undergraduate research assistant
- 1 PhD Student
- 1 Postdoc promoted to Research Scientist
- 2 Research Scientists
- 4 Professors

UW: 1
- 1 Research Associate

USDA-ARS HRSL Maryland: 2
- 2 Postdoc

USDA Wyoming: 2
- Post doc research associate
- Remote sensing Specialist)

OSU: 2
- 2 Research Assistants

MSU: 15
-Intensive site Module:
- 1 Postdoc
- 1 Graduate Student
- 1 Project Manager

-Water Module:
- 8 Researchers

-EOV Module:
- 3 Researchers

-Economic Module:
- 1 PhD Student

Quanterra: 2
- 2 Full time equivalent

TAMU (Texas A&M University): 2
- 2 Researchers

TNC (The nat5ure Conservancy): 1
- 1 Researcher

1.4. Have there been any changes to your organization's IRS 501(c)(3) non-profit status since you were awarded the grant? If yes, please explain.

NO

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2. Accomplishments

2.1. 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. (up to 500-word limit)

The goal of the project for this reporting period (10/01/2022 – 9/30/2023) was to continue project activities, including intensive monitoring hubs and producers' sites. Specific objectives of the project for this period were:

1 - Intensive measuring – This is up to date. Second year intensive measuring of grazing management at OK and MI hubs and first year of WY.

2 - Creation of data scaffolding – This has been created by the data team from CSU.

- Comprehending the characteristics of datasets and data acquisition workflows.
- Designing and developing the initial data framework and gateway for data management, QA/QC, and visualization capability
- Data Framework Gateway demo: demo_clip_final.mov

3 - Soil and EOV on producers' sites – We have done EOV in 58 producers' sites. Soil was completed at half of the producers' sites for each hub (30 producers – Total of 1080 cores collected) for the baseline data. We also deployed 30 towers at the same producers' sites. The rest of the producers will be sampled in YR3.

Producer sampling on 10 Michigan sites, completed July 2
Producer sampling on 10 Colorado and Wyoming sites, completed September 20
Producer sampling on 10 Oklahoma and Texas sites, completed October 27

4 - Producer interviews, training – Selection of 60 producers, some have backed out and we contacted others. Intake interviews happened from April through October 2023. They have been trained for EOV and will receive some online training by the end of 2023.

5 - Producer meeting (3 sites) – Schedule for Oct 26th (CO/WY hub), Oct 31st (MI hub), Nov 2nd (OK/TX hub).

- We needed to push the meetings to the end of the year (beginning of YR3 of the project) based on producers' availability.
- All modules have prepared presentations for all the producer meetings, which will be delivered in person/virtual at the meetings in OK, MI and WY.

2.2. 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-word limit)

- Grazing management module/data collection was included. Collection of on-the-ground grazing management data is critical for characterizing grazing management practices and identifying where each producer falls on the grazing management gradient.
- Producer meetings were scheduled for the end of October/beginning of November 2023 which falls into Y3. Planning for the producer meetings have occurred during Y2.
- Part of the intensive producers' sites implementation (for OK/TX producers) fell into Y3 due to availability of producers.

2.3. 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 2,000-word limit)

1. ***Major activities***

a) *Intensive sites*

- Intensive site monitoring & data collection continued
- Onboard producers

b) *Soil Module*

- Soil sampling at 30 producers' sites across OK, TX, MI, WY, and CO
- Soil processing, archiving, and analyses from intensive sites in OK, MI, and WY collected in 2022

c) *Flux Module*

- Undertake analysis to identify optimal tower locations that support research objectives at producer sites
- Build and deploy 30 flux systems at 30 producers' sites
- Undertake maintenance and routine data collection at 28 intensive monitoring sites
- Prepare initial data analysis for intensive monitoring sites

d) *Water Module*

- Intensive site monitoring
- Deployment of water sensors at 30 producers' sites

e) *EOV Module*

- Sample producer sites for various ecological monitoring
- Sample YR2 of Intensive monitoring sites

f) *Remote Sensing Module*

- Development and evaluation of remotely sensed evapotranspiration (ET) image timeseries at intensive sites
- Development and evaluation of remotely sensed leaf area index (LAI) image timeseries at intensive sites
- Assessment of historical response of ET, LAI, and grassland phenology to climate drivers (e.g., drought) at intensive sites

g) Socio-Economic Wellbeing/Resilience Module

- Designed qualitative data collection tools for this module
- Onboard producers across OK, TX, MI, WY, and CO
- Data collection (quantitative and qualitative) completed with all producer participants.
- Producer training
- Assist with regional meetings in OK, MI, and WY

h) Grazing Module

- Producers training on grazing data collection
- Provide options to producers on where to capture their grazing management
- Organize regional meetings

i) *Data Scaffolding Module*
- Creation of Data Scaffolding
- Understanding datasets and data acquisition process at the project sites
- Constructing the backend storage infrastructure for management of soil carbon/water/EOV/flux tower data
- Designing and implementing a web-based data management user interface tailored for the compilation of dataset from the experimental sites encompassing soil carbon/water/EOV/flux tower measurements
- Designing and developing map-based data visualization features and analytics toolkits tailored to the dataset collected from the experimental sites

2. ***Specific Objectives***

a) *Intensive sites*
- Implemented grazing treatments at WY intensive site
- Continue data collection regarding Grazing, Water, EOV and Remote sensing modules in OK and MI intensive sites
- Monthly remote sensing measurements in OK, MI, and WY
- Data assistance with data inputs for data scaffolding
- Recruited, selected & onboarded producers for project participation
- Assisted in instrumenting producers' sites
- Help with planning producer meeting to be held in the beginning of Y3

b) *Soil Module*
- Completed preprocessing (sieving, drying, grinding, root, rock, litter separation) for 1277 soil samples collected at the intensive sites in 2022
- Completed DRFIT-Mid-IR scanning for 1277 pulverized samples. It will help with total %C and %N prediction and texture
- Conduct analyses for site level characterization in selected sites. As a result, 168 soil samples, from 3 triangles per plot (same used by the water team), were analyzed for texture, water stable aggregates, pH, and cation exchange capacity
- Completed soil sampling collection from 20 producer sites: 10 in MI and 10 in WY/CO
- The MEMS model has been further developed to simulate grazing. We have added:
    - grazing as a management event to allow the user to define the start and end of each grazing period, the type and amount of animal
    - elevated CO_2 effect on plant growth which represents the climate change effect
- The model has been modified:
    - to represent the feces/manure addition and decomposition
    - to dynamically update soil hydraulic parameters
- The model has been improved:
    - to better simulate grass growth by adding an explicit carbohydrate reserve organ
    - for the green up/senescence timing predictions
    - for standing dead biomass effect on new shoot growth
    - Improvements were also made to the input and output file system. There is more flexibility and less storage requirements for data input and output

c) *Flux Module*

- Analysis and site selection for producers' sites
- Sourcing components and sensors for producers' sites
- Building 30 flux monitoring systems
- Installation of 30 flux systems at producers' sites
- Maintaining systems at intensive monitoring sites
- Collecting data from towers at intensive monitoring sites
- Preliminary processing and data analysis for intensive monitoring sites

d) *Water Module*
- Measured/Gathered data from saturated hydraulic conductivity using the Saturo infiltrometer at each of the intensive sites
- New infiltration measurements, soil samples, and soil moisture sensors were installed at producer sites
- The soil moisture sensors were connected to Zentra Cloud, an online platform for collecting remote data at all producer sites except Michigan, which will be collected manually
- Soil samples were collected at each of the producers' sites where soil moisture sensors were installed to measure volumetric water content of the soil
- A central database was developed for storing the water monitoring data on the MSU cloud, and the team has started developing scripts to share those data with the overall project's cross-module database at CSU
- Water samples were collected at observation wells at Michigan core sites in the spring to help inform modeling
- Hire a temporary field technician and one post doc research associate
- Install all monitoring equipment for soil moisture measurements and complete infiltration measurements at the first 10 producer sites in each region. This objective has been completed for Michigan, Wyoming, and Colorado. This objective will be completed for Oklahoma and Texas in October 2023.

e) *EOV Module*
- Conducted the Y2 monitoring of the short-term monitoring sites at the intensive sites
- Completed the setup of EOV short- and long-term monitoring sites for producers' sites

f) *Remote Sensing Module*
- Develop multi-year (2019-2022) 30-m resolution ET timeseries for the three intensive sites in OK, MI, and WY and surroundings
- Evaluate regression relationships between VOR (visual obstruction recordings/readings) in the field to 1) field clipped biomass and 2) remote sensing biomass estimates
- Evaluate regression relationships between field clipped biomass and remote sensing biomass estimates
- Hired post doc research associate and remote sensing specialist

g) Socio-Economic Wellbeing/Resilience Module
- Re-budgeted to move second postdoc funding to OSU so both postdocs can be under management of Gosnell at OSU
- Recruited and onboarded two new Postdocs for Wellbeing/Resilience Module
- Individual Development Plans developed for postdocs
- Assisted other project partners in recruitment and final selection of producers' participants
- Designed recruitment survey and analyzed data
- Designed qualitative data collection tools with the postdocs
    - Interview protocol completed May 2023
    - Resilience assessment data collection activity protocol completed in Fall 2023

- 65 producer interviews completed in summer 2023
- Creation of economic wellbeing framework
- Develop survey along with social and economic science teams
- Create economic data collection instruments, financial statement templates and enterprise budget templates
- Hosted 2 webinars to discuss economic data collection with participating producers
- Conducted in-person and Zoom interviews with participating producers
- Wellbeing survey was completed by 55 participating farms (81 surveys submitted) in summer 2023, as planned and by original milestone date
- Began data analysis

h) *Grazing Module*

- Webinars have been conducted to introduce producers to grazing management data collection methods
- A simple grazing management spreadsheet has been created as an option for producers to record their grazing management
- Producers who have indicated that they would like to use Pasture Map to record their grazing management have been connected with Grassroots Carbon personnel to begin the onboarding process
- Secure individual folders have been created for and shared with producers to upload monthly grazing management records for Grazing Module to analyze
- Three regional producer meetings were scheduled for late October/early November 2023 and are being planned and organized by the Grazing Module team
- Planning activities have included: securing venues, catering, and hotel room blocks

i) *Data Scaffolding Module*

- *Facilitating Consultative Sessions with Project Teams*: A series of consultative sessions has been undertaken with each team. These sessions encompass three distinct phases: pre-consultation, data consultation, and analytics consultation
- *Backend Storage Systems:* Our backend storage framework encompasses various storage systems tailored for the efficient management of diverse data formats. During this reporting period, we concentrated on the design and implementation of storage schemas tailored to accommodate soil carbon, water, Ecological Outcome Verification (EOV), and heat-flux datasets. Also, we have developed a data storage middleware that facilitates multi-resolution data retrieval for the remote sensing dataset
- *Web-Based User Interface:* We have conceptualized and developed a web-based user interface optimized for the visualization of datasets, metadata, site details, and data upload/download processes. Within this reporting period, our primary focus was directed towards handling data collections derived from the experimental sites
- *Map-Based Visualization and Graphing Tools:* Our web interface incorporates an advanced map-based data visualization toolkit, enriched with graphing utilities and data retrieval functionalities. Furthermore, our data graphing tools offer the capability to compare attributes within a specific data collection

3. ***Results***

a) *Intensive sites*

- Results from intensive sites will be provide in the next report

b) *Soil Module*

- Data of density distribution of predicted carbon (%) by soil depth at each intensive site. One graph from OK site can be seen below (Figure 1)

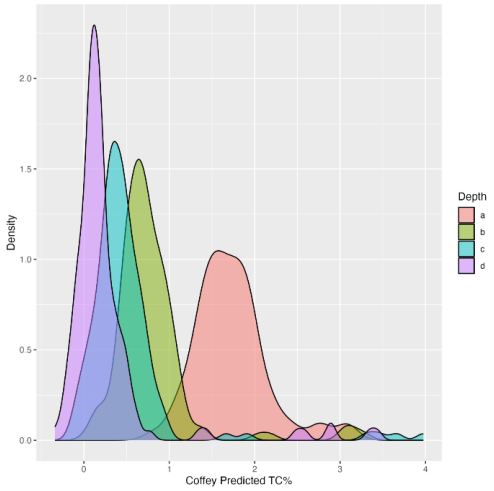

Figure 1: Density distribution of predicted %C at Coffey Ranch (OK) by soil depth: (a) 0-15cm, (b) 15-30cm, (c) 30-50cm, (d) 50-100cm

- Improvement of MEMS Model: An improved model that represents grazing and its effects on plants and soils

c) *Flux Module*

- Preliminary data analysis has suggested that the immediate impact of grazing events and other management practices may be detectable on very short timescales, reinforcing the requirement for collection of as much management information as possible
- Initial analysis also highlights the variation of outcomes across sites, possible wider influences on outcomes, and importance of gathering a multi-year data set

d) *Water Module*

- Early observations of infiltration showed significant differences between fall and spring filtration rates. However, more analysis is needed

e) *EOV Module*

- Results are going to be shared as soon as data transfer is done

f) *Remote Sensing Module*

- Initial efforts have focused on VOR data from Oklahoma and Michigan sites, data from Wyoming site was just received for year 1
- Legacy datasets from other ranch visits done in Colorado and Wyoming have been pulled together to evaluate regression relationships for those geographic areas
- Modeling workflows have been refined from site work in Colorado used previously to accommodate these different site data
- Remote sensing LAI in 2022 were compared to ground LAI measurements in the Oklahoma and Michigan sites with a bias of -0.48 in the Oklahoma site and 1.28 in the Michigan site. The correlation coefficients were around 0.75 for both sites. More comparisons are needed from 2023 to validate the LAI model
- At coarse scales, ET anomalies over this period correlated well with periods of drought, particularly at the OK and WY sites, suggesting good response of remote sensing products to climate drivers

- Flux data have been obtained from the Flux Team for the Oklahoma tower sites for 2022-mid 2023 and were used to evaluate the 30m remotely sensed ET timeseries extracted within the tower footprints
- Model-observation agreement at the Red River Ranch flux sites in terms of energy budget partitioning is excellent
- The larger pasture sites at Coffey Ranch (CR) also show similarly good error statistics. Agreement at the smaller CR sites, nestled in forested boundaries, is reduced indicating limitations in pixel resolution and/or tower fetch

g) Socio-Economic Wellbeing/Resilience Module

- We developed a well-constructed survey using established social science methods. The survey covered questions including demographics, ranch history and characteristics, grazing management, and economics
- Survey Distribution: Across all hubs, we received 408 producer responses
- Producer Selection: We conducted initial intake interviews to make decisions about their qualifications and study fit. Based on these interviews, we finalized a list of 20 producers in each region who met the study needs, spanned a relevant ecological and geographical gradient, and ranged from adaptive scores. The list of producers for each region has been finalized
- Interviews covered a broad range of topics including participant background, operation characteristics, management goals, grazing management practices, monitoring, relational values, and producer wellbeing
- Relational values were linked to three types of relationships: animal relationships, land relationships, faith relationships
- Of the 55 farms/ranches, 20 were in Michigan, 19 were in Wyoming and Colorado, and 16 were from Oklahoma and Texas. Responses per ecoregion were 29, 29, and 23, respectively
- The data from the socioeconomic wellbeing survey was used to calculate a wellbeing index score (WB index), ranging from 0 to 100, where a higher score indicates a better level of wellbeing. The results reveal a high level of wellbeing among farmers/ranchers across the ecoregions. Producers in Oklahoma and Texas have an average WB index score of 83 out of 100, followed by producers in Wyoming and Colorado averaging 79 out of 100, and Michigan producers with an average of 76 out of 100
- For reference, mean values for subjective wellbeing metrics in Western countries typically fall around 75% of the scale score (Cummins et al., 2003; Cummins & Wooden, 2014)
- Development of a new economic wellbeing framework

h) Grazing Module

- Nothing to report at this time

i) Data Scaffolding Module

- *Consulting Session*: As a result of conducting a comprehensive series of consulting sessions, we have successfully understood the data acquisition processes employed by each team. Furthermore, we have gained insights into the data-specific characteristics and preferences of each team regarding the data management process
- *Backend Storage Framework Integration:* The first version of our backend storage framework has been integrated
- Currently, we are preparing for ingesting newly acquired data collections, encompassing soil carbon, water, EOV, and heat-flux data recorded during the years 2022 and 2023
- Our storage middleware for the remote sensing dataset is ready for software testing and integration to the data framework

4. ***Outcomes***

a) *Intensive sites*

- Grazing data from the intensive sites will be shared with producers at each regional meeting in OK, MI, and WY

b) *Soil Module*

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

c) *Flux Module*

- Exploration of temporal trends due to e.g., management interventions or meteorological influences
- Analysis has also highlighted potential benefit could be gained by sitting 'control towers' on ungrazed pastures at intensive monitoring sites

d) *Water Module*

- Establishment of a cloud-based monitoring network at all the research sites
- Development of an MSU database for storing water monitoring data

e) *EOV Module*

- Ecological Outcomes Verification reports will be sent to all producers by December 1st, 2023

f) *Remote Sensing Module*

- Remote sensing LAI models generated for the three intensive sites using MODIS LAI and Harmonized Landsat and Sentinel-2 (HLS) data
- The 30m daily and monthly LAI data products from 2013-2022 have been produced for three intensive sites and surroundings

g) Socio-Economic Wellbeing/Resilience Module

- Financial statements and enterprise budgets will be available for each producer by the end of 2023
- Social wellbeing framework was presented at the 2023 International Association for Society and Natural Resources (IASNR) Conference (June 11-15, Portland, ME)
- Preliminary findings on 3M participants' perspectives on and use of monitoring in grazing management was presented at the Rangeland Management, Monitoring, and Policy Workshop (September 26-28, High Lonesome Ranch, De Beque, CO)
- Organizing an all-module 3M session at the 2024 Society for Range Management conference to be held January 28-February 2 in Reno, NV
- Conceptual framing of grazing typology/spectrum underway along with other modules

h) Grazing Module

- Nothing to report at this time

i) Data Scaffolding Module

- *Live Web-Based User Interface:* The first version of a web-based user interface is now live and equipped with sample datasets. This sample dataset will be discarded as soon as the actual data is ingested. This interface is accessible through the project's web page, hosted by the Noble Research Institute at https://cs.colostate.edu/3M-FFAR/.

- *Data Visualization Features:* Our data visualization capabilities encompass data filtering, map-based visualization, and plotting functionalities.
- A software demonstration is available at: demo_clip_final.mov

2.3.1. 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. If there are no broader impacts to date, state "Nothing to Report."

- *Tools developed*
- Recruitment survey tool
- Wellbeing survey tool
- Intake interview protocol
- Economic wellbeing framework and economic data collection tools for enterprise budget and farm financial statements
- MATLAB code has been developed to process fluxes measured using SATURO infiltrometers to correct estimated Ksat values for instability of infiltration rates
- Development of the MEMS model to represent grazing management – see activities above. Once the data from the 3 intensive sites will be fully available in the database, we will be able to calibrate and validate the model to be used as a decision support tool for the producers in the ecoregions of calibration
- Short-term monitoring online training tool for the producers to participate in during the non-growing season. There will be a practical component that the producers will complete during the Y3 monitoring season
- Initial analysis of Evapotranspiration data has been used by USDA for comparison purposes as part of ongoing development of ET modelling capabilities
- A prototype has been developed to assess near-real time biomass for pastures (https://cperviewer.com/)

2.4. 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-word limit)

- There were some challenges in recruiting producers. Despite efforts to obtain a diverse pool of applicants for the project, some states (i.e., Michigan) had limited submissions
- Some issues with producers not being able or willing to provide Economic data. We are being flexible and still working with many to get some of the information.
- Hodbod's contract at Leeds is still incomplete. A Personal Service Contract is being worked on which will utilize funding for expenses related to the project. There was a delay but will be on track for 2023-2024.
- A tower that failed, due to damage by cattle, in Wyoming has been replaced with a new system at Quanterra's expense. The downtime was sufficiently low that it will be possible to use gap filling techniques to address data loss.
- Several smaller system outages were corrected. In all cases data loss was sufficiently small as to be addressed using gap filling techniques.
    - CO_2 sensor failure in Lake City, Michigan
    - Rodent and seed drill damage to power and soil sensor in Red River, OK.
    - Lightning damage to sonic anemometer in Coffey, OK.

- A building flooding event (burst pipes) over Christmas 2022 led to damage to RAID storage containing much of the remote sensing imagery processed to date for this project. These data were regenerated during the first part of 2023
- Due to damage remediation to the building resulting from this flood, our laboratory building has been shut down for much of this year and scientists and postdocs have been working remotely. The turnover in the program support staff for our laboratory and area has led to delays in agreements processing. The postdoc hired under this project returned to a position in his home country, but a new candidate has been identified and accepted the position. Despite these challenges, we have accomplished the goals we established for this year and have made significant progress in our analyses
- Our initial modeling for evaluating regression relationships between VOR (visual obstruction recordings/readings) in the field to 1) field clipped biomass and 2) remote sensing biomass estimates have yield poorly fitting models for the Oklahoma and Michigan sites with year 1 data. We are awaiting year 2 data from both sites to see if a similar trend exists in this poor fit. The VOR data from the Wyoming site (year 1) was just collected here in 2023 and was just sent to us a week ago

2.5. *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-word limit)*

No major changes. However, some surface water monitoring that was originally proposed has been replaced with modeling due to the significant disturbance that might result from the installation of this equipment.

2.6. *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-word limit)*

- Intensive and producer sites monitoring, and on-site producer monitoring and sampling has provided students and staff to participate in data collection and engage with producers throughout all the states
- The Noble Research Institute has received many visits from graduate students from other institutions and a lot of discussions have been done
- The University of Wyoming hosted ranch Tours at the intensive site with 113 participants
- Individual Development Plans (IDP) have been developed for graduate students and post doc in this project
- Researchers from Noble Research Institute were able to have a refresher training for the EOV sampling
- Post doc from EOV module participated in two invited presentations for agricultural producers in the state. She also completed trainings on decolonizing education, Universal Design for Learning, implicit bias, and anti-racism
- Field technicians have received training analyzing soil nitrate and soil ammonium in soil samples collected at core and producer sites
- Grad Student from Economic module attended the Agricultural and Applied Economics Association Annual Meeting. He presented a poster on this research and attended other professional development activities at the conference

- Post docs from Wellbeing/Resilience module have both had the opportunity to assist in mentoring graduate students working on related topics. They are mentoring an MS student on a range riding project and a PhD student on a dissertation chapter about human-animal relations in regenerative agriculture
- Group learning in collaborative data analysis using MAXQDA software
- Post docs from Wellbeing/Resilience module mentored in leading IRB submissions for human subjects research and developing procedures for safeguarding identifiable data on a multi-disciplinary research team
- CSU soil team has trained graduate students, undergraduates, and research assistants in several analytical methods including soil processing and archiving, FTIR, texture via rapid pipette method, and water stable aggregates. The PhD student received extensive training in biogeochemical modeling, machine learning and data assimilation in numerical models to develop the skills to optimize model parameters, observation operators, and state variables
- CSU hosted undergraduates, research associates, and an international undergraduate intern (from the Earth University) for field soil sample training in September 2023. They learned how to collect soil samples using a hydraulic probe, how to identify problems and troubleshoot solutions, how to process samples in-field, and appropriate transportation methods
- Postdoctoral Scholar from CSU was trained to proposal writing and renewed IRB certification, and the PhD student completed first-time training on methods, restrictions, and access for how to maintain producer confidentiality during research activities
- CSU has leveraged this project for professional development training of one PhD student via the FFAR Professional Development Fellowship. This cohort-based fellowship will provide the student with hands-on professional skills and networking opportunities. Additionally, she will have the chance to share her research and learn from industry partners throughout the three-year fellowship
- We arranged a one-day workshop at CSU, with experts in grazing management and grazing land biogeochemistry, to train the MEMS modeling team on the system and elements to consider when developing the MEMS model to represent grazing landscapes and management
- Under funding from this project, USDA MD have supported one postdoc, and regular group meetings are conducted to foster information sharing and collaborative advancement of project goals on multiple front
- Workflow enhancements in the remote sensing data have been incorporated into our efforts and we are anticipating training/professional development opportunities in Python and R to be part of the Individual Development Plans (IDPs) for both the post doc research associate and remote sensing specialist in performance year 2024

2.7. 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-word limit)

- 1 post Doc from intensive site in OK (Noble Research Institute)
- 1 Post Doc and one graduate student from Intensive site in MI (MSU)
- 2 PhD students from Intensive site in WY (University of Wyoming)
- 1 Post Doc from EOV module (MSU)
- 1 Post Doc from Water module (MSU)
- 3 PhD students from Economic module (MSU)
- 2 Post Doc, 1 undergraduate research assistant; 1 graduate research assistant from OSU/MSU (Wellbeing/Resilience module)
- 2 Post Doc from USDA Maryland
- 1 Post Doc from USDA Wyoming
- CSU:

- 5 undergraduate students: education in field and laboratory methods, education in soil organic matter dynamics as part of the Soil Innovation Laboratory (SoIL)
- 1 international (Tanzanian) undergraduate intern from the Earth University: same as above
- 3 research associates: In addition to the educational activities listed above, our research associates have learned valuable skills in project management, laboratory flow, and advanced analytical methods
- 2 graduate students: PhD students are completing course work in their second year of graduate studies. The 3M project has provided valuable opportunity to apply course work in field, laboratory, and model development settings in an applied research setting
- 2 graduate students in Computer Science: PhD students
- 1 postdoctoral scholar: has learned valuable skills in project management of a large research endeavor, has managed/administered field and laboratory work for all undergraduates and research associates, and coordinated field work for the CO/WY producer sites

2.8. 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-word limit)

- Intensive sites data has been collected for over almost 2 years and thus 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 (e.g., CO_2 flux, water) whereas discrete samples (e.g., soils) are still being processed. Results pending. Some data will be presented at the Annual Producer Meetings with producers throughout the states in Y3
- Producer sites data collection began late in this reporting year and will not be available until samples and data have been processed and analyzed
- Individual summaries of wellbeing survey findings are being prepared
- Intensive sites have disseminated methodology and initial findings with visitors in each intensive monitoring site
- A Post doc from CSU presented the 3M soil sampling method at an oral session at the American Geological Union conference in Chicago in December 2023
- A Post doc from CSU discussed the 3M project on a public podcast in August 2023: Podcast link
- Dr. Cotrufo presented the scope of the 3M project within her research seminars delivered during last year at the University of Purdue, the University of Wyoming, the Swedish University of Agricultural Sciences, the University of Vienna, and the University of Campania, Italy
- Project goals and preliminary results have been mentioned in several scientific presentations given during this reporting cycle (see Sec 3.1 under Information Products)
- Two manuscripts are in preparation on LAI and ET product generation and evaluation. We anticipate these will be submitted in the next funding cycle.

- As we progress, we are planning to provide preliminary results to producers involved in the ranch visits at upcoming regional meetings

2.9. *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-word limit)*

No significant changes to original goals, objectives and plans. Activities will focus on:

Intensive Sites Module
- Continued leadership and oversight of the project
- Efforts to move forward with data processing, analysis, interpretation, and dissemination
- Continued monitoring and data collection at the intensive sites

Soil Module
- We will complete the soil sampling at 10 producer sites in Oklahoma, and sample the remaining producer sites at the three regional hubs
- We will continue soil processing and analyses
- We will be presenting additional 3M soils work at the upcoming American Geological Union in 2023, and at the Society for Range Management in 2024
- We will continue the MEMS model development and calibrate and validate it using the data collected at the three intensive sites

Flux Module
- Maintenance and data collection from 58 flux towers systems
- Advancing processing of data and supporting interpretation alongside management information
- Advancing collaborative analysis and comparative review with other data sources
- Advancing mechanisms for data sharing across the project team and with producers

Water Module
- We will start working with the modeling groups to help define data inputs and outputs, and establish the next steps required to start the water modeling activities
- We will also complete a user-needs assessment for the producer feedback tool, develop the tool schema, and begin developing the app prototype
- Lastly, we will complete the development/calibration of the hydrologic models at the core research sites

EOV Module
- Monitoring on producer sites and the intensive sites will continue over the remainder of the grant. Annually, in the non-growing season, all producers who are choosing to receive

accreditation for their ecological stewardship will be given a report detailing what the monitors found and some suggestions for continued improvement

Remote Sensing Module

- High resolution ET image timeseries will be extended into 2024, and back to 2017
- Model evaluation will be expanded to all three intensive sites and to include 2023-2024
- New modeling domains will be established over target producer sites:
    - Establishing accuracy of the ET products at the daily timestep
    - Evaluating the spatial representativeness of the tower measurements beyond the tower footprint
    - Quantifying the differential response of tower fields to climate drivers such as rainfall and drought
    - Contrasting vegetation water use and stress response between intensive sites
- LAI data products at 30m resolution will be produced for 2023 and 2024, and LAI validation will continue. The spatial and temporal variability of LAI will be analyzed based on over ten years of remote sensing LAI data products. Uncertainty of LAI retrievals related to green and dead grasses will be investigated using ground photos
- Refit models for evaluating regression relationships between VOR (visual obstruction recordings/readings) in the field to 1) field clipped biomass and 2) remote sensing biomass estimates using 2 years of data for OK and MI, and fit initial models for the WY site with year 1 data
- Provide initial summarization of when/where VOR is an appropriate rapid monitoring method for standing biomass

Socio-Economic Wellbeing/Resilience Module

- Continued quantitative (wellbeing survey) and qualitative (online interview)
- Data collection and analysis in 2023/24 at the three producer regional meetings
- Data analysis of workshop, interview, and survey data
- Work with other modules on creation of first draft of typology/spectrum of grazing management
- Dissemination of findings at conference session/s – SRM, IASNR
- 2024 SRM Annual Meeting – 3M Symposium Session (Metrics, Management, and Monitoring: Linking grazing management, soil health, and producer wellbeing). Our session includes an overview of the 3M project, presentations by module leads of preliminary findings from Years

1 and 2 of data collection, and a discussion of the "how" of data integration in a collaborative, multidisciplinary research project.
- IASNR session planning in progress
- Analyze the 2022 economic data collected. We will create a cow-calf enterprise budget and whole farm financial statements (balance sheet, income statement, and cash flow statement) for each farm.
- Collect 2023 economic data. We will follow the same process as 2022, but plan to complete this earlier in the year
- Write and publish manuscripts:
    - Relational values and regenerative agriculture literature review
    - Relational values empirical data
    - Producer perspectives and use of monitoring
    - Wellbeing framework

Grazing Module
- Monitor producers' Google Drive folders to ensure grazing management records are being uploaded regularly
- Begin analysis of grazing management data. Grazing management data will be used to calculate metrics such as stocking rate, stock density, grazing events, rest period lengths, regrazing frequencies, and changes in these metrics over time
- Plan, organize, and facilitate second annual regional producer meetings

Data Scaffolding Module
- We will stage in the datasets from our experimental sites. The first datasets to be staged include soil carbon, water, and EOV datasets. Then, we will stage in the heat-flux tower observations
- We will continue conducting the consulting sessions with teams once the actual datasets are staged
- We will continue testing the software and soliciting feedback from our project team members
- We will integrate the data framework for the remote sensing datasets
- We will design and develop the global indexing scheme to provide analytics capability across datasets
- We will incorporate publicly available ecological datasets into our data framework to facilitate overlay visualization for comprehensive data exploration. The integrated datasets include:
    - Soil Survey Geographic Database (SSURGO)
    - The National Ecological Observatory Network (NEON)
    - gridMET: daily high-spatial resolution (~4-km, 1/24th degree) surface meteorological data

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.

- Video, images, reports from intensive sites and producers
    - Collection, each of the 3M/FFAR galleries: https://www.flickr.com/photos/137252487@N06/collections/72157721064412897/

- Posters:
  - "Assessing the effect of grazing management on field scale water and nutrient fluxes on pasture and rangeland" presented at Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI Biennial Colloquium, June 11, 2023 – June 14, 2023, Tahoe City, CA) by the Water team
  - Results of the water field monitoring and modeling will be presented at annual SSSA meeting in St. Louis, MO, October 28-31, 2023, by the water team
  - Proceedings paper from the 2023 America's Grasslands Conference hosted in Cheyenne, WY based on a poster presentation and a presentation at the intensive research site from University of Wyoming by the WY intensive sites team
  - "Financial Well-Being of Farm Households: A Theoretical Framework and Case Study." Poster presentation at the Agricultural and Applied Economics Association Annual Meeting, Washington, D.C. July 23-25, 2023, by Economic team
  - Graduate Student Showcase poster presentation in November 2022 (2nd place, PhD student from Soil team)
  - Front Range Student Ecology Symposium poster presentation in February 2023 (1st place, PhD Student from Soil team)

- 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, and upcoming Ameriflux consortium by Remote Sensing team
  - American Geological Union conference oral presentation in December 2022 (Postdoctoral scholar from Soil team)

- Webinars
  - Hosted 2 webinars about the economic data collection process

3.2. Please provide a list of citations for the information products produced during this period.

Nothing to report

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.

Nothing to report

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.

- The 3M research activities and purpose are described on the recently published SoIL website: https://agsci.colostate.edu/soilinnovationlab/current-research-themes/
- 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/
    - Software demonstration: demo_clip_final.mov

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).

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. (up to 500-word limit)

- Video - contains producer 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

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 other can access and re-use these data in the future?

- The data will be stored in a website, and anyone can access it in the future
- Future information products will be shared at conferences, workshops, and social media channels at IWR. This may include IWR YouTube Channel, FB, Twitter, and website
- Each institution has been working with communication to notify the public of events and activities.
- Soils data dictionary has been developed for use by all other science modules to maximize data sharing and access.
- 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
- As we move forward, we will develop relationships for all different sites, and develop approaches to sharing the data and establishing collaborations for access and re-use of this data

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

- Soil Module Datasets
  - Producer site maps, including flux tower fetches and 20 random sampling sites
  - An up-to-date data dictionary with all metadata
  - Datasets on FTIR, water stable aggregates, soil texture, and raw bulk density data

- 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 at three depths and three locations
    - Visual data containing charts and graphs of soil moisture dynamics
  - Saturated hydraulic conductivity
    - Tabular data of infiltration rates at three locations
  - Observation well water depth
    - Tabular data of water level depth on several pastures on the Michigan Lake City research site only currently
  - Soil samples
    - Tabular data containing analysis of volumetric water content of soil samples
  - 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

- Remote Sensing Module Datasets
  - 30m daily timeseries of ET for 2019-2022 over domains including the OK, WY and MI intensive sites
  - 30m daily and monthly timeseries of LAI for 2013-2022 over domains including the OK, WY and MI intensive sites

- Socio-Economic Wellbeing/Resilience Module Datasets
  - Quantitative dataset from recruitment survey
  - Quantitative dataset from wellbeing survey
  - Qualitative dataset from intake interviews
  - 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:

- All datasets generated during the reporting period are indexed by geospatial location and temporal information
- 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
- 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 60 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. Producers' data is still being cleaned and de-identified, records for sharing in preparation.

Certification

The undersigned hereby certifies that to the best of their knowledge and belief, the above report and all supporting documents are true, accurate and complete. I am aware there is asignificant penalty for submitting false or misleading information.

If applicable, I agree that my electronic signature is legally binding, equivalent to, and has the same validity and meaning as my handwritten signature. I willnot claim otherwise.

PI Full Name: Isabella Cristina de Faria Maciel

PI Signature: Isabella Maciel Date: 11/01/2023

Authorized Signing Official (ASO): A. Jill Wallace

ASO Signature: _____ Date: _____