# On-Farm Experimentation

By Simon Cook, James Cock, Thomas Oberthür and Myles Fisher

**The authors examine how farmer experimentation differs from 'conventional' experimentation, and how it might be reintegrated with conventional science and help in improving soil management. The focus is on the competence of farmers in using on-farm experimentation built around their experiences and an approach of "operational research", based on the observation and analysis of farm operations so as to improve them, to manage crops better.**

Rich Bennett, who raises corn, soybeans, wheat and cover crop seed in Napoleon, Ohio, relies on research to support his management… but not just research from professional scientists outside the farm. Bennett experiments on-farm, using his own equipment and land (Sare, 2004). The value in on-farm research, he said, is gaining information you can trust. "A farmer will learn more about his soils and stretch to be more efficient," said Bennett.

Experimentation has been a part of farming for millennia, as farmers experimented on their own land with the entire gamut of manageable factors that comprise farming practice. The change supported by this kind of experimentation could be quite rapid, such as in parts of Europe between the 17th and 19th centuries that saw multiplication of crop and livestock productivity through the adoption of institutional and technological change. Industry at this time was also growing rapidly. However, scientific principles could not be applied to farming in the same way as they were applied to industry because of the confounding underlying variability of the natural landscape and the consequent 'disorganized' nature of farming. This uncontrolled variation due to the many site and time-specific effects was a major impediment to the development of agricultural science. In the early 20th century, Fisher and co-workers at Rothamsted developed methods of statistical analysis to clarify experimental treatment effects within the field. This had a huge impact on agricultural research that continues to this day. Yet, as with all scientific methodologies, there is a risk that the method starts to define the problem. Scientists can place more value on the information about the quantifiable effects of factors and discount information about the farming environment in which they occur. Under this scenario, the effects of factors are known, while the interaction with the farmed landscape less so.

This of course, moves agricultural knowledge towards generalizable 'scientific' statements that are true within the bounds of experimentation. But it moves knowledge away from the competence that farmers need to manage particular conditions that exist on-farm. In this way, farmer experiments were left behind and the knowledge they demonstrated was relegated to 'demonstrations' that were considered non-scientific (Maat and Glover, 2012). Where the problem can be defined by a limited set of factors, on-farm research can be astonishingly effective and has underlain the growth of agricultural production. However, the approach leaves a huge proportion of variability unexplained. The highly competent farmer, or those supported by advisers, may be able to bridge the gap between the 'scientific' world of factors and the more complex world of farm management. But many farmers find insights from formal experiments difficult to apply.

**Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; OFE = on-farm experimentation.**

## Why Farmers Experiment?

Experimentation is defined as a process of discovery, hypothesis testing, or demonstration. We consider this to be the domain of scientists, yet practitioners also experiment. They do so to try out new things or to adapt an idea to their situation. This type of experimentation, which is in essence the collection of information, is not reported in the literature and is generally not considered to be research. In both cases, the purpose of experimentation is to reduce uncertainties. We use the framework of Rowe (1994) to explain how. This framework classifies decision uncertainty generally according to four categories: translational, structural, metric, and temporal.

Both scientists and farmers experiment to reduce uncertainty, but they give different priority to different types of uncertainty (**Figure 1**). For example, translational uncertainty (i.e., the contrast between sets of values and meaning of information) is a serious concern to farmers who must consider all factors relevant to a decision, even if they only apply beyond the farm gate. For example, the decision of a farmer to sow a certain variety of crop depends not only on the expected yield but also on factors such as price and availability of seed. By contrast, scientists refer less to external values, in order to

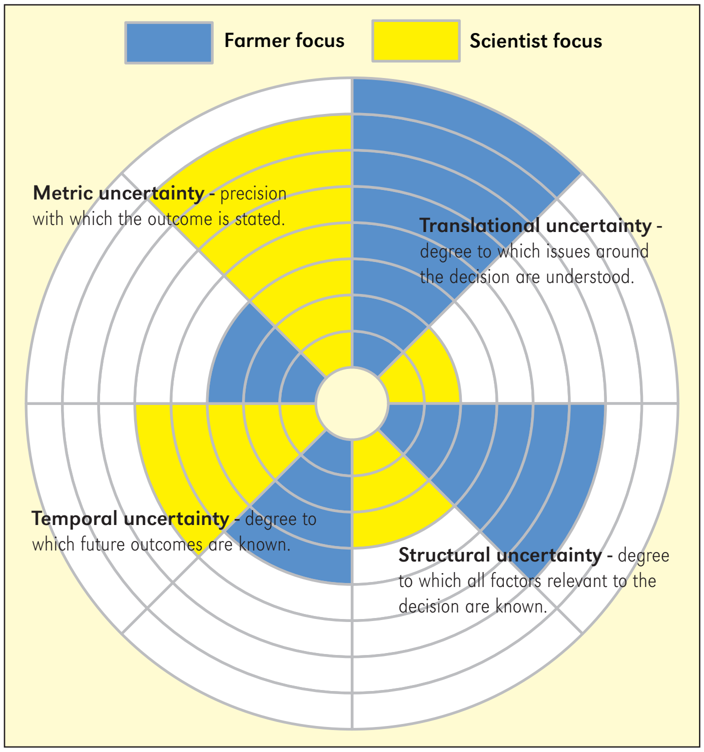

**Figure 1.** Farmers and scientists focus on different kinds of uncertainty.

focus on clarity of result. Translational uncertainty is reduced by knowledge of the desired outcomes of decisions. Based on experience, good farmers can predict the outcome of decisions with reasonable certainty, despite a wide range of confounding uncertainties. The scientist experimenter will want to reduce these to a limited number of generalizable conditions that can help define the relevance of experimentation.

Scientists often reduce structural uncertainty (i.e., uncertainty caused by variations in the completeness with which people describe systems) by pre-defining part of a system as an object of experimentation, for example, by locating experimental plots in sites selected to avoid complicated terrain. Farmers, conversely, are obliged to manage their farmland as they find it and modify their practices to fit the variation, rather than ignore it. This can be handled during on-farm experimentation by resisting, as far as possible, the temptation to reduce the scope of experimentation to the point at which it ceases to represent 'normal' management.

Conversely metric uncertainty (i.e., uncertainty caused by the difficulty of measuring the state of an attribute) is of greater concern to scientists than structural uncertainty. Agricultural scientists can seek a clear, unambiguous statement of treatment effects far beyond the precision needed by farmers. Virtually all scientists learn statistical analysis to identify improvements that are frequently quite small, and often irrelevant for farmers given the magnitude of uncertainties stemming from non-metric variation.

Similarly, farmers also handle temporal uncertainty (i.e., uncertainty related to past and future events, which influences the relevance of insight gained from long-term observations), but through experience of prior events and conservatism. For example, farmers who live in areas with a strong influence of the El Niño will design a robust strategy that ensures that even if there is a El Niño year they will not face a total disaster, whilst at the same time providing them with an acceptable result in a non-El Niño year. Thus, farmers will use the experience of an El Niño year to design their strategy, but will not base this strategy solely on the results from the El Niño year.

The aim of on-farm experimentation is to enable farmers to improve their competence in terms of metric and temporal uncertainty, whilst at the same time allowing them to take into account their existing strengths of handling translational and structural uncertainty. **Table 1** summarizes these complementary approaches to uncertainty.

**Table 1.** Comparison of scientist and farmer approaches to experimentation.

| Scientist-based | Farmer-based |
|---|---|
| Focus on one or two factors for maximum clarity | Multiple-factors included for maximum realism |
| Assumes insignificant interactions with other factors | Strong interactions observed between other factors |
| Intended to provide insight for all individuals | Intended to provide insight for specific individuals |
| Intended to provide insight for specific features | Intended to provide insight for all features present |
| Deals with abstract / invisible attributes | Deals with tangible / visible attributes |
| Hypothesis driven | Outcome driven |
| Focus on accuracy | Focus on relevance |
| Experimentation to address specific questions | Experimentation as a continuous learning process |
| Artefact/technology-focussed: deriving optimal parameters for individual technologies | System focussed: optimizing performance for sustainable profits |
| Analyses of average response | Analyses of processes |

There are two underlying principles for the proposed use of on-farm experimentation and operational research. The first principle is heuristic (experience-based): each and every time a farmer prepares a field, plants and manages a crop, he observes and experiments with a unique set of conditions (Cock et al., 2011). Thus, farmers are continuously, although often unconsciously, experimenting as they manage their crops to cope with the changing circumstances, which are a feature of agriculture. The second principle is cognitive (information-based): farmers frequently try to answer specific questions by consciously experimenting on their farms. Farmers do not necessarily attempt to provide propositional knowledge—the why—in either case. In the former case they let their competence guide them in managing their crops according to the particular social, economic and environmental conditions that occur. In the latter case, they wish to increase their competence by obtaining knowledge based on deliberate experimentation that can help them manage variation in the future. The observations of both, conscious experimentation and day-to-day variation in management, are obviously most valid for the farm on which they are produced, but at the same time can be used by others under similar conditions, and may also prompt more conventional experiments. Thus, observations of on-farm experimentation apart from their immediate and direct effect on farm management may encourage scientists to bridge the boundaries between 'formal' science and farming practice. The bridging of this gap and the direct use of the results of on-farm experimentation can reduce management uncertainties and allow farmers to make informed decisions.

## Recent On-Farm Experimentation Examples Relevant to Soil and Nutrient Management

### Using Precision Agriculture Technology for Fertilizer Application in Australia

Precision agriculture (PA) technology was applied to broadacre grain farming in Australia in the early 1990s (Cook et al., 1999). Scientists realized that while PA could support the goal of the 4R Nutrient Stewardship philosophy, however the concepts of prescription farming being promoted at that time were less appropriate in a farming landscape over which the average farm-size was greater than 2,000 ha. But farmers were keen for change and used PA to install full-scale experiments, borrowing the concept of on-farm experimentation from operations research (Cook et al., 1999). Where farmers had it, variable rate technology (VRT) was used to install fertilizer experiments over entire fields covering 100's of hectares according to mega-replicated designs. Where VRT was not available, designs were restricted to strips or other easy-to-install designs. In all cases, yield maps were analyzed to determine the effects of treatments

(Bramley et al., 1999). The concept is simple: identify controllable and non-controllable sources of variation, vary one or more of the latter as desired by the grower, and determine the effect. The goal is less to understand than to observe. The principle is one of continuous improvement through experimentation.

### Recommendations in Variable Colombian Sugarcane Production Systems

The influence of weather at the time of the previous harvest on the yield in the following ratoon crop is of great interest. Growers for years had been aware of the potential loss in yield of ratoon crops, which were damaged during the previous harvest, but no solid experimental data existed to quantify the effects and relate them to harvesting conditions. Reduced production has long been attributed to damage to the stools and soil compaction at harvest under wet conditions, but it has been impossible to quantify these effects using controlled experiments. The Colombian Sugarcane Research Centre (Cenicaña) collected and compiled data on almost all the fields harvested in the large Colombian production region (Cock and Luna, 1996, Isaacs et al., 2007). The basic premise is that farmers or growers are constantly producing crops under a wide range of management practices and varied growing conditions, and that a structured interrogation of their observations can lead to improved management (Cock et al., 2011). The analysis of these commercial data indicated that, with all other things being equal or held constant, for every 100 mm of rainfall in the month before harvest, the production of the succeeding sugarcane crop is reduced by 8 t cane/ha.

Several specific observations can be derived from the two experiences we have related here:

1. Farmers were extremely enthusiastic about designing and carrying out their own experiments, which were generally implemented at low additional costs. In the Australian case, one farmer with whom researchers had agreed to install 12 experiments decided to double the number of experiments, much to the consternation of the data analyst, who initially could make no sense of the data over 'normal' areas that had, in fact, received experiments. Similarly, the experience in the Colombian sugar industry suggests that farmers believe in the results, as there is no gap between experimental plots and commercial fields, and no need for validation trials (Cock et al., 2011), and technology transfer through farmers groups is facilitated due to high credibility of the generated knowledge (Isaacs et al., 2007).
2. Farmers often valued the results of experiments designed to elucidate one problem to understand other aspects of their farm operations. In the Australian case, a P-experiment led the grower to see that he needed to address a micronutrient deficiency. Another farmer deduced from an N experiment that he had K deficiency. A third used the results of an experiment of crop varieties to contrast their performance on good and poor soils. A fourth used a K x N experiment to understand the impact of soil physical variation on actual yield.
3. Farmers were able to place experiments in their local context: Farmers within the highly risky Western Australia environment modified treatments gradually. By contrast, when the results were presented to a group of farmers in an irrigation area elsewhere in the country, they suggested they would more rapidly change in response to on-farm experimental results.
4. Once compiled, farmers interpreted the results of experiments readily in relation to observed features such as micro terrain, wet areas or weed-load. Factors external to the experiment were important guides to interpretation. This indicates that social organization is required so that sufficient information can be compiled and data can be shared between growers to have confidence in the conclusions (Cock et al., 2011). Furthermore, institutionally-guided compiling of data enhances relevance of results beyond the individual farm by enabling more rigorous analysis using the increased data.
5. Consultants and 'formal' experimentalists have frequently been less enthusiastic than farmers about the concept of OFE. Partially, this has been out of an inability to handle technologies. Other reasons include the shift in authority that OFE introduces with the scientist losing control.
6. Finally, scientists regard statistical significance as an essential test of experimental method, since it distinguishes effects that are due to the treatment from those, which might equally occur as a result of chance. Such tests also enhance the efficiency of experimentation, because they enable experiments with relatively small sample populations to generate clear insight of non-random treatment effects. Do the same methods apply to experiments on-farm? It is not at all clear that these methods are appropriate for on-farm experimentation. Several authors suggest that practitioners adopt a pragmatic approach to significance testing (Armstrong, 2007), as conventional tests of statistical significance may help identify non-random effects, but not their relevance for practitioners.

## Conclusions

How can OFE support agriculture in general and crop nutrition in particular as it responds to increasing pressure to produce more food and fuel without increasing its use of natural resources?

Projections by the Food and Agriculture Organization of the United Nations (FAO) indicate that agriculture must produce about 70% more food over the next 40 years to meet the demands of a greater and more demanding population. It must do so while maintaining or even reducing its call on natural resources. Few question the importance of knowledge to achieve this, as vast gains of eco-efficiency are yet to be realized by agricultural systems. How can such knowledge be developed for agriculture? Clearly, the linear transfer of the technology model of change—codified knowledge (Mokyr, 2005)—needs to be amalgamated with more collaborative approaches in which researcher and farmer activities complement one another. This is effectively a social process of developing farmer competence through both on-farm and conventional experimentation, and experience with OFE suggests that 'formal' and 'on-farm' research exists as two complementary streams of knowledge generation that address different forms of uncertainty. Furthermore, OFE, whether based on experiments designed to resolve a specific question or on observations on farmers' commercial operations, generates information familiar to farmers which they can easily convert to practical and readily understandable farm practices.

The remaining question is how to practically integrate OFE into the agricultural development process, including that for improved crop nutrition? Most agricultural scientists continue to regard on-farm experimentation as a marginal activity. However, OFE fits well into the concept of adaptive management—an ongoing process of developing improved practices for efficient production and resource conservation by use of participatory learning through continuous systematic assessment (IPNI, 2013). Few farmers receive the support that is critical for its success. We suggest that a review of farmer experimentation should be organized with a principle focus to promote sharing of experiences between farmers themselves, with emphasis on farmers groups or associations, and between farmers and researchers. In order to better share experiences we will need social and organizational change together with standardized means of describing experiences, systems to compile multiple experiences and to accommodate a wide range of data from multiple sources. Adequate statistical analysis and interpretation of the data needs to be developed, to present information to farmers in a format that they can readily understand and incorporate in decisions.

We suggest two immediate areas for consideration that have specific significance for improved nutrient management, and where ideas can be developed and piloted: (1) OFE can reduce dramatically the uncertainties of fertilizer use efficiency and thereby supports the development of intensive yet sustainable farming systems. It can therefore enable responsible nutrient stewardship for targeted increase of fertilizer applications that increase production; (2) OFE can facilitate the development of supply chains for specialty fertilizer products by supporting the extension of diversified production systems into ecological niches. We suggest that if agronomists wish to support adaptive management they should see OFE as a valuable ally rather than a process 'for demonstration purposes only'. OFE provides farmers with the analytical power to adapt broadly-based solutions to their operations with greater certainty. This could convert site variability from an obstacle to agricultural development to one of its greatest assets—where ecological niches are sought for high value product.

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