Helping farmers experiment with biologicals by adding data layers

Louis Longchamps[1], Fatimetou Toure[1], Shumei Cai[1], Phillip Lanza[1], Marcelo Chan Fu Wei[2], Alexander Yore[1], Alicia McElwee[1] & Daniel Buckley[1]

[1] *School of Integrative Plant Sciences, Cornell University, Ithaca, US*

[2] *Department of Biosystems Engineering (LEB), University of São Paulo, Piracicaba, Brazil*

LL928@cornell.edu

e-presentation

Abstract

While the nitrogen (N) cost for maize fertilization increases, new products, such as biologicals, may offer a cheaper and more sustainable alternative as an N source. Before applying a biological to their entire farm, farmers are eager to learn whether a product works for them. Based on the biological company's suggestions, the experimentation process consists of reducing the N rate by forty units in areas treated with biologicals and applying a full rate of N in the control area. If no difference is observed, this would indicate that the product works. This design leaves little room for interpretation for farmers looking at yield. A group of scientists from Cornell University proposed supporting their experimentation by collecting additional information, such as a crop's N status and the presence of the biological organism in the soil. The results of this current study showed that yield alone could not have provided a clear answer, and that this partnership between farmers and scientists proved beneficial in the farmers' learning process.

Introduction

Farmers conduct On-Farm Experimentation (OFE) to guide their actions and better understand how to manage their farms (Hansson 2019). This endogenous experimentation process tackles practical questions that are important for farmers to invest their own time and money in investigating them (Griffin et al., 2014). Despite the importance of this process in supporting change and the amount of information it generates, scientists often disregard endogenous experimentation as anecdotal and do not contribute to scientific knowledge (Bramley et al., 2022).

contextualized), endogenous experimentation remains a slow process that is prone to misinterpretation due to a limited number of observations and imprecise metrics (e.g., average yield of treated vs. control). It also remains highly context-specific and thus does not contribute to shared knowledge without a means of sharing contextualized data. With digital agronomy, there is the potential to scale the support of endogenous experimentation, which may accelerate the transition toward a sustainable food production system by streamlining the sharing of contextualized OFE observations (Lacoste et al., 2022; Toffolini and Jeuffroy, 2022).

This study hypothesized that supporting farmers with digital agronomy in their OFE can de-risk (better chances to learn) the on-farm use of results and render the results usable within observational research, thereby contributing to more generalizable knowledge. The objectives were to initiate an OFE project in New York to (1) evaluate the interest of New York farmers in conducting their experimentation in collaboration with scientists, and (2) gather new insights that could help farmers interpret their results beyond the total yield.

Material and methods

The on-farm experimentation context

In 2022, the rising prices of N motivated farmers to experiment with alternatives to supply N to their maize crops (Schnitkey et al. 2022; Merrigan 2022). One of these solutions was the addition of biological additives (i.e., N-fixing microorganisms) to the crop at planting, combined with a lower (about 40 kg N ha^{-1} less) rate of N as a side-dressing. Several farmers experimented with N-fixing biological additives (NFBAs) during the 2022 and 2023 seasons with the intent of lowering their N costs. They hypothesized that if there was no yield decrease in the areas where an NFBA was applied with a 40 kg N ha^{-1} reduction, this would indicate that the product works. Farmers indicated where on their farm they had placed their experiment. Farmers decided on the experimentation topic, design, and placement without any involvement from scientists.

Farmers' engagement

Farmers were identified by Cornell Cooperative Extension personnel and two providers of agronomy services. These agronomists, working closely with farmers, were aware of their experimentation and acted as liaisons to connect directly with the farmers. Fifteen farmers participated in this study for a total of twenty-two sites selected in the Western New York region in 2022 and 2023. This document shows the results from 2023 for sites in which a yield monitoring system was used (ten sites in 2023). Farmers were interviewed to learn about their experimentation, their motivations, and the questions that they were trying to answer with this experimentation process.

Data collection

At each site, four locations (two within the control area and two within the treated area) were visited for data collection at maize growth stages V3 to V6 and again at V7 to R1 (depending on the site). At each location, the plant population was measured five times along 2-m row sections, and aerial biomass (five entire plants were randomly selected) was collected. Dry biomass was measured, and total N (%) was analyzed by combustion using a Primacs SNC 100-IC analyzer (Skalar Analytical B.V., Breda, Netherlands). Also, 5 g samples of soil for analysis of microbial communities were collected from the soil attached to the roots of five plants at a depth of 7.5 cm, and one plant was sampled at depths 2.5, 7.5, and 15 cm. Rhizosphere soil samples were stored at -70°C until processing for quantitative polymerase chain reaction analysis (qPCR). Sampling geolocation was recorded with an Arrow Gold RTK GNSS receiver (EOS Positioning Systems®, Inc., Terrebonne, QC, Canada). All data were collected within a 3-m radius of the georeferenced location. In addition to the on-site data collection, information about crop management and remotely sensed Normalized Difference Vegetation Index (NDVI; Planet Scope, Planet Labs PBC, San Francisco, CA, USA) data were collected.

Data analysis

Participating farmers were interviewed for two hours using a semi-structured interview process. Preliminary analyses of the data revealed two main themes: 1) digitalization of farm management information and 2) OFE. While questions about farm digitalization were analyzed through a rigorous process and presented in a publication (Friedman et al. 2024), questions on OFE are currently being analyzed; therefore, preliminary results in the form of quotes are presented here.

A quantitative polymerase chain reaction was used to quantify the DNA of the NFBA from the rhizosphere samples. Soil rhizosphere DNA was extracted with the DNeasy PowerLyser PowerSoil kit following protocol from QIAGEN catalog no. 12255-50 (Qiagen N.V.®, Düsseldorf, Germany). The qPCR assay was found to have a detection limit of 1.5 x 10^4 gene copies per gram of soil; hence, rhizosphere samples were scored as positive for the NFBA when the number of gene copies detected exceeded this threshold. For each location, if any rhizosphere sample (at any depth, or any date) tested positive, the field was classified as positive for the presence of the NFBA. Remote sensing NDVI maps were used visually to better interpret the distribution of yield values outputted in the form of density plots.

Results

Farmer’s interest

All farmers who were contacted for this study accepted the invitation to collaborate without hesitation. The agreement was that they would indicate where the experiment was set up, provide crop management data for both the treated and control areas, and allow a research team to visit their field during the crop-growing season. Farmers appreciated this “low commitment” way of collaborating with scientists, with one farmer mentioning, “The more people looking at my data, the better.” Another farmer mentioned, “We run side-by-side experiments and compare total yield using data coming out of the weight wagon.” This illustrates the kind of observations that farmers use to make business decisions and demonstrates that scientists may be able to support their processes with digital agronomy to reduce the risk of misinterpretation. Farmers may be more inclined to collaborate with scientists when they can implement their own experimental design rather than a prescribed one.

Experimentation results

Figure 1 shows that an NFBA was detected in six out of ten fields harvested with a yield monitor in 2023. The higher yield was not systematically aligned with the presence of an NFBA in the rhizosphere, which could have been misinterpreted by farmers without additional data collected in this OFE project. For instance, in Fields 5 and 12 (Fig. 1), farmers may have interpreted that the product did not work because the yield was slightly lower in the treated area. This could be correct, or it may be related to mishandling the product or to weather conditions at crucial stages for adequate colonization of the roots. Similarly, Fields 13 and 23 (Fig. 1) showed no difference in yield, as anticipated from the experiment’s hypothesis, which indicates that the product works. However, when looking at the presence of the microorganism in the rhizosphere, it was undetected. Our inability to detect the NFBA in all sites where it was applied suggests that it did not colonize plant roots equally in all farms. A lack of persistence could be caused by many factors, including mishandling of the product, a dose that is too low, or soil properties, such as pH or SOM, that may not be conducive to efficient colonization.

In the sites where the NFBA adequately colonized plant roots (i.e., Sites 3, 14, 19, 20, 21, and 24), the yield outcome was inconsistent. While in most sites no apparent yield difference was observed, which is consistent with the experiment’s hypothesis, in site 21, the control area clearly showed lower variability and higher yield relative to an NFBA treatment, thus triggering additional questions for interpretation. Upon looking at remote sensing data (NDVI generated from Planet Imagery on July 7, 2023) and at the yield map (Fig. 2), it appears clear that the treatment area for this field was located in a lower-performing region of the field, indicating that this result was due to inherent spatial variability at the site rather than to treatment effects. Again, yield alone may have misled the interpretation of the results, showing that when scientists support farmers in their experimentation by adding layers of data, such as would be done in conventional research, it helps farmers better interpret the outcomes of their experiments.

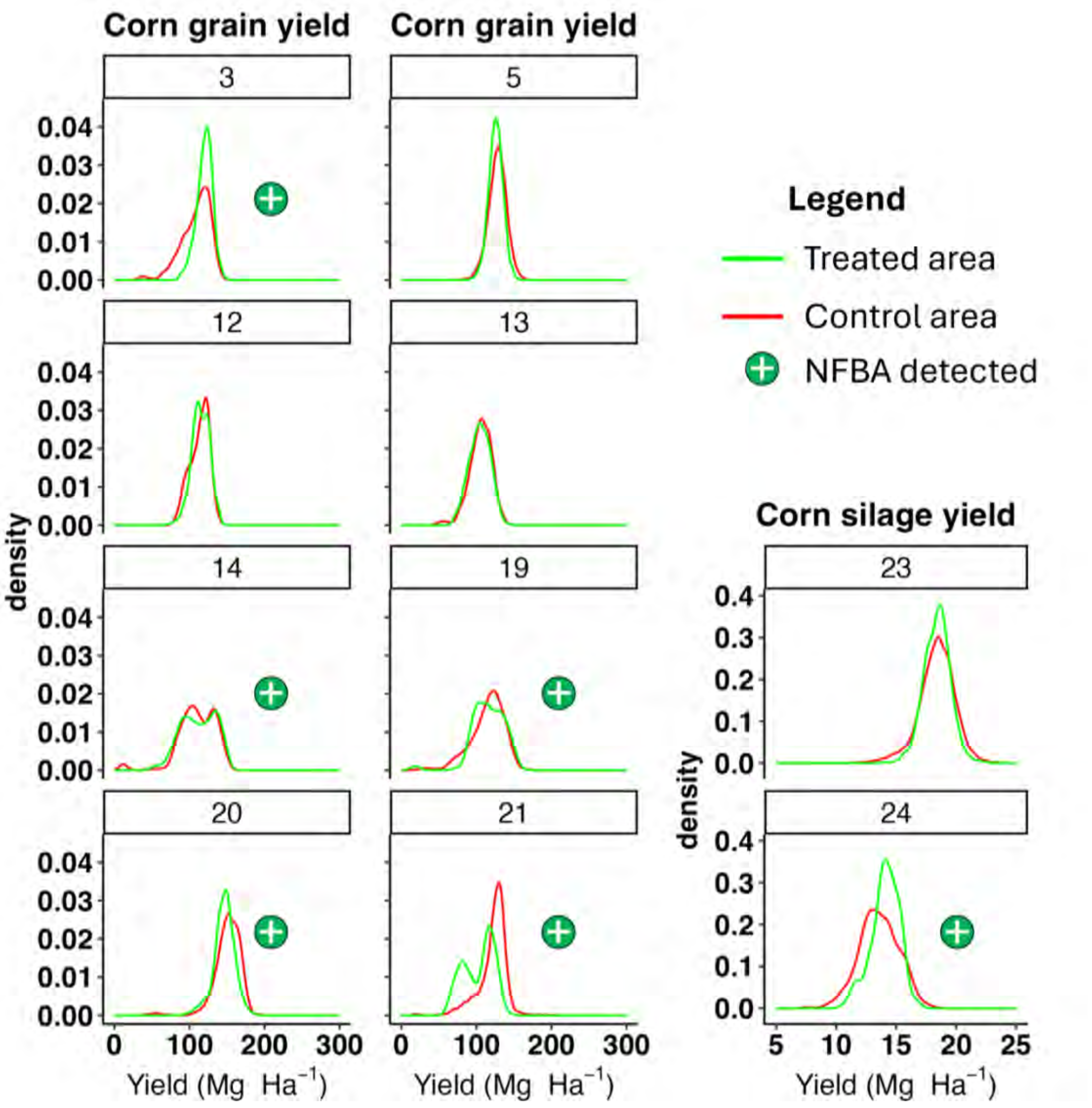

Fig. 1 I Density plots of the 2023 yield data coming from either the control (red) or treated (green areas). The white and green cross dots indicate the presence of the NFBA as detected by qPCR analysis. The numbers indicate site number and only results for the site where yield monitor data is shown here. The blue line of Field 12 shows the result of an additional treatment of an NFBA application with no N fertilizer added.

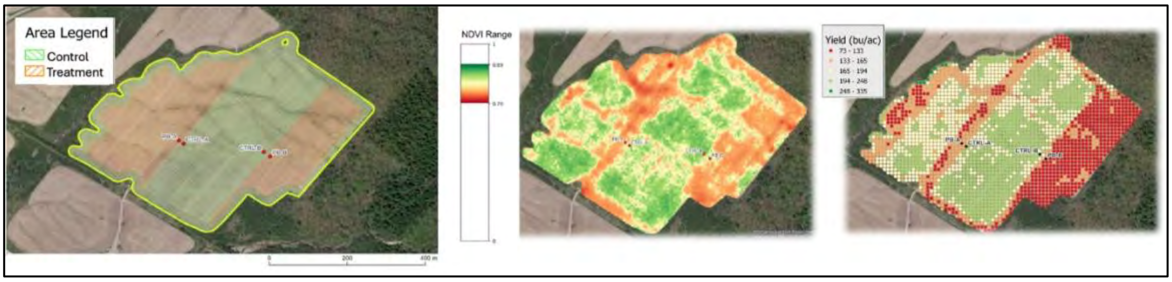

Fig. 2 I Maps showing spatial variability of NDVI and yield for Site 21

Conclusion

To adopt new practices and inputs that will lead to sustainable agriculture, farmers must conduct OFE. Scientists can support the farmer-led OFE process by adding layers of meaningful data that will help interpret farmers' observations. In this current research project, an N-fixing biological additive was tested on twenty-two fields where farmers compared control (full N dose and no NFBA) to treatment (addition of an NFBA at planting and reduction of 40 kg N ha^{-1}) based on total yield to assess the efficacy of this product. The qPCR analysis results and NDVI maps showed that additional insights can help farmers better interpret their observations. Observing OFE also has the potential to provide scientists with a wealth of contextualized data to rapidly evaluate the performance and context interactions of tools, approaches, and inputs that can be conducive to sustainable cropping systems.

Acknowledgments

Special thanks to Erik Smith, Mike Stanyard, Jodi Letham, Avery DeGoyler, and Tim Lewis for identifying participating farmers. This project was funded by the Cornell Institute of Digital Agronomy and the Cornell University Agricultural Experiment Station.

References

Bramley, R. G. V., Song, X., Colaço, A. F., Evans, K. J. & Cook, S. E. (2022) Did someone say "farmer-centric"? Digital tools for spatially distributed on-farm experimentation. *Agronomy for Sustainable Development*, *42*(6), 105. https://doi.org/10.1007/s13593-022-00836-x

Cho, J. B., Guinness, J., Kharel, T., Maresma, Á., Czymmek, K. J., van Aardt, J. & Ketterings, Q. M. (2021) Proposed method for statistical analysis of on-farm single strip treatment trials. *Agronomy*, *11*(10), 2042. https://doi.org/10.3390/agronomy11102042

Cook, S., Cock, J., Oberthür, T. & Fisher, M. (2013) On-farm experimentation. *Better Crops Plant Food*, *97*, 17–20.

Cordero, E., Longchamps, L., Khosla, R. & Sacco, D. (2019) Spatial management strategies for nitrogen in maize production based on soil and crop data. *Science of the Total Environment*, *697, p.133854.*

Friedman, N., Tan, Z., Haskins, M. N., Ju, W., Bailey, D. & Longchamps, L. (2024) Understanding farmers' data collection practices on small-to-medium farms for the design of future farm management information systems. *Proceedings of the ACM on Human-Computer Interaction*, *8*(CSCW1), 1–28.

Griffin, T. W., Mark, T. B., Dobbins, C. L. & Lowenberg-DeBoer, J. M. (Eds.). (2014) Estimating whole farm costs of conducting on-farm research on Midwestern US corn and soybean farms: A linear programming approach. *International Journal of Agricultural Management, 4(1), pp.21-27*. https://doi.org/10.22004/ag.econ.262338

Hansson, S. O. (2019) Farmers' experiments and scientific methodology. *European Journal for Philosophy of Science*, *9*(3), 32. https://doi.org/10.1007/s13194-019-0255-7

Lacoste, M., Cook, S., McNee, M., Gale, D., Ingram, J., Bellon-Maurel, V., et al. (2022) On-farm experimentation to transform global agriculture. *Nature Food*, *3*(1), 11–18. https://doi.org/10.1038/s43016-021-00424-4

Laurent, A., Kyveryga, P., Makowski, D., & Miguez, F. (2019). A framework for visualization and analysis of agronomic field trials from on-farm research networks. *Agronomy Journal*, *111*(6), 2712–

2723. https://doi.org/10.2134/agronj2019.02.0135

Leal, M. & Losos, J. B. (2015) A naturalist's insight into the evolution of signal redundancy. *The American Naturalist*, *186*(4), ii–iv. https://doi.org/10.1086/682704

McFadden, J., Njuki, E. & Griffin, T. (2023) Precision agriculture in the digital era: Recent adoption on US Farms US Department of Agriculture, Economic Research Service 248. 2023. Available online: **https://www.ers.usda.gov** . Accessed on 21 August 2024.

Merrigan, K. (2022) Opinion: With sky-high fertilizer prices, there's an opportunity to grow crops more sustainably. *Modern Farmer*. https://modernfarmer.com/2022/06/fertilizer-prices-sustainable-crops/. Accessed 25 January 2024.

Nleya, T., Chungu, C. & Kleinjan, J. (2016) Corn growth and development. *Grow Corn Best Management Practices,* pp. 5-8.

Plénet, D. & Lemaire, G. (1999) Relationships between dynamics of nitrogen uptake and dry matter accumulation in maize crops. Determination of critical N concentration. *Plant and Soil*, *216*(1), 65–82. https://doi.org/10.1023/A:1004783431055

Riedell, W. E. (2014) Nitrogen fertilizer applications to maize after alfalfa: Grain yield, kernel composition, and plant mineral nutrients. *Journal of Plant Nutrition*, *37*(12), 2026–2035. https://doi.org/10.1080/01904167.2014.911892

Schnitkey, G., Zulauf, C., Paulson, N., & Baltz, J. (2022) Outlook for nitrogen prices in spring 2023. *Farmdoc Daily*, *12*(168).

Toffolini, Q. & Jeuffroy, M.-H. (2022) On-farm experimentation practices and associated farmer-researcher relationships: A systematic literature review. *Agronomy for Sustainable Development*, *42*(6), 114. https://doi.org/10.1007/s13593-022-00845-w

Trevisan, R. G., Bullock, D. S. & Martin, N. F. (2021) Spatial variability of crop responses to agronomic inputs in on-farm precision experimentation. *Precision Agriculture*, *22*(2), 342–363. https://doi.org/10.1007/s11119-020-09720-8

Ziadi, N., Brassard, M., Bélanger, G., Cambouris, A. N., Tremblay, N., Nolin, M. C., et al. (2008) Critical nitrogen curve and nitrogen nutrition index for corn in eastern Canada. *Agronomy Journal*, *100*(2), 271–276. https://doi.org/10.2134/agronj2007.0059