**APPENDIX D**
**SAES-422**
**Format for Multistate Research Activity**
**Accomplishments Report**
*Note: This report is submitted each year of an activity's duration and is due 60 calendar days following the annual meeting. The SAES-422 is submitted electronically by AAs into NIMSS. Annual Reports for MRF projects are available to NIFA through NIMSS.*

**Project/Activity Number:** NC1210
**Project/Activity Title:** "Frontiers in On-Farm Experimentation"
**Period Covered:** January 1, 2022 – January 1, 2023
**Date of This Report:** February 1, 2023
**Annual Meeting Date(s):** January 4, 2023

Participants: Provide information with a focus on the decisions made. As an alternative, list the URL for the meeting minutes, if that report contains the list of those who were present. And, if available, add the address for the list server as well. (Max characters = 4,000. Suggested Format: "Last name, First name (email) - Institution;" The semicolon is used to separate participant information.)

***Excel Sheet embedded: Double Click to view entire sheet & scroll down*

| | | | | | | |
|---|---|---|---|---|---|---|
| **VIRTUAL** | | | | | | |
| Curran | Keith | IT, University of Connecticut | | | | |
| Abdul Mota | Ammar | University of Texas at Arlington | | | | |
| Hawkins | Elizabeth | Ohio State University | | | | |
| Puntel | Laila | University of Nebraska-Lincoln | | | | |
| Thompson | Laura | University of Nebraska-Lincoln | | | | |
| Sheppard | John | Montana State University | | | | |
| Mieno | Taro | University of Nebraska-Lincoln | | | | |
| | | | | | | |

**Brief summary of minutes of annual meeting:** Provide information with a focus on the decisions made (Max characters = 12,000. Single line breaks are not preserved, use double line breaks instead or use a <p> tag to separate paragraphs.). As an alternative, list the URL for your meeting minutes.

***Excel Sheet embedded: Double Click to view entire sheet*

| | | | |
|---|---|---|---|
| 19:00 | 19:15 | Get Pizza | |
| 19:15 | 19:30 | Welcome and Overview of Agenda | David Bullock, University of |
| 19:30 | 20:00 | Overview of 2022 DIFM Trials | Bob Dunker, University of Illi |
| 20:00 | 21:30 | Meet and Greet | |
| | | | |
| | | | |
| | | | |
| | | Thursday, January 5, 2023 | |
| | | | |

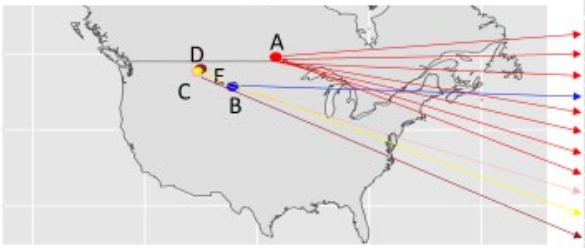
Taro Mieno: Due to the limitations of the previously preferred method to estimate site-specific yield response functions after OFPE, we started to use causal forest, a causal machine learning method. It has been shown to perform better than other popular machine learning methods like random forest, boosted regression forest, and convolutional neural network in estimating site-specific EONR accurately (cite Shun's paper). Further, a graduate student funded through this grant is currently working on developing a new innovative cross-validation approach of selecting the right model that does not rely on yield prediction accuracy, which has shown to be problematic (cite Shun's paper). The results have been promising and our new model selection approach can select the model fairly accurately.

Brittani Edge: This year we improved our optimal variable rates using causal forest, a recent heterogeneous treatment effect estimation method. We integrated causal forest into our automated analysis reports, including reporting the two field characteristics with the largest impact on the yield response to the input rates. We are also improving our figures in the automated trial reports. Some figures have been changed for easier interpretation, and other figures that were previously made manually in QGIS and PowerPoint are now fully coded in R. These figures are being integrated into the new automated reports, which are also under construction after feedback from our extension team. These new reports should present our participants with the information they need and figures or tables that are easy to interpret. With each iteration of the automated reports, we can automate more of the text, requiring less time reviewing and editing reports by the NC-1210 team.

Bruce Sheppard, Sasha Loewen: Sasha Loewen (student of Bruce Maxwell, Montana State University) successfully conducted OFPE organic trials. See map with table below.

# OFPE in the field

Methods: farms and agronomic conditions




| Year | Crop | N Source | Field-year | Acres | State/ Province | Precip from norm (%) | GDD from norm (%) |
|---|---|---|---|---|---|---|---|
| 2020 | Wheat | Manure | 1 | 80 | Manitoba | 75 | 102 |
| 2021 | Hemp | Manure | 2 | 80 | Manitoba | 82 | 119 |
| 2022 | Oat | Manure | 3 | 80 | Manitoba | 125 | 93 |
| 2021 | Winter wheat | Bloodmeal | 4 | 320 | Montana | 65 | 117 |
| 2019 | Wheat | Manure | 5 | 160 | Manitoba | 122 | 94 |
| 2020 | Hemp | Manure | 6 | 160 | Manitoba | 74 | 103 |
| 2021 | wheat | Manure | 7 | 160 | Manitoba | 81 | 119 |
| 2022 | Oat | Manure | 8 | 160 | Manitoba | 124 | 93 |
| 2021 | Winter wheat | Pea GM | 9 | 230 | Montana | 61 | 111 |
| 2021 | Barley | Pea GM | 10 | 80 | Montana | 69 | 112 |
| 2021 | Winter wheat | Pea GM | 11 | 80 | Montana | 71 | 111 |
| | *Experimentally varied input | | | | | | |

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John Sheppard: Within the larger DIFM effort, one of the key components is the development of an "analytical engine," whose role is to provide tools for analyzing data collected through on-farm experiments, subsequent optimized input applications, and other factors. The ultimate goal is to provide information to farmers whereby they can make informed management decisions. A key component of the analytical engine is the creation of a number of artificial intelligence and machine learning tools.

Current efforts in the AI/ML parts of the analytical engine are subdivided into optimization (artificial intelligence) and output prediction (machine learning). In 2022, the work on intelligent optimization has focused on improved methods for handling multiple competing objectives by applying so-called "factored evolutionary algorithms" (Strasser et al. 2016; Peerlinck and Sheppard 2022, Peerlinck *et al.* 2022). In addition, methods have been developed for archive management as a means for better selecting a subset of the Pareto Set to assist farmer decision making (Peerlinck and Sheppard, 2023). Results indicate improvements in the ability to find Pareto optimal sets that balance such objectives as net return, equipment maintenance, and environmental impact. The work on output prediction, which is needed to support optimization, has focused on improved methods for generating yield response curves with deep learning (Morales *et al.* 2023), learning prediction intervals on the response curves for uncertainty quantification (Morales and Sheppard 2022), and applying counter-factual analysis for determining key inputs that drive responsivity (Morales and Sheppard 2023).

In 2023, work related to optimization will focus on designing input prescriptions that balance optimization and experimentation by incorporating information on the uncertainty in the output predictions. Work related to machine learning will be extended to incorporate "equation learning" as a means of extracting the physical and mathematical elements that best explain how the response curves are being generated.

**Accomplishments:**

*This section focuses on intended activities, outputs, and short-term outcomes. Committees should build information built around the activity's milestones, as identified in the original proposal. Please indicate significant evidence of linkages both internal to the project/committee and to external peer groups, stakeholders, clientele, and other multistate activities. The report should also reflect on the items that stakeholders want to know or want to see. The committee should describe plans for the coming year in no more than one or two short paragraphs. If the committee is filing an annual report, the accomplishments will cover only the current year of the project; for termination reports, list accomplishments from the entire span of the project.*

*Plans for Coming Year.*

NC1210 has been teaming up with the DIFM project to recruit crop consultants to participate in the 2023 research. Recruiting efforts have been successful, and numerous crop consultants will be participating, along with their farmer-clients. We will work with those consultants and their farmer-clients, to evaluate their experiences "test-driving" the DIFM cyber-infrastructure which is central to our current activities. NC1210 applied for and has been granted $50,000 in funding to hold the 1st Annual Conference for On-Farm Precision Experimentation in January 2024. The first day of that conference will be NC-1210's usual Annual Meeting. But in the following three days scholars, farmers, students, and agri-business people will be meeting to view presentations about the experiences of farmers and others in conducting OFPEs. The conference will also include extensive training sessions on the DIFM/NC-1210 "Cyber-infrastructure." That is, the meeting will present that cyber-infrastructure to the world. The plan for 2023, then, is to develop that cyber-infrastructure, as a whole and as the conglomeration of its five components—we must have something that really works.

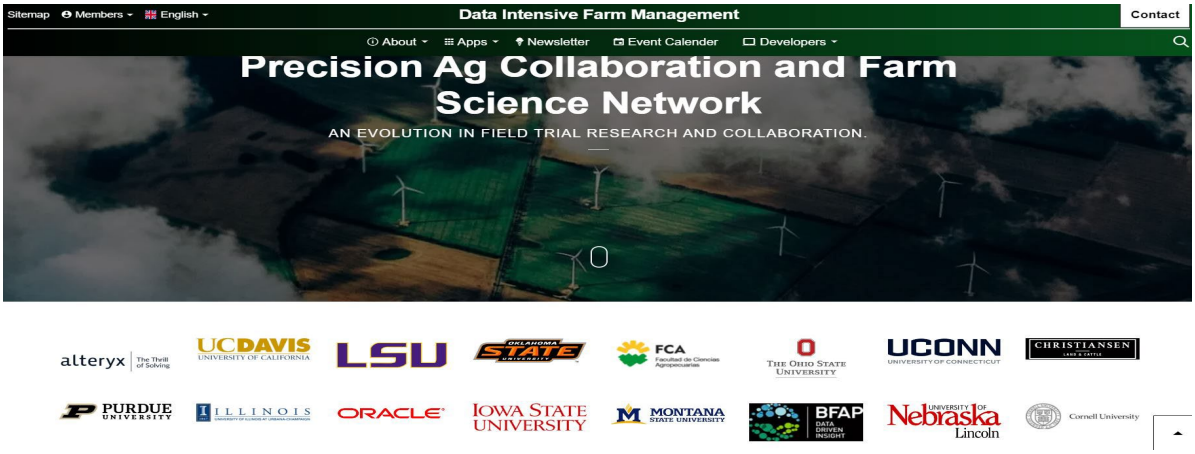
***Short-term Outcomes:*** *Quantitative, measurable benefits of the research outputs as experienced by those who receive them. Examples include the adoption of a technology, the creation of jobs, reduced cost to the consumer, less pesticide exposure to farmers, or access to more nutritious food.*

Several farmers expressed thanks to us for the information we provided them in our reports about the results of our analyses of their field trials. Some believed that the management implications of the data analyses would increase their farms' profits by thousands of dollars per year. It is too early in the project to measure how great these economic gains actually are. We are designing a research cyber-infrastructure that will benefits farmers more and more as the number of experiments and numbers of years of experiments increases. Eventually, we will design the trials to provide data to test hypotheses about whether the information farmers

receive from analyses of their trials increases their profits. Those kinds of statistical tests will be possible over the next few years, but for now we can only rely on anecdotal evidence.

**Outputs:** Defined products (tangible or intangible) that are delivered by a research project. Examples of outputs are reports, data, information, observations, publications, and patents.

We launched a live website (work in progress): Frontiers in On-Farm Precision Ag Experimentation (difm-cig.org) that will be the primary base of our online presence. This website will not only be available for the public to find all information related to our project, trial participants to sign up, and more - but also have a backend for project members to login and communicate. See Figure 1




**Activities:** Organized and specific functions or duties carried out by individuals or teams using scientific methods to reveal new knowledge and develop new understanding.

**Milestones:** Key intermediate targets necessary for achieving and/or delivering the outputs of a project, within an agreed timeframe. Milestones are useful for managing complex projects. For example, a milestone for a biotechnology project might be "To reduce our genetic transformation procedures to practice by December 2004."

In the past 6 months the following has been completed:

- *Large field Farm Trial Design Database Tables and backend is complete. ETL – Import Scripts for Ag Data were built and modified to import legacy farm data.*
- *Database for DIFM – CIG completed ready to store Yield Data, AsApplied Data, Protein, Farm, Field geometries. Spoke with nearly 60 software firms to develop our Ag App. Presented top 10 proposals.*

- *Created wireframe for Trial Design and Farmers Portal portion of the Software Application. Documented database tables and columns meta-data with descriptions, documented tables, and the database.*
- *Production version of website SSL, and https:// is installed and operational. Authored web content and design for difm-cig.org.*

**Impacts:** This section focuses on actual or intended potential long-term outcomes and impacts. Committees should build information around the activity's milestones, as identified in the original proposal. The report should also reflect on the items that stakeholders want to know or want to see. List any grants, contracts, and/or other resources obtained by one or more project members as a result of the project's activities. Include the recipients, funding source, amount awarded and term if applicable. If the committee is filing an annual report, the impacts will cover only the current year of the project, for termination reports, list impacts from the entire span of the project.

**Activities:** Organized and specific functions or duties carried out by individuals or teams using scientific methods to reveal new knowledge and develop new understanding.

- Established a successful bi-weekly seminar series that started in May 2022. Several project participants and students presented their research which helped keep other project members connected and on the work we're doing. We plan to continue this throughout the remainder of the project as we found it was a great solution to improving project communication.
- Principal Investigator David Bullock was invited to give in person a 60-minute presentation on on-farm experimentation at the Brazilian Precision Agriculture Conference (ConBap) in August 2022 in Campinas, Brazil (http://www.asbraap.org/conbap/ ). Over 600 farmers and agri-business people attended the talk.
- In September 2022, Principal Investigator David Bullock traveled to the 5th Annual Conference on Agri-Tech Economics for Sustainable Futures at the Global Institute for Agri-Tech Economics at Harper Adams University in Shropshire, England to give an invited Keynote Address on the economics of precision agriculture. (https://smartagrihubs.eu/latest-events/5th-Symposium-on-Agri-Tech-Economics-for-Sustainable-Futures)
- In February 2022, Principal Investigator David Bullock was invited to give and gave a webinar presentation about on-farm precision experimentation as part of Les Webinaires Grandes Culture series put on by the Quebec Ministry of Agriculture, Fisheries and Food. (https://www.youtube.com/watch?v=UsN0JEyXMx8&list=PLXP-9RICLI-OJt3Kjp-x6SILuur_dqUOE&t=296s ) Approximately 450 Canadian farmers, crop consultants and agronomists were registered for the webinar.
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**Milestones:** Key intermediate targets necessary for achieving and/or delivering the outputs of a project, within an agreed timeframe. Milestones are useful for managing complex projects. For example, a milestone for a biotechnology project might be "To reduce our genetic transformation procedures to practice by December 2004."

In NC1210's initial application, we were asked to replace Milestones with a timeline of each objective. Those objectives were listed as:

February 2021-2024. Second through Fifth All-Project meetings. Present, discuss research on analyses of earlier OFPEs. Discuss successes and challenges of project in previous year.
All-Project meetings were held in both January 2022 and January 2023. The 2022 meeting was held virtually. The January 2023 meeting was held in Corpus Christi, Texas. As described above, research presentations were made, and the group worked together to plan and coordinate our work for 2023. Discussion about project challenges in 2022 were discussed at length, and plans were made for overcoming those challenges in 2023.

Growing Seasons, 2021-2024. OFPEs conducted, including planting, fertilization, and harvests. Plant phenotype data collected using UAS and robots. Publicly available vegetative index data from satellites is collected.
In 2022 members of NC1210 conducted approximately 60 OFPEs. Data of the types described above were collected.

**Indicators:** Qualitative surrogate observations or indirect measures of quantitative performance measures which permit monitoring the achievement of outcomes when direct measurement of performance is difficult, too costly, or not possible. An indicator of cultivar adoption might be seed certification records, rather than actual land area planted to that cultivar.

Project progress was indicated by the 60 OFPEs that were designed and run, but the progress made in database development, the analytical engine, and in the trial design software.

**Publications:**

***Excel Sheet embedded: Double Click to view entire sheet*

| Key | Item Type | Publicatior | Author | Title |
|---|---|---|---|---|
| 6QMGDJHF | journalArti | 2022 | Hegedus, Paul; Ewing, Stephanie; Jones, Claim; | Using spatially variable nitrogen app |
| QCZWVBCC | conference | 2022 | Hegedus, Paul; Maxwell, Bruce | OFE is most meaningful to farm mana |
| 2TGKHDZH | conference | 2022 | Hegedus, Paul; Maxwell, Bruce | Constraint of Data Availability on the |
| NNI4K4D4 | journalArti | 2022 | Hegedus, Paul; Maxwell, Bruce; Mieno, Taro | Assessing performance of empirical n |
| 4ZU4RZ7V | presentatic | 2022 | Tibbs and Boerngen | Examining the perceptions of precisi |
| FB5ASUZP | journalArti | 2023 | Morales, Giorgio; Sheppard, John; Hegedus, Pa | Improved Yield Prediction of Winter |
| NT7FYLCK | conference | 2022 | Peerlinck, Amy; Morales, Giorgio; Sheppard, Jo | Optimizing Nitrogen Application to M |
| D4SBKJDL | conference | 2022 | Morales, Giorgio; Sheppard, John; Peerlinck, Ar | Generation of Site-specific Nitrogen F |
| 3V8JQCWF | conference | 2022 | Maxwell, Bruce; Hegedus, Paul; Loewen, Sasha; | Decision Support From On-Field Prec |

**References**


Giorgio Morales and John W. Sheppard, “Counterfactual Explanations of Neural Network-Generated Response Curves,” submitted to IEEE International Joint Conference on Neural Networks (IJCNN), January 2023.

Giorgio Morales, John W. Sheppard, Paul B. Hegedus, and Bruce D. Maxwell, “Improved Yield Prediction of Winter Wheat Using a Novel Two-Dimensional Deep Regression Neural Network,” *Sensors*, 23(1):489, January 2023.

Giorgio Morales and John W. Sheppard, Dual Accuracy-Quality-Driven Neural Network for Prediction Interval Generation, submitted to *IEEE Transactions on Neural Networks and Learning Systems*, November 2022.

Giorgio Morales, John Sheppard, Amy Peerlinck, Paul Hegedus, and Bruce Maxwell, “Generation of Site-specific Nitrogen Response Curves for Winter Wheat using Deep Learning,” *Proceedings of the International Conference on Precision Agriculture*, June 2022.

Amy Peerlinck and John W. Sheppard, “Addressing Sustainability in Precision Agriculture via Multi-Objective Factored Evolutionary Algorithms,” *Proceedings of the 14th Metaheuristics International Conference (MIC)*, July 2022.

Amy Peerlinck, Giorgio Morales, John Sheppard, Paul Hegedus, and Bruce Maxwell, “Optimizing Nitrogen Application to Maximize Yield and Reduce Environmental Impact in Winter Wheat Production,” *Proceedings of the International Conference on Precision Agriculture*, June 2022.

Amy Peerlinck and John W. Sheppard, “Managing Objective Archives for Solution Set Reduction in Many-Objective Optimization,” submitted to ACM Genetic and Evolutionary Computation Conference (GECCO), February 2023.

Shane Strasser, John Sheppard, Nathan Fortier, and Rollie Goodman, “Factored Evolutionary Algorithms,” *IEEE Transactions on Evolutionary Computation*, Vol. 21, No. 2, April 2017, pp. 281–293.