Long-term systems experiments and long-term agricultural research sites: Tools for overcoming the border problem in agroecological research and design

Erin M. Silva, Marc Tchamitchian

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Erin M. Silva, Agroecology Faculty, University of Wisconsin, Madison, USA,

Department of Plant Pathology, University of Wisconsin, Madison, USA.

Marc Tchamitchian, Ecodéveloppement, INRA, 84000 Avignon, France.

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ABSTRACT

To most effectively integrate research across scales and disciplines, long-term system experiments (LTSE) can serve as a valuable tool in agroecological studies. In this paper, we dis-cuss the role of LTSE in understanding agroecosystem function, as well as components to effective design these studies to further the implementation of agroecological practices. Further, we describe the contributions of long-term agricultural research sites (LTARs) to LTSE, as places at the crossroad of stakeholders and civil society, agricultural, economic, and social stakes, research and practical questions, and disciplines and methods (if not paradigms). In use ways, LTSEs and LTARs help overcome what we term the border problem of conventional agriculture research. Maintaining LTARs in a world dominated by short-term funding remains a key challenge to support agroecological research in need of multidimensional data, but is essential to address the need for interdisciplinary and transdisciplinary approaches to solve the "wicked problems" facing today's society.

INTRODUCTION

Farmers, policy-makers, and scientists are increasingly recognizing agroecology as entailing the integration of science, practice, and movement concerns (Wezel et al. 2009). Such integration results in a more contextualized under-standing of the agricultural endeavor, and thus a fuller ecological under-standing (Bell, this issue, and Bell and Bellon, this issue). For agricultural scientists, such as ourselves, this is a welcome change. Defined simply, the science of agroecology can be described as the use of ecological research methods to understand, develop, and apply holistic management of agricultural systems (Bensin, 1930 (cited in Klages 1942)); Wezel et al. 2009). As advances in the science of agroecology further our understanding of agroecological function on the individual farm and landscape levels, the design of sustainable and multifunctional agricultural systems can be facilitated, further promoting the integration of agroecology with farming practices and movement concerns (Altieri 1995).

Decades of agricultural research have contributed to the development of modern industrial agricultural practices, many of which are reliant on synthetic and exogenous inputs. Short-term experiments based within a single discipline, characterized by a reductionist approach, and focused on the plot or field scales have been used to develop universalistic recommendations upon which these systems are based (Sadler et al. 2015). However, reduction-ism limits contextual understanding by concentrating the scientist's view on components in highly controlled situations, often deliberately excluding real-world complexities and consequences. Agroecological farming, with systems-based management built upon ecological processes, requires inherently different approaches in the development of best practices. Thus, a different research model is needed that allows for the design and execution of experiments across multiple scales, integrating diverse biological, physical, and social dimensions, and an appreciation for context.

Traditional short-term, small-plot, 3–4 year studies do not suffice to answer questions concerning agroecosystem function, including its drivers and consequences. Indeed, short-term, single-factor experiments often fail to provide contextual, systems-level insights (with all the associated embedded interactions), including as to the longer-term impacts of farming decisions on agroecosystems properties (e.g., changes in soil organic matter and biota, yield and market trends, and watershed quality). We term this the border problem of agricultural research. To account for the complex relationships between the endogenous and exogenous factors impacting the agroecosystem at all relevant scales – the field scale, farm scale, landscape scale, and food system scale – long-term systems experiments (LTSEs) may be more appropriate. In this paper, we will discuss challenges of agroecosystem research and the role of LTSEs in understanding agroecosystem function and optimization, including components to effectively design these studies to promote further implementation of agroecological practices and help overcome the border problem.

Challenges of studying agroecosystems: the challenge of scale, interdisciplinarity and diversity

Borders are a critical consideration in the design and interpretation of food systems research. While traditional agronomic research has extensively addressed the field scale, less attention has been devoted to impact of agricultural practices on the landscape or foodshed scale, and conversely, how land-scape and foodshed factors influence agronomic management decisions by the farmer (Dalgaard, Hutchings, and Porter 2003; Francis et al. 2003; Gliessman 2007; Méndez, Bacon, and Cohen 2013; Wezel et al. 2014; Wezel and David 2012). In contrast, ecological research, largely focused on broader spatial scales, more often includes factors beyond the human-dominated landscapes into unmanaged areas, but often to the exclusion of managed agricultural fields (Anderson, 2008). Agroecological research has taken a more intermediate approach, moving beyond the field scale that typifies agronomic research, and including the farm scale (such as the influence of field borders) and territory scale into the broader dimensions of the food system, such as villages, water-sheds, and territories (Conway 1985; Wezel et al. 2016; Wezel and Soldat 2009).

Agroecological research also moves past a second set of borders – the social and intellectual borders traditionally established by the silos which characterize discipline-specific scientific methods. Understanding and implementing agroecological practices requires transcending individual subject areas, instead integrating agronomy, soil science, livestock husbandry, processing and marketing, economic and political decisions, and consumer behavior (Wezel et al. 2009). Research that will contribute to the successful development of agroecologically based farm and food policy must be overlaid with biological, physical, social, and economic diversity of environment and resources, and will require interdisciplinary and transdisciplinary approaches (Harris and Lyon 2013; Nelson 2000; Sheringer et al., 2000).

The importance of an interdisciplinary approach for agroecological research has long been recognized. Conway (1985) articulated the importance of placing agroecosystem analysis within the context of interdisciplinary study, using working farms as case studies (Francis et al. 2003). Frequently, interdisciplinary studies are conceptualized and implemented through collaborations between natural and physical scientists – soil scientists, agronomists, entomologists, and plant pathologists. However, Bawden (1991) highlights that the more frequent partnerships of natural sciences can be enriched by social science methods that explore farmer decision-making and policy implementation. The integration of social science is particularly important to ensure successful agroecological system transformations across scales; natural science methods can inform design of ecologically sound agricultural practices and contribute to the creation of decision-support tools that assist in their implementation; social science methods can be used to integrate human dimensions and more effectively consider key factors that impact adoption and equity, including economic and community dynamics (Francis et al. 2003).

Long-term Agricultural Research Sites: Addressing challenges of scale and interdisciplinarity to understanding and designing agroecosystems

To most effectively integrate research across scales and disciplines, LTSE can serve as a foundation for agroecological studies. Ecologists have recognized long-term agricultural research (LTAR) sites as invaluable tools in the study of ecosystem dynamics (Callahan 1984). The definition of long-term sites varies; some refer to the properties of the systems, such as the definition of Strayer. et al. (1986), which describes a long-term site as one which "continues for as long as the generation time of the dominant organism". Woodmansee (1984) promotes that long-term sites have an intended life span sufficient to reliably estimate the eventual steady-state condition of key ecosystem attributes. Alternatively, Pickett (1991) espoused a more pragmatic view, defining “long-term” as “persistence beyond the usual limits of funding cycles, completion of a graduate degree, or the length of time ‘ho’ ideas remain fashionable”, which is more closely tied to research interests. In all cases, LTARs are characterized by the stability of the questions and of the physical design.

While LTSEs can be conducted on many different platforms – natural lands, communities, watersheds – with differing levels of management and influence by the researchers, LTARs can function as a more defined area where LTSE occurs. More recently, researchers and policy makers have recognized the role of LTARs to address questions related to agricultural management across a wider range of conditions and beyond the typical 2-4 year funding cycles (Robertson et al. 2006). While LTSEs can be success-fully conducted in many different settings, LTARs can allow for precise documentation of system inputs and outputs while absorbing the risks associated with innovative experimental practices, allowing for better recognition of context and thus more rigorous research over decadal cycles. Additionally, LTARs have vital capacity to capture the more episodic impacts of extreme weather, pest and disease outbreaks, as well as the slower trends in soil physical and biological properties, providing insight as to potential impacts resulting from our changing climate (Robertson et al. 2006). In all these ways, LTARs help place LTSEs within a landscape context, thus helping overcome the border problem of agricultural research.

These sites have additionally been identified as platforms to engage across scientific disciplines, fostering collaborations between the biophysical and social sciences, although not specifically through an agroecological lens. In their white paper, Robertson et al. (2006) list four goals for LTSE programs that directly align with the goals of agroecosystem research and design and its effect to handle the border problem. Broadly summarized, these include: (1) understanding of how multiple management aims (e.g., the enhancement of ecosystem services) can be balanced against known trade-offs; (2) greater integration of the biophysical and social sciences to understand economic and social costs; (3) improved knowledge of the impact of practices and implementation of practices across scales, including scale of production and scale of study (e.g., the field and farm scale), and (4) improved both the relevance of research to stakeholder needs and public understanding of these systems with their social, environmental, and management. With this strong alignment of goals, the use of LTSE in agroecosystem research can be quite complementary in their approaches and outcomes.

Optimizing long-term trials to address agroecosystem transition

While LTARs have a strong role in the generation of research-based information, the existence of data alone does not ensure the transformation of our agroecosystems to meet the needs of the 21st century and beyond. While field experiments, including LTARs, provide validated data collected with scientific rigor (Doré, 2011), they can remain disconnected from the realities of working farms and food systems. LTARs, while more integrated than reductionist experiments that provide "turnkey" solutions to production issues, still only reflect a very narrow set of soil conditions, weather conditions, and management variables (Neef and Neubert 2011) and must be understood within their contexts.

To more effectively assess the complex interactions of a set of integrated agricultural practices within wider environmental conditions and surrounding landscape, LTSEs can be designed that combine controlled LTAR field trials with on-farm data collection from "real-world" farms, more accurately capturing the wider impact of agricultural practices on the agroecosystem (Doré et al. 2011). As these on-farm sites incorporate a broader range of environmental, climatic, and landscape influences, more robust data sets are collected, with the LTARs serving as a hub to provide statistical replication and coordination on-farm sites.

However, despite the involvement of working farms, the research design and data analysis often remain researcher-led, with minimal involvement from the farmer beyond providing permission to collect data on the land and farm.

Moving beyond this more simplistic model of on-farm data collection, LTARs can create a more valid participatory model, incorporating the input of farmers, local and regional planners, and policymakers. Stakeholders (often in the form of an advisory board to an LTAR) can contribute in the design of research, the execution of the project (including serving as on-farm research sites), evaluation of the results, and dissemination knowledge to farmers, consumers, and policymakers (Barbercheck. et al. 2011). Using these co-design models for the implementation of LTSEs and LTARs, food system actors can be fully engaged in the process, influencing more expansive agroecological transition. To achieve an interdisciplinary perspective, stake-holders should reflect the diversity of roles instrumental in food system function. Farmers, as expert practitioners with intimate knowledge of their farm's ecosystem, can provide their wealth of insight as to the successes, failures, and impacts of specific practices, either singly or in combination, guiding the choices of treatments to be included in research design (Van der Laan 2006). Buyers and processors can provide valuable insight as to the influence of markets and economics on farm practices. Further, consumer representation can reflect the impact of consumer behavior on market trends. This diverse and well-represented panel of stakeholders can facilitate science's integration and contextualization into the decisions of local com-munities and legislation (Sadler et al. 2015).

Continued assessment of LTARS to achieve agroecosystem goals: a dynamic design approach

Traditionally, agricultural research, including that conducted on LTARs, has often been structured on rigid research plans that cannot be easily modified during the research process (cf. McDougall and Braun 2003). This rigidity can inhibit the ability to integrate timely stakeholder feedback and react to research outcomes, reinforcing the social border problem of agroecological research. An open and flexible plan, on the other hand, can be more receptive to stakeholders' priorities, experiences, and perspectives, while providing space for negotiation of methods, experiments, and adaptation to new conditions (Neef and Neubert 2011).

One method to effectively engage stakeholders is through the creation of "dynamic integrated cropping systems" research (Tanaka et al. 2002) or iterative design and evaluation (Debaeke et al. 2009). Rather than evaluating a static set of predetermined parameters against an often predetermined set of metrics, this design strategy aims to adapt the treatments to continually optimize the system towards agroecological goals, including production, economic and environmental (Hendrickson et al. 2008). To successfully implement this strategy, a multi-directional exchange between stakeholders – including researchers – is essential to adapt and change the system. Thus, instead of maintaining a defined, static cropping system (defined as a crop rotation or more largely as the set of rules from which the crop rotation and technical management derive) and treatments over the course of years or decades, this strategy would integrate farmer innovation, policy changes, market drivers, and other food system elements to continually respond to system performance and optimize for ultimate performance goals, such as sequestration of soil carbon; soil biology; prevention of nutrient leaching and erosion; support of pollinator and beneficial insects; support of local food products; and even issues of equity, access, and food justice.

To apply this dynamic design process, a four-step approach can be employed. Based on work by Vereijken (1997) and Loyce and Wery (2006), the steps can be summarized as the following: (1) Define goals and constraints for new cropping/farming systems; (2) with stakeholder input, propose systems compatible with the constraints and able to meet the goals; (3) assess the proposed systems; (4) test and disseminate the most innovative systems to operators (e.g., farmers), and make appropriate system adjustments. This strategy capitalizes on the unique strength of the LTARs – the provision of replicated, rigorous research data – to provide metrics upon which to assess whether goals have been met. Farmers and stake-holders provide feedback as to whether the goals have been achieved – for example, whether the new agroecological practices and systems enhance a farmer's quality of life, farm succession to the next generation, access to markets, etc. This dynamic design model deviates from the predominant design paradigm of many LTARs in the US, which tend to be more static in their approach, rather than adapting with producer innovation, cultural and policy shifts, and market dynamics.

CONCLUSION: LTSE and LTARs as a tool for agroecological design

With increasing recognition of the complex, dynamic, and integrated nature of our agroecological systems, interdisciplinary LTSEs will undoubtedly serve a vital function in defining solutions for the issues facing global food production. LTARs, serving as places at the crossroad of stakeholders and civil society, agricultural, economic and social stakes, research and practical questions, disciplines and methods (if not paradigms), are a key component in the implementation of LTSEs. LTARs allow for research to be conducted while continually adapting and innovating, mindful of context and the problems of ecological and social borders in our research. Any profound redesign of our production systems will require innovative and risky integra-tion of a range of disciplinary approaches; such experiments are well-suited for LTARs. Maintaining LTARs in a world dominated by short-term funding remains a key challenge to support agroecological research in need of multi-dimensional data. While the integration of on-farm data collection solves part of this challenge, it does not allow for the same venturing trial designs provided through LTARs. Thus, LTARs serve an essential role to foster imagination, drive innovation, and enhance dissemination.

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