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On-Farm Research: Experimental Approaches, Analytical Frameworks, Case Studies, and Impact

Peter M. Kyveryga*

ABSTRACT

On-farm research is becoming widespread due to a growing interest among farmers, agronomists and the research community. While the concept of on-farm research is not new, the scale and influence of on-farm studies conducted by farmers in partnership with industry and university researchers are expanding. New technologies, tools, and analytical approaches are rapidly evolving to advance the reach and impact of on-farm research. Papers in this special issue include the use of on-farm testing to increase economic and environmental sustainability in Africa and South America, the development of a new analytical collaborative frameworks for better summarization, visualization and communication of research results, and a new analytical approaches based on Bayesian hierarchical and multivariate analyses that can be used to assess complex relationships between management, genetics, soils, and the environment. Simulation approaches were also tested to identify the most efficient experimental designs and estimation methods of statistical parameters. In all situations, on-farm research leads to improved productivity, better economics, higher adoption of conservation practice and greater farmer satisfaction.

Core Ideas

- Precision agriculture technology adoption benefits on-farm research expansion.
- New analytical and visual frameworks aid in farmer decision making.
- On-farm research reduces barriers to adoption of new management techniques.
- On-farm research increases farmer interest and motivation.

INTRODUCTION

On-farm research and participatory learning are becoming standard practices due to their facilitation through new technologies and farmers' growing interest in local results. While the concept of on-farm research is not new, the scale and impact of on-farm studies conducted by farmers in partnership with industry and university researchers is expanding due to demonstrated improved crop and land management with greater productivity.

New technologies, tools, and analytical approaches are rapidly evolving to enhance on-farm research. The papers in this issue cover a range of topics. Almost every study found that on-farm data collection and analyses enhanced farmer experience and their satisfaction in participatory learning through improved productivity and economic performance and it increased their adoption of conservation practices. In addition, this special issue contains papers that showed how to improve data analyses and summarization of a large number of experiments containing similar treatments across years and locations.

Precision Agriculture Technology Tools and Farmer Motivation through On-Farm Research

On-farm research has expanded rapidly during the last two decades, especially in developed countries. This increase is attributed to an increase in the wider use of precision agriculture (PA) technologies. Technologies in the PA tool box such as yield monitoring, Global Navigation Satellite Systems (GNSS), light bars, auto guidance, and variable rate devices enable farmers and researchers to conduct on-farm experiments at a field scale, in multiple locations and at much lower cost. Extensive analyses of private and government survey data collected in different countries around the world showed that GNSS, sprayer boom control and planter shutoffs technologies have been adopted at the highest rates (Lowenberg-DeBoer and Erickson, 2019). Surprisingly, variable rate technologies, one of the main and original components in the PA tool box, have not been widely adopted by farmers. On a whole country or regional basis the adoption rate rarely exceeds 20% of farmers. In the United States, 2016 data showed that 54% of maize farms have a yield monitor but only 32% use yield maps, in part due to the difficulty in interpreting the reasons for yield variability within fields. The largest PA adoption gap is the low rate of uptake by small and medium size farmers in developing countries, due in part to their lack of mechanization and also the cost of PA. In the future, on-farm research has

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Abbreviations: GNSS, Global Navigation Satellite Systems; PA, precision agriculture.

tremendous potential especially in developing countries, as PA technologies become less expensive and more adopted.

A study from Nebraska was focused on farmer motivation in on-farm research and on-farm study impact (Thompson et al., 2019). In-depth interviews of 40 participants of the Nebraska On-Farm Research Network and qualitive summaries of the survey data revealed that farmers conducted on-farm trials mainly because of the potential to increase profit, general curiosity and the need for unbiased results. The farmers responded positively to interaction with university researchers and other farmers. About 75% of those farmers interviewed indicated that they made changes on their farms due to on-farm study participation or confirmed that their practices do not require changes. Researchers proposing topics and ideas to farmers did not appear to diminish the farmers' experiences compared to farmers generating ideas themselves; however, farmers expressed the desire to be more involved in all phases of conducting an on-farm research project.

Analytical Approaches for On-Farm Trials

One of the critical components of on-farm research is to effectively analyze and summarize study outcomes and communicate results to farmers and agronomists. There are several on-farm research networks across United State that conduct on-farm strip trials with farmers. These networks are affiliated with university extension, private companies or grower associations. Often, results of these on-farm trials are presented to farmers as individual field reports in electronic or hardcopy format. There is a need for developing a new analytical data framework to make better informed management decisions using on-farm strip trial data. Researchers from Iowa have developed an analytical framework called the "Interactive Summary of On-Farm Strip Trials" (ISOFAST) (Laurent et al., 2019). The analytical component of the online tool is based on Bayesian Hierarchical analyses of treatment yield differences or yield ratios and the visual component is based on RShiny dynamic and interactive graphics. The tool is based on more than 2500 on-farm replicated strip trials on corn and soybean conducted during the last 15 yr and is publicly available and providing users with dynamic graphics that better communicate statistical summaries and yield differences. The tool also provides break-even economic analyses using cost and price inputs that can be adjusted by users. The dynamic summaries also include summaries of scouting, soil and tissue observations and online downloadable reports for aid in decision making by farmers and agronomists. This tool can help researchers and users understand better complex relationships between treatments, weather, and management.

On-farm trials with wheat have additional complexity because of the need to consider grain quality and complex interactions that are common in different types of agricultural and, specifically in on-farm experiments. A study from Mexico has proposed a statistical method to analyze of bread and durum wheat on-farm trials conducted by the International Maize and Wheat Improvement Center (CIMMYT) to quantify Genotype and Environmental interaction expressed as farmer-irrigation-year combinations (Hernández et al., 2018). The proposed method is based on Linear Mixed Model and Factor Analyses to identify crossover interaction and non- crossover components of the genotype × environment. Analyses were successful in separating the dynamic (unpredictable) component (year) from the more static component of the interaction due to farmer, irrigation level, and wheat lines across all environments. Using on-farm trials with wheat from the Yaqui Valley of southern Sonora, México, the same group of researchers used multivariate Bayesian analyses to estimate random effects of Genotype × Environmental and Genotype × Environmental and Trait combinations (Montesinos-López et al., 2018). Compared with traditional methods to analyze similar data from breeding on-farm trials, this analytical method allows more precise and simultaneous estimation of random effects and genetic and residual correlations of different wheat traits.

In developed countries, on-farm research is often done using GNSS enabled combine yield monitors to produce crop maps from spatially variable fields overtime. A study from New York used 847 fields, a total of 9084 ha, from six dairy farms to map and analyze silage corn (*Zea mays* L.) yield maps and derive yield variability-based management zones (Kharel et al., 2019). Corn silage yield across years was aggregated into 10-m by 10-m grid-cells that were classified into four categories. Two categories had consistently higher or lower yields than the farm average yield, category three had variable but higher yield than the farm average; and the last category had variable but lower yield than the farm average. Analyses showed a relatively low correlation between spatial and temporal variability, indicating the need to consider both factors for developing management zones. The area per farm classified as variable (Q2 and Q3) ranged from 30 to 44%, illustrating the importance of implementing precision agriculture technologies and in-season management adjustments.

There are many choices of experimental design and statistical analysis for on-farm experiments. Simulation study was focused on assessment accuracy, bias and Type I error of the hypothesis testing of 10 on-farm experimental designs and 27 estimation methods of statistical parameters (Alesso et al., 2019). The simulations have shown that the structure of the on-farm experiments, experimental design and estimating method did not have substantial effect on the overall treatment mean. Efficiency of estimating statistical model parameters has increased and Type 1 Error rates have increased with higher spatial autocorrelation. However, accuracy of estimation has increased with more replication and treatment randomization increased the variance of estimated parameters. Split-plot, chessboard or strip trials were the most efficient design for two-treatment on-farm experiments.

A multi discipline "Data-Intensive Farm Management" project is focused on developing a research framework to conduct randomized agronomic field trials testing multiple factors in farmers' fields using precision agriculture technologies (Bullock et al., 2019). Currently the framework is being tested across nine U.S. states, and in Argentina, Brazil, and Colombia. Additional objectives are to develop a cyber infrastructure to allow collaborative efforts of different research disciplines to design and implement on-farm trials, process, manage and analyze data and make better and efficient agronomic decisions.

On-Farm Research Encourages Participatory Learning

On farm research can involve direct engagement with farmers to support research relevance, and to enhance adoption. Researchers from Michigan State University described two case-studies that involved mother-and-baby trials conducted with small holder farmers in Malawi and under intensive agriculture systems in Michigan (Snapp et al., 2019). Productivity, environmental, and economic domains were presented via radar charts. In Malawi, a mesic site was associated with steep sustainable agriculture tradeoffs compared with a marginal site. In Michigan, diversity in tillage practices, field crop performance, and soil health were affected by local environment. Farmer participatory learning lead to greater adoption and greater farmer satisfaction.

Farming in southern Africa is subject to multiple external risk factors in addition to soil degradation, declined soil fertility and climate change. To optimize resource allocation, it is important to know where conservation practices outperform conventional practices and should be scaled for larger regional benefits. A study conducted with 17 communities, 883 farms in three agro-ecological regions in Mozambique, assessed how different conservation practices affect risk preference of small holder farmers and farm economic returns (Kidane et al., 2019). Compared with conventional tillage, maize yields were higher, and variability was lower with conservation tillage practices at low and high elevation zones. Power utility analyses showed that direct seeding technology was preferable at higher elevations. For extremely risk-averse farmers, conventional practices could be preferred at low altitudes.

On-farm research is critical to quantify the benefits of various conservation practices, especially in vulnerable regions of the word (Barrera Mosquera et al., 2019). Farmers' fields in Ecuador's Andean highlands with excessively high rates of soil erosion and rapid declines in crop productivity were used to study the impact of surface water deviation ditches, reduced tillage, retention of crop residue on the soil and reduced nitrogen rates on yield and farm profitability with improved crop rotations. Analyses showed that crop productivity and economic returns in a long-term potato-pasture system have increased by 21% using tested conservation compared with traditional farming practices. Short-term economic benefits were detected at the beginning of the project that aided in greater interest and adoption by farmers of the conservation practices.

Demonstration on-farm trials on farmer fields can be effective in adoption of drought tolerant maize hybrids in Sub-Saharan Africa. Approximately 5000 demonstration plots of 39 drought tolerant hybrids were tested on farmers' fields in Kenya (Obunyali et al., 2019). Drought impact on maize yield could be reduced by planting drought tolerant hybrids. Results were discussed at about 250 field days and workshops with local farmers, increasing the chance of adoption and that farmers will continue use drought tolerate seeds in the future.

SUMMARIES AND CONCLUSIONS

This collection of 12 papers demonstrates advancements and experiences in on-farm research and farmer participatory learning in North and South America and Africa. Examples presented include different data collection, data summarization and visualization frameworks, decision management aid tools and community approaches through farmer networks and collaboration among farmers and researchers. In the future, on-farm research will continue to contribute to the body of knowledge in different disciplines and will aid in adoption of conservation practices and technologies to improve the economic wellbeing of farmers and the sustainable development of local communities.

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