
# An On-Farm Experimental philosophy for farmer-centric digital innovation

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***Abstract.*** *In this paper, we review learnings gained from early On-Farm Experiments (OFE) conducted in the broadacre Australian grain industry from the 1990s to the present day. Although the initiative was originally centered around the possibilities of new data and analytics in precision agriculture, we discovered that OFEs could represent a platform for engaging farmers around digital technologies and innovation. Insight from interacting closely with farmers and advisors leads us to argue for a change in the ways we approach OFE research. Acknowledging that conditions have changed and drawing from business and social sciences, we suggest that OFE approaches today should develop aspects related to skill development, value generation and value sharing, the social dimension of change, and a renewed focus on farmer-centric research to better bridge industry requirements and scientist inputs.*

***Keywords.*** *On-farm experiments; OFE; farmer-led research; digital agriculture; business models; adoption; innovation; experimental design; uncertainty measure; research paradigms.*

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## Introduction: early digital OFE history in Australia

In the mid-1990s, the CSIRO Precision Agriculture Research Group in Australia initiated a process of On-Farm Experimentation (OFE) using yield monitoring equipment. We produced a series of reports and publications from this experience, including Adams & Cook (1997; 2000); Cook & Bramley (1998, 2000); and with amendments in Bramley et al. (2013).

We understood quickly the mechanics and practical advantages of the process, including the use of Variable Rate Technology (VRT) to install spatially distributed experiments over entire fields (the so-called "checkerboard" design), or the analysis of treatment effects from yield monitor data. However, we had a poor grasp of the underlying change offered by OFE, and how to scale up from the activities of individual participants to a broader process of change within the agricultural industry. As we observed (Cook & Bramley, 2000), part of the problem was a shortage of engagement with other scientists. The process was popular with farmers but less so with consultants or our agronomist colleagues to whom we offered (largely without success) the option of transferring ideas developed at plot scale to field-scale or greater. Another problem was that the practice of OFE did not seem to fit with what was then the conventional process of technology transfer from scientist to farmer. A third issue was that our knowledge of how commercialization occurred around information technology was rudimentary, even though large businesses were very active in agricultural machinery, agrochemicals and germplasm R&D.

In this paper we consider how much these conditions have changed, and to what degree we can be optimistic about OFE as a broad vehicle for innovation. Our observations are mainly from Australia, but we hope they can provide valuable insight for OFE globally.

## Process and experimental design

The OFE process as we saw it was similar to the Taguchi concept of on-line experimentation (e.g. Antony et al., 2006). This approach was adopted by Japanese manufacturers to help engineers improve product quality. Its key element is the use of deliberate variation of inputs to provide unambiguous information about their effect on output (Cook & Bramley, 2000). This is an empirical approach to help manage complex systems for which a priori knowledge of the causes of variation are difficult to quantify.

An early checkerboard experiment, a N trial over 72 hectares, revealed major spatial variation in treatment response. Subsequent experiments included the so-called 'eggbox design', using a two dimensional sinewave for two-factor variation (see Cook & Bramley, 1998 for early descriptions). In addition, we installed strip trials, two-way strip trials and, for those farmers who cultivate in a concentric pattern rather than in parallel lines, the 'donut' (Bramley et al., 2006).

The introduction of continuous yield monitoring and, to a lesser degree VRT, provided the measurement and control technology to enable this approach to be applied to broadacre agriculture. The key elements of our approach were as follows:

1. OFE is farmer-driven, as far as possible. The treatment variables are those that interest the grower. The experiments are large scale, and the parameters of variation are agreed with the farmer and determined by him to be acceptable.
2. Experiments should be as large scale as possible in order to include the effects of environmental variation within a given season, and conducted as far as possible under management conditions.
3. Experiments should use conventional farm machinery to ensure no additional work at peak times of seeding and harvest.
4. Analysis of results should aim to provide insight of the scale of the treatment effect; its variation over space and – as far as possible – the causes of variation.

The analytical methods we used focused on clarifying the treatment effects and their spatial variation. Typically, the spatial variation of effect dwarfed the overall treatment effect, requiring substantial further inspection to help explain their causes. Normally this proved a positive experience, since this was where dialogue between the farmer and specialist really converged: the analyst provided numerical insight; the farmers brought a rich qualitative observation and a historical perspective.

At times, interpretation of the causes of variation was limited by a lack of ancillary data. Additionally, interpretation did not always reach a point at which sufficient understanding of the mechanisms at play occurred. Nevertheless, the prevailing experience is that farmers found the process useful, even where it merely refined their intuitive understanding of variation. In recent years, the use of zoning by growers in Western Australia has increased (Bramley & Trengove, 2013; Llewellyn & Ouzman, 2015). In these cases, OFE can provide a useful 'first check' of the positioning of zones.

## The fundamental change that OFE represents

OFE requires a fundamental change in the way we perceive scientists' role in agricultural development. In this respect, much has changed since we started OFE in the way people understand change in agriculture. In the 1990's with notable exceptions (e.g. Ruttan & Hayami, 1973), the technical transfer approach remained the prevailing conceptual model of change. In this model, scientists are seen as external to the system undergoing change. Maat & Glover (2012) describe several problematic aspects of this process, including the way in which farmer experimentation – which is credited with supporting change throughout the 18th and 19th centuries, was downgraded to 'trial status only' on the emergence of formal scientific experimentation. In this way, the status of formal scientific knowledge is promoted above that of others on account of the clarity of insight. Using the framework of Cash et al. (2003) the scientific information is at risk of being valued for its credibility more than its salience or legitimacy.

An alternative model to technology transfer describes growers embedded in innovation systems (Hall, 2015). The change process in innovation systems is more dynamic, non-linear and non-directed. Innovation systems describe growers, scientists and other actors collaborating in response to drivers that are often (but not exclusively) concerned about greater income. Information within innovation systems can be generated from different sources. While the driver is what fuels the innovation system, someone needs to instigate change and negotiate with partners who are necessary for change to occur.

This clearly raises problems for the adoption of insight from formal, scientist-driven experimentation into management practice. These issues include:

1. *Precision vs relevance*. In formal investigation, the precision of information about specific features is valued as of paramount importance. However, strategic decision makers may prefer approximate information about a range of factors they consider relevant.
2. *Semantic vs pragmatic content*. Scientists value the semantic content of insight on which to make statements that are generally true; conversely, decision makers may care less about the underlying truths, preferring information for its pragmatic content.
3. *Significance*. The cornerstone of experimental agriculture is the '$p < 0.05$' rule of significance, and the wealth of statistical analytical methods that lead to it. The concept has unquestioned benefits to reduce the likelihood of 'false positive' inferences. However, questions are increasingly asked about its value to identify factors of practical significance (Cumming, 2013).

These and other features limit the direct application of scientist-centered investigation. OFE provides an alternative farmer-centric process (Table 1). In an earlier paper (Cook, 2013), we postulated how to increase the complementarity of the two approaches.

**Table 1. Strengths and weaknesses of On-Farm Experiment (OFE) in relation to alternative experimental approaches.**

| Type | Farmer trial | Farmer-driven OFE | Scientist-driven OFE | Plot trial | Lab experiment |
|---|---|---|---|---|---|
| **Basis** | Farmer is curious. Tries something new. Observes (possibly with measurement). | Farmer/manager requests an experiment to test one or more inputs of interest. | Farmer/manager hosts an experiment to test interests of scientist or field officer. | Scientist decides to test factors in the field. Reports results. | Scientist focusses on process under controlled environment. |
| **Strengths** | Simple cheap and easy. Can be highly meaningful to the farmer. | Pragmatic. Directly transferrable to the managed system. At the same scale, and co-variable | Clear goals of experimentation. Clear design. | Represents factors of field production. Clear results, often meaningful to growers. | Strong semantic content. Causality is clear. High accuracy. |
| **Weakness** | Insight may not translate to other conditions. Uncontrolled. | Low semantic content. Needs interpreting to provide generalizable insight. | Partial representation of system. Addresses scientist question, maybe not growers. | Ignores spatial variation. Not scaled. Does not represent management factors. | Distant from practical decisions. Focus on one factor may make analysis irrelevant. |

## Managing uncertainties in farm decisions

Information from OFE acquires value when it removes critical uncertainties from decision-making. The types of uncertainty it removes are different from those removed by conventional science. An easy way to clarify this is to use the framework of Rowe (1994) which distinguishes four classes of uncertainty:

1. Metrical uncertainty and variability in measurement;
2. Structural uncertainty due to complexity, including models and their validation,
3. Temporal uncertainty in future and past states; and
4. Translational uncertainty in explaining uncertain results.

We explain details in Cook (2013) and summarize here: metrical uncertainty is paramount to scientists. Scientists pursue precision of measurement in order to identify effects from a small sample. Knowing the scale of the effect of a treatment is also important to farmers but a big, realistic estimate is more useful to them than a small precise one. Structural uncertainty is far more important to farmers than scientists, who may ‘excise’ a problem from its context in order to quantify it, whereas the farmer is obliged to deal with all relevant factors within the farming system. Temporal uncertainty is somewhat important to scientists; farmers will manage it largely through experience of prior events. Translational uncertainty is more important to farmers than scientists since farmers must understand results in the context of their management operations.

The practical importance of distinguishing these classes of uncertainty is that OFE reduces uncertainty in key areas that conventional experimentation normally cannot influence. Structural uncertainty in OFE is managed by experimentation ‘on site’ within existing management systems. The effects include all relevant factors, even if they cannot all be explained. Temporal uncertainty is managed in OFE by relating results to past experience of the same land. Translational uncertainty is managed in OFE by initiating discussion with the farmer from the beginning as to their interests and preferences for experimentation. After the OFE, results are discussed again to explore their meaning.

## Different business models to create and share value

A recent extensive review of the status of precision agriculture in Australia (Leonard et al., 2017) concluded that a prime reason for lack of adoption is the failure to demonstrate value from the technology. We now understand that it is vital to develop processes around the analysis to generate value, as well as to share it. Benefits and costs must be distributed within many different groups in order to ensure the continuity of these processes.

One very widely used approach to define value propositions and explain these complex relationships is the business model canvas of Osterwalder & Pigneur (2010). This approach details the components that are necessary to assemble:

- The value proposition is the core of the idea and describes how value will be generated, for example that OFE will support more precise investment, greater product value or land value;
- The tasks, resources and specialists need to achieve this. Invariably this will include a mix of technical and organizational activities;
- The costs of fulfilling these functions, including risks faced by clients;
- The range of clients likely to receive and share value, including a description how they are engaged and kept within the process; and
- The revenue or benefit streams that can reasonably be attributed to the process. These should include non-monetary benefits.

Depending on the scale of operations and the types of decisions being supported, the OFE process can contain several types of business models. A major benefit of business modelling is that it articulates all components that are essential for change to occur. The approach also shows the range of actors involved in the process and how they are related. Porter and Kramer (2011) stress the big-picture importance of shared value. Depending on the type of organization, value sharing is likely to be essential to the widespread growth and function of OFE. Value sharing requires a degree of collaboration. Competition and collaboration appear to be mutually exclusive behaviors, but the coexistence of both in the Netherlands vegetable grower industry is a widely reported characteristic behind its success (Vanhaverbeke et al., 2007). Competition is the impetus for change but collaboration provides the technical capacity and collective negotiating power to achieve it.

Many obstacles confront the development of sustainable business models. Some of the early commercial products of precision agriculture offered analytical power to farmers from their yield monitor data. For some, farmers became clients of products from their own data. While this kind of sharing is common amongst many business models involving big data, the way it is developed is important to keep people engaged. For example, Australian farmers resent several aspects - real or perceived - of approaches that analyzed yield monitor data on their behalf, including the loss of IP and of control over distribution of their data (Wiseman & Sanderson, 2017).

While there exists a renewed interest in OFE from farmers, suppliers, grower groups and others, we envisage the development of business models that engage people around data capture and analysis to be key to the long-term success of OFE.

Considering that conditions have changed, the following factors could be key to understand how the OFE approach can be develop further:

1. *Broadly based technology and skill*. The essential technology is already widely adopted. In Australia, almost 100% of growers have yield monitoring technology which facilitates OFE. More importantly, the skill-base of farmers and consultants has deepened dramatically so that a variety of business cases can evolve – something that is important for innovation to occur and that we observed to be absent in the 1990s (Cook & Bramley, 2000)
2. *Value generation and value sharing*. We understand now that for the adoption of new technology to succeed, it is vital to identify early on where the value will come from. This extends beyond the demonstration of simple profitability from single uses of use, but through a range of benefits enabled by more secure management: from fertilizer selection and application, chemical use, variety selection or changes in crop rotation. We understand now that the improved decision process in management is more important

than the profitability of individual applications. This concept was alluded to by an important early publication by the NRC (1997) but was perhaps eclipsed by technical considerations and the need to focus on simple quantifiable gains.

3. *The social dimension of change*. Change in digital agriculture is enabled by the attributes of societies around technology. Considerable clarity on these processes has been provided by researchers such as Osterwalder et al. (2005) and Van't Spijker (2014) who describe how business models develop around technologies. We expect OFE to make an important contribution because it focusses on different models of engagement around technology, a factor that, we argue, needs to be developed for precision agriculture to achieve its potential. Once established, we expect a platform of engagement around OFE to provide many opportunities to explore additional technologies. For example, the role for UAV data becomes much clearer if it is used to explain observed variation in performance from OFE.
4. *Farmer-centric change*. An obvious feature of OFE is that it is strongly farmer-centric. We see this as fundamentally important to develop processes of co-innovation that recognize farmer skill. This process is vital to endogenous change on which sustainability is founded (Romer, 1990). OFE provides insights to reward skill development amongst farmers, their advisors and suppliers, while drawing in new technologies that offer new information and the power to control.

## Summary

We started on-farm experimentation in Australia over two decades ago as a means of exploring the power of information contained in yield maps. Beyond analytical benefits, OFE showed us a potential pathway for industry change. However, that understanding was incomplete: we were unclear how that change would occur in agricultural management. We assumed the scope was important because we had seen similar changes through the adoption of Taguchi methods in other industries. However, we noted that there, too, adoption was not always straightforward: “since the arrival of the Taguchi Methods in America, reaction to them has ranged from unrestrained praise to public condemnation” (Moller-Wong, 1988 p.2).

At that time, we received substantial interest, particularly from farmers and some advisors. But we struggled to communicate the more profound nature of change, especially its importance as a vehicle for farmer innovation.

Re-visiting this topic, we are pleased to note that OFE has a wide appeal and, in light of our experience, argue for an alternative approach more inclusive of business and social sciences to 1) place agricultural experimentation closer to the farmer, and 2) acknowledge that change is a process requiring additional tools to those promoted so far by the positivist approach, i.e. business models, co-innovation processes, skill building and network constructions. Together, these aspects pave the way for a new OFE philosophy, i.e. a different way to think about and even conceptualize OFE.

It may seem unusual to present so many ideas that refer back to experiences from two decades ago. But we do so unapologetically as we observe that many notions that now seem central to our understanding of the world have witnessed a far from smooth or linear progress. The development pathway of technologies is often unpredictable, opportunistic and multi-branched, with technology that looked promising in its prime reaching a dead-end, to be usurped by alternatives that may have been virtually unknown a few years earlier. This is the nature of innovation.

The importance of OFE is that it draws farmers themselves into the center of innovation, and promotes the growth of endogenous skill which defines sustainability. Such fundamental, transformational change is always more challenging than incremental improvement. We hope that for the reasons we outline above, the process will now grow and be seen as a major complement to exogenous, scientist-centered change.

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