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A Review of Long-Term Organic Comparison Trials in the U.S.

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Abstract

Long-term organic farming system trials were established across the U.S. to capture baseline agronomic, economic and environmental data related to organic conversion under varying climatic conditions. These sites have proven useful in providing supporting evidence for successful transition from conventional to organic practices. All experiments chosen for this review were transdisciplinary in nature; analyzed comprehensive system components (productivity, soil health, pest status, and economics); and contained all crops within each rotation and cropping system each year to ensure the most robust analysis. In addition to yield comparisons, necessary for determining the viability of organic operations, ecosystem services, such as soil carbon capture, nutrient cycling, pest suppression, and water quality enhancement, have been documented for organic systems in these trials. Outcomes from these long-term trials have been critical in elucidating factors underlying less than optimal yields in organic systems, which typically involved inadequate weed management and insufficient soil fertility at certain sites. Finally, these experiments serve as valuable demonstrations of the economic viability of organic systems for farmers and policymakers interested in viewing farm-scale organic operations and crop performance.

Keywords: agroecology, transdisciplinary research, organic transition

1. Introduction

As early as 1843 in Rothamsted, England, and 1876 in the Morrow Plots in Illinois, U.S.A., agricultural researchers recognized the importance of documenting the impacts of long-term farming systems on crop productivity, soil quality and economic performance. The link between soil quality and farm viability was well understood, as Andrew Sloan Draper, who was President of the University of Illinois when the Morrow Plots were established, stated prophetically that “The wealth of Illinois is in her soil, and her strength lies in its intelligent development” (University of Illinois [UI], 2015). More recently, long-term organic farming system trials across the U.S. have been established to capture similar information. These long-term crop rotation studies also enable more robust economic analyses of potential profit outcomes as compared to experiments of shorter duration (Delbridge, Coulter, King, Sheaffer, & Wyse, 2011).

This paper examines six of the oldest grain-crop-based organic comparison experiments in the U.S. (Table 1), the goal of which is to demonstrate the unique contributions of each site and the usefulness of these sites in communicating agronomic, as well as environmental and economic outcomes from organic agroecosystems, to both producers and policymakers. Of particular interest to producers is the transition period at these sites: the 36 months between the last application of prohibited synthetic inputs and certified organic status. Long-term cropping systems trials can provide baseline data, monitor trends over time, and evaluate new technology in each system, within the context of sustainability indices (Baldock, Hedtcke, Posner, & Hall, 2014). Each site is categorized based on location (weather), soil type, crops, and organic/conventional management practices, to allow comparisons across sites. Additionally, notations on whether the site is certified-organic or organic-compliant (using organic practices without certification) are included. Recently, organic farmers have argued for organic research that is conducted on certified organic sites to ensure a modicum of equivalency as compared to practitioners’ experiences. Thus, rotation treatments that would not qualify for organic certification have been discouraged from future comparisons (e.g., one site described below has changed their 2-yr to a 3-yr organic rotation).

Table 1. Long-term organic comparison trials in the U.S.

Name of experiment	Date initiated	Comparisons	Main crops	Lead entity and location
Farming Systems Trial (FST)	1981	Conv[1] C-S vs. Org 3 and 4-yr rotations	Corn, soybean, wheat	Rodale Institute Kutztown, Pennsylvania
Sustainable Ag Farming Systems (SAFS)	1988	Conv C, W, S, B and T vs. Org C, W, S, B, T, O	Corn, tomato, wheat, bean, safflower, oat/vetch/pea	University of California Davis, California
Variable Input Crop Management Systems (VICMS)	1989	Conv C-S vs. Org 3 (dropped Org 2) and 4-yr rotations	Corn, soybean, oat, alfalfa	University of Minnesota Lamberton, Minnesota
Wisconsin Integrated Cropping Systems Trials (WICST)	1989	Conv C-S vs. Org 3 and 4-yr rotations	Corn, soybean, wheat, oat, alfalfa	University of Wisconsin-Madison Arlington, Wisconsin
Beltsville Farming Systems Project (FSP)	1996	Conv C-S vs. Org 2, 3 and 6-yr rotations	Corn, soybean, wheat	USDA-ARS Beltsville, MD
Long-Term Agroecological Research (LTAR)	1998	Conv C-S vs. Org 3 and 4-yr rotations	Corn, soybean, oat, alfalfa	Iowa State University Greenfield, Iowa

[1] Conv = following conventional practices; Org = following certified organic practices. C=corn; S=soybean; W=wheat; O=oat; B=dry bean; S= safflower; T=tomato.

Key among organic practices is the necessity of extended crop rotations and organic-compliant soil amendments to optimize production, with each of these practices affecting soil quality, carbon sequestration, nitrogen cycling, and other associated functions. Soil quality is the main driver of optimal organic crop yields. Management of soil organic matter (SOM) to enhance soil quality and supply nutrients is a key determinant of successful organic farming, which involves balancing two ecological processes: mineralization of carbon (C) and nitrogen (N) in SOM for short-term crop uptake, and sequestering C and N in SOM pools for long-term maintenance of soil quality. The latter has important implications for regional and global C and N budgets, including water quality and C storage in soils. The importance of yield comparisons in long-term studies cannot be overlooked, as Seufert, Ramankutty, and Foley (2012) in their meta-analysis of organic and conventional crop yields recognized that optimal yields are central to sustainable food security, in addition to the range of other ecological, social and economic benefits organic farming can deliver. For example, when reviewing the relative yield performance of organic and conventional farming systems worldwide from studies beginning in 1988, Seufert et al. (2012) documented a 5% to 34% lower yield under organic management, depending upon crop and soil type, along with experience related to effective nutrient and pest management practices.

Several commonalities exist among the long-term experiments selected for this review (Table 1). All are systems-level experiments with rotation treatments derived from organic crop rotations practiced in each specific area. With corn (*Zea mays* L.) and soybean (*Glycine max* L.) production comprising 56% of the major crops grown in the U.S. (USDA-NASS, 2011), and wheat (*Triticum aestivum* L.) the third largest crop, one to three of these major crops are present in the trials discussed, as representative of the U.S. agricultural landscape. Because organic systems are complex in nature, in systems-level experiments, the abiotic and biotic components (structure) of the system can be evaluated in terms of the effects on system function (Drinkwater, 2002). Resulting system function data is then used to elucidate factors underlying less than optimal yields (Seufert et al., 2012) and help fine-tune best management practices to improve organic systems.

2. The Farming Systems Trial (FST) Rodale Institute, Pennsylvania

The Farming Systems Trial (FST) at Rodale Institute (RI) is the longest-running comparison of organic and conventional agriculture systems in the U.S. Located near Kutztown, Pennsylvania, the soil type is a moderately well-drained Comly silt loam. Established in 1981, in the year following the release of the first comprehensive study of organic agriculture by the USDA, which advocated such comparisons (USDA, 1980; Youngberg & Demuth, 2013), the FST compares two organic systems with a conventional system, using 0.17-ha plots in eight replications, with each crop in the rotation grown every year (Rodale Institute [RI], 2011). The farming systems chosen were based on typical grain crops grown in Pennsylvania: in the conventional system, corn and soybean were grown for 23 years, then wheat was added to the rotation starting in 2004. The two organic systems consisted of corn, soybean, wheat, and red clover (*Trifolium pretense* L.)-alfalfa (*Medicago sativa* L.) hay in the rotation, and compared contrasting methods for maintaining soil fertility: 1) legume cover crops only, vs. 2) manure-based fertility with cover crops. The conventional system followed land-grant university recommendations for synthetic chemical nutrient and pest management inputs. The FST was one of the first research units to report on the "transition effect" (Liebhardt et al., 1989), where organic grain yields matched conventional yields after an initial yield decline during the transition years. In 2008, genetically modified (GM) crops and glyphosate-based no-till treatments were added to the conventional comparison, in response to public pressure to compare more current conventional systems. Although organic plots could not be certified organic due to inadequate distance from GM crops, the organic systems always adhered to organic-compliant practices. While many in the organic community were opposed to RI adding GM crops in the FST, it has been interesting to note that, even with this advanced technology, conventional yields have not improved over non-GM conventional crops, contrary to what proponents believed would occur (RI, 2011). In addition, organic systems have demonstrated greater resiliency during drought, when organic corn yielded 8,411 kg ha^{-1} compared to 6,403 kg ha^{-1} in the conventional system (Lotter, Seidel, & Liebhardt, 2003).

The FST was one of the first comparison experiments that monitored water quality, through an underground lysimeter system, and found that leachate from the conventional system more frequently exceeded the NO_3-N drinking water standard of 10 ppm than the organic systems (Pimentel, Hepperly, Hanson, Douds, & Sidel, 2005). The RI also conducted a detailed energy analysis, which included the energy used in the manufacture, transportation and application of fertilizers and pesticides in each FST system. Their analysis identified that FST organic systems consumed 45% less energy than the conventional systems, with N fertilizer composing the largest conventional system energy input at 41% of total energy consumption. Thus, production efficiency was 28% higher in the organic system, with the conventional no-till system having the lowest efficiency, based on high-energy requirements for input manufacturing. In a concomitant analysis, greenhouse gas (GHG) emissions associated with the conventional systems were 40% greater per volume of production than the organic systems (RI, 2011).

Soil health, one of the key attributes in agriculture promoted by RI research, was shown to be greatest in the organic system where manure fertilization was employed, followed by the organic legume system. Annual carbon (C) increases were 981 kg C ha^{-1} in the organic/manure system, 574 kg C ha^{-1} in the organic/legume system, and 293 kg C ha^{-1} in the conventional system (Pimentel et al., 2005). Based on the higher soil quality promoting similar yields to the conventional system, the organic system has proven to be economically competitive, with an analysis conducted by Hanson and Musser (2003) showing only a 10% organic premium price was needed to ensure parity with the conventional system. When prevailing organic price premiums were added, the organic system returns averaged 2.9 to 3.8 times the conventional system (Moyer, 2013). Organic price premiums should be included in economic analyses, as they represent the reward organic farmers reap when practicing organic farming—a premium organic consumers are willing to pay in support of farmers who utilize less environmentally harmful methods of farming (Lin, Smith, & Huang, 2008).

3. The Sustainable Agriculture Farming Systems Project (SAFS), Davis, California

The Sustainable Agriculture Farming Systems project (SAFS) was established in 1988 at the University of California, Davis, to study the transition from conventional to low-input and organic crop production practices (University of California [UC], 2015). The experiment was unique in its study of Mediterranean crops, growing on Reiff loams (coarse-loamy, mixed, non-acid thermic Mollic Xerofluvents) and Yolo silt loams (fine-silty, mixed, non-acid, thermic Typic Xerothents). The SAFS site was located in the state with the highest number of organic farmers in the U.S., which led to the integral role of farmers and farm advisors in the planning, execution, and interpretation of results for greater dissemination to the organic farming community. In addition, organic plots were certified organic by California Certified Organic Farmers (CCOF), a critical factor in the site's applicability for regional farmers. Treatments included two conventional systems: a 2-yr (conv-2) and 4-yr (conv-4) crop rotation; and two 4-yr low-input and organic crop rotations (Poudel et al., 2001). The three 4-yr rotations included tomato, safflower, bean, and corn, while the conv-2 system was a tomato-wheat rotation. In the low-input and organic treatments, an oat/vetch/pea mixture was also part of the rotation. Four replications of each treatment and all crop rotation entry points were planted in 0.12 ha–plots, arranged in a randomized block, split-plot design. Furrow irrigation was used for all systems, typical of farming operations in California. Animal manure and winter cover crops provided fertility in the organic system, while the conventional systems received synthetic fertilizer inputs. The inclusion of a low-input system in long-term organic comparison trials can be problematic (unless it is the sole conventional comparator), because few, if any, of the "low-input" systems follow an equivalent pattern of input applications to allow comparisons across regions. For example, the SAFS low-input system used cover crops and animal manure during the first 3 years, then switched to cover crops and synthetic fertilizer, which would render it as essentially a conventional treatment.

Soils research at SAFS resulted in significant gain in our understanding of the processes involved in enhanced soil quality resulting from organic practices, including increased storage of plant nutrients and C, a reduction in soil-borne diseases, increased pools of P and K, higher microbial biomass and activity, an increase in mobile humic acids and soil water-holding capacity (Clark, Horwath, Shennan, & Scow, 1998). The SAFS site was one of the first experiments to examine soil microbial abundance and activity and determine the importance of cover crops and fall irrigations in promoting bacterial-feeding nematode populations and N mineralization (Jaffee, Ferris, & Scow, 1998), which led to improved organic tomato yields. Additionally, adjustments of grass/legume cover crop mixtures according to soil fertility conditions, along with rotating cover crops, helped prevent stem and foliar diseases. The inclusion of winter cover crops in the low-input and organic systems was a key factor in the success of these systems by supplying soil nutrients and aiding in water infiltration, which proved problematic under conventional management. Suppression of the root-knot nematode, *Meloidogyne javanica*, was associated with high levels of microbial biomass observed in the systems using cover crops (Bossio, Scow, Gunapala, & Graham, 1998). The conventional systems were the least efficient at storing N inputs, which are critical for long-term fertility maintenance (Clark et al., 1998). Microbial community variables were positively correlated with mineral N in the organic system, while the opposite was observed in the conv-4 system (Gunapala & Scow, 1998).

Under California's often challenging climate, organic crops with high N demands, such as tomato and corn, were more susceptible to yield losses compared to conventional and low-input systems receiving annual applications of synthetic N fertilizer, while organic bean and safflower crops produced comparable yields (UC, 2015). As with the FST economic analysis, the importance of premium prices for economic viability was demonstrated, where, among the 4-yr rotations in the SAFS study, the organic system with premium prices was the most profitable (Clark, Klonsky, Livingston, & Temple, 1999). Interestingly, while the low-input system outperformed the organic system agronomically, because of the conventional prices received for low-input crops, this system fell below the two conventional systems in profitability.

In 2002–2003, SAFS began a second phase to examine the interaction of tillage effects on the three historical systems, and explore off-farm environmental quality by joining the Long Term Research on Agricultural Systems (LTRAS) project (UC, 2015). Many in the academic community were disappointed about the loss of such a valuable, long-term certified organic site as SAFS. The history of the SAFS site illustrates the fragility of long-term comparisons absent a strong and enduring institutional commitment. While important information may be derived from the LTRAS site, the LTRAS site does not have the same history of organic farmer involvement and oversight that the SAFS site invited, and many feel is critical for the success of long-term organic sites. As stated on the SAFS website: "Ideas that were once considered to be impractical or even radical are now gaining in popularity. As consumer demand for organic foods increases more growers are considering the transition to organic farming systems and seek out the SAFS project to get information and advice" (UC, 2015).

4. The Wisconsin Integrated Cropping Systems Trial (WICST), Arlington, Wisconsin

The WICST was established in 1989 but, because of a staggered start, every crop phase was not present every year for all the crop rotations until 1992 (Posner, Casler, & Baldock, 1995). Four replications of each crop phase were planted on 0.3–ha plots. The main soil type is a well-drained Plano silt loam (fine-silty, mixed, superactive, mesic Typic Argiudoll). The treatments include six cropping systems (CS): 1) conventional continuous corn (CS1: CC); 2) conventional corn–soybean (CS2: C-S); 3) organic corn–soybean–winter wheat with frost-seeded red clover (CS3: C-S-W/RC); 4) conventional corn–alfalfa (CS4: C-A); 5) organic corn–alfalfa–oat (*Avena sativa* L.) plus field pea (*Pisum sativum* L.) mix, followed by a year of alfalfa hay (CS5: C-A/O/P-A); and a rotationally grazed pasture (CS6: RC/T/BG/OG) seeded to a mixture of red clover, timothy (*Phleum pratense* L.), brome grass (*Bromus inermis* L.) and orchardgrass (*Dactylis glomerata* L.). Soil changes at this site have not been as consistent as other long-term sites, primarily because of a history of a dairy–forage cropping system of corn and alfalfa with manure returned to the land for 20 years before establishing the trial, leading to high organic matter levels (47 kg g^{-1} at 0–15 cm) prior to the start of the experiment. The most salient observation from the WICST has been the correlation between weather, weeds and organic crop yields (Posner, Baldcock, &

Hedtcke, 2008). Because mechanical weed cultivation in organic systems is dependent on dry weather, in the years when wet weather prevented timely weed management, organic corn yields ranged from 72 to 84% of conventional corn yields, and organic soybean yields ranged from 64 to 79% of conventional soybean yields. Gaining experience and more advanced equipment for organic operations may have also impacted yield differences, as systems nearly equalized when better technology was introduced in the organic systems, and all cropping systems produced positive, average corn yield trends ranging from 0.1 to 0.2 Mg ha^{-1} yr^{-1} (Baldock et al. 2014). Similar to the FST results, adding GM crops did not improve yields. This was the first long-term trial to demonstrate that organic forage crop yields were equal or greater than conventional counterparts, with quality sufficient to produce an equivalent volume of milk as the conventional systems (Posner, Baldock & Hedtcke, 2008).

5. The Variable Input Crop Management Systems (VICMS) Trial, Lamberton, Minnesota

The Variable Input Crop Management Systems (VICMS) trial was established in 1989 at the University of Minnesota Southwest Research and Outreach Center near Lamberton, MN. Soil types at the site include Normania clay loam (fine-loamy, mixed, superactive, mesic Aquic Hapludolls), Revere clay loam (fine-loamy, mixed, superactive, mesic Typic Calciaquolls), Ves clay loam (fine-loamy, mixed, superactive, mesic Calcic Hapludolls), and Webster clay loam (fine-loamy, mixed, superactive, mesic Typic Endoquolls) (Porter et al. 2003). Two crop rotations and four management strategies are included in the trial, resulting in eight distinct crop management systems. The original crop rotations were a 2-yr corn-soybean rotation, and a 4-yr corn–soybean-oat/alfalfa–alfalfa rotation. The management strategies are zero-external-input (ZEI), low-external-input (LEI), high-external-input (HEI), and organic-inputs (OI). Liquid swine or beef manure was the external nutrient source in the 2- and 4-yr OI systems (applied at 129-138 kg N ha^{-1}). Treatments were replicated three times in a split-plot arrangement, with main plots as crop rotation, and all phases of each rotation present in each year. Split plots, constituting management systems, are 0.16–ha. As previously mentioned, the original 2-yr organic rotation has been replaced with a 3-yr rotation of corn-soybean-wheat/red clover to align the study more closely with predominant organic crop rotations in the region. From 1992 to 2007, corn grain yield was not reduced in LEI and OI 4-yr rotations compared to the HEI 2-year rotation (Coulter, Delbridge, King, Allan & Schaeffer, 2013). Highest organic corn yields, as observed in other long-term sites, were associated with timely weed management. The benefit of the longer organic rotation was observed with soybean yield response, as the relative soybean yield as a percentage of the HEI 2-yr rotation was greatest in the OI 4-yr rotation from 1992 to 2003 (65%) and in the OI 2- and 4-yr rotations from 2004 to 2007 (38 and 41%, respectively) (Coulter et al., 2013).

Soil quality increased in the organic systems in a similar pattern as other long-term sites. The OI system contained the greatest amount of particulate organic matter and potentially mineralizable C compared to the other systems in both rotations (Coulter et al., 2013). Total soil organic C and microbial biomass was higher in the 4-yr OI system than the 4-yr HEI system. Some of the most important contributions from the VICMS site included a detailed economic analysis of the organic systems, including risk analysis. Delbridge et al. (2011) found that when organic price premiums were applied, the average net return of the organic rotation was considerably larger than that of both conventional rotations (\$1329 ha^{-1} vs. an average of \$761 ha^{-1}). Across years and crops, net return was 88% greater with the OI 4-yr rotation than the HEI 2-yr rotation. Organic systems also were found to be stochastically dominant to conventional rotations at all levels of risk aversion (Delbridge, Fernholz, King, & Lazarus, 2013).

6. USDA-ARS (Agricultural Research Service)-Farming Systems Project (FSP)

The FSP was established in 1996 at the USDA-ARS Henry A. Wallace Beltsville Agricultural Research Center (BARC) in Beltsville, Maryland. In contrast to other sites, the FSP was designed to evaluate the sustainability of organic rotations, using typical tillage regimes, compared to conventional cropping systems using both tilled and no-till operations (Cavigelli, Teasdale & Spargo, 2013). Farmers, extension agents, agribusiness professionals, and agricultural researchers were involved in system design. The FSP is comprised of five cropping systems: 1) conventional no-till (NT) corn–soybean–wheat/double-crop soybean rotation: NT: C–S–W/S; 2) a conventional chisel-till (CT) corn–soybean–wheat/soybean rotation: CT: C–S–W/S; 3) a 2-year organic corn–soybean rotation (Org2: C–S); 4) a 3-yr organic corn–soybean–wheat rotation (Org3: C–S–W); and 5) a 6-yr organic corn–soybean–wheat– alfalfa (3 years) rotation (Org6: C–S–W–A–A–A). All plots are 0.1 ha in size and all are managed using full-sized farming equipment. Soils at the site range from poorly-drained to well-drained Ultisols. Results observed at the FSP support the association between system stability and diversity, with lengthening rotations improving agronomic, economic and environmental performance. Specifically, N availability was greater in the 6-yr organic rotation and yields were greater than the 3-yr organic rotation and 2-yr conventional

C-S yields.

Regarding other aspects of soil quality, POMN and SOC in all organic systems were greater than in the conventional NT, which signaled the first report of this phenomenon. Conventional no-till farming, which relies on petroleum-based glyphosate herbicide, is advocated throughout the U.S. for its soil quality enhancement, but the N mineralization potential of the organic system at the FSP was, on average, 34% greater than conventional NT after 14 years. Total potentially mineralizable N in organic systems (average 315 kg N ha^{-1}) was significantly greater than the conventional systems (average 235 kg N ha^{-1}) (Spargo, Cavigelli, Mirsky, Maul & Meisinger, 2011). The SOC was greater in the 6-yr organic rotation compared to NT at all depths except 0 to 2 inches. Despite the use of tillage in organic systems, soil combustible C and N were higher after 9 years in an organic system that included cover crops compared with the three conventional no-till systems, two of which included cover crops, suggesting that organic practices can potentially provide greater long-term soil benefits than conventional no-till (Teasdale, Coffman & Mangum, 2007). Weed pressure decreased with longer rotations (Teasdale & Cavigelli, 2010), suggesting an allelopathic or competitive effect from multiple years of alfalfa–a solid-seeded crop that was cut regularly, which inhibited weed growth. Economic risk also decreased as rotation length increased, and organic returns averaged \$706 ha^{-1} compared to \$193 ha^{-1} (Cavigelli, Hima, Hanson, Teasdale, Conklin, & Lu, 2009). Throughout the mid-Atlantic states, rising concerns regarding nitrate and phosphate fertilization pollution into fragile waterways, like the Chesapeake Bay, has led to increasing restrictions and research on pollution-mitigation methods. A beneficial outcome of the 6-yr organic rotation in this regard was that less poultry manure was needed for optimal yields compared to shorter rotations, thus decreasing nitrate and phosphate pollution potential.

7. The Long-Term Agroecological Research (LTAR) Experiment, Iowa

The LTAR experiment was established in 1998 at the Iowa State University Neely-Kinyon Farm in Greenfield, Iowa, with funding from the Leopold Center for Sustainable Agriculture. This support allowed focus groups of conventional and organic farmers to help determine the appropriate design and purpose of the LTAR experiment (Delate & DeWitt, 2004). Farmers requested a long-term comparison of the ecological and economic outcomes of conventional and organic cropping systems. The research was then constructed to evaluate alternatives to the traditional corn–soybean rotation in Iowa, and investigate production processes based on agroecological principles, designed to reduce off-farm energy demand and to increase the internal resilience of agroecosystems, which consequently increases their adaptability to potential climate change. Unlike purely research-based experiments, the goal of the LTAR site is to encourage transition to organic production, by documenting the environmental services in organic systems that contribute to climate change mitigation and enhancement of soil quality, crop health, productivity, and food quality. Objectives include identifying cropping systems within the LTAR experiment that maximize yields and soil quality, by fostering carbon sequestration and minimizing nutrient loss; promoting supporting and provisioning ecosystem services of biodiversity, pest suppression, water quality, and soil health through the integration of C-stabilizing components; increasing economic returns by reducing costs of production in field operations and labor, decreasing dependence on external sources of applied fertility, lowering energy costs, and gaining carbon credits. Finally, educational objectives include field days, workshops and pasture walks for farmers, students, and agricultural professionals to increase understanding and facilitation of the transition to organic production.

The LTAR experiment is located on a 7-ha ridge top with a uniform slope of 0 to 2% with the predominant soil type a moderately well-drained Macksburg silty clay loam (fine, smectitic, mesic Aquic Argiudolls). The cropping system treatments at the LTAR site were designed based on local farmer input with the goal of organic certification 36 months after establishment. Each crop in each rotation is replicated four times in 0.1–ha plots. Rotations include: 1) conventional corn-soybean (C–S); 2) organic corn-soybean-oats/alfalfa (C–S–O/A); and 3) organic corn-soybean-oats/alfalfa-alfalfa (C–S–O/A–A). Conventional crops are maintained with synthetic fertilization and pesticides, while certified organic fertilization and pest management methods are used in organic plots, using typical farming equipment for the area. Effects of system and rotation treatments are determined for crop productivity and yields; weed, insect, disease, and nematode pest management; soil quality and fertility; nutrient retention and balance; and grain quality. Economic analyses, determined for each treatment, include costs of inputs, subsequent yields, and selling price of organic and conventional crops.

Over 13 years, LTAR organic corn and soybean yields were equivalent or greater than conventional counterparts. Unlike many studies where organic yields suffer during the transition phase, the first LTAR transitioning-to-organic phase demonstrated corn yields in the organic system that were 92% of conventional corn yields while organic soybean yields were 99.6% of conventional soybean yield (Delate & Cambardella, 2004). The advantage of the longer, 4-year organic rotation, which included two years of a perennial legume crop, was exhibited by organic corn yields that averaged 99% of the average conventional corn yield in the post-transitioning phase (Delate, Cambardella, Chase, Johanns, & Turnbull, 2013). Organic soybean yields were 5% greater in the organic rotations than conventional soybean yields. Soil quality results from the LTAR showed that overall soil quality, and especially soil N mineralization potential, was highest in the 4-year organic crop rotation. The organic soils had more soil organic carbon, total N, microbial biomass C, labile organic N, higher P, K, Mg and Ca concentrations, and lower soil acidity than conventional soils. A particularly interesting soils result was obtained in 2012, when an extended drought period was experienced, with 22 cm below normal rainfall during the growing season, and an average of 3 °C above normal temperatures in July. At the end of the 2012-growing season, particulate organic matter C (POM-C) was higher in the organic soils than the conventional, likely because of altered rates of decomposition of new residue C inputs during this especially dry year (Table 2). Soil quality enhancement was particularly evident for labile soil C and N pools, which are critical for maintenance of N fertility in organic systems, and for basic cation concentrations, which control nutrient availability through the relationship with cation exchange capacity (CEC). Despite the serious drought conditions during the growing season in 2012, organic management enhanced agroecosystem resilience and maintained a critical soil function, the capacity to supply nutrients to the crops. Carbon budgets developed after 10 years of organic production showed that the 4-yr organic cropping system can potentially sequester as much soil organic carbon (SOC) in the top 15 cm as obtained when converting from plowing to no-tillage, which is considered the best management practice in conventional farming.

Table 2. Neely-Kinyon Long-Term Agroecological Research (LTAR) experiment soil quality–Fall 2012

	SOC gkg^{-1}	TN gkg^{-1}	POM-C gkg^{-1}	POM-N gkg^{-1}	MBC mgkg^{-1}	PMIN-N mgkg^{-1}	NO$_3$-N mgkg^{-1}	P mgkg^{-1}	K mgkg^{-1}	Mg mgkg^{-1}	Ca mgkg^{-1}	pH	Aggs %	BD gcm^{-3}
ConvC-S[1]	23.1	2.4	3.0	0.31	275	40.1	21.4	21.2	185	366	3487	6.09	34.9	1.27
OrgC-S-O/A	25.7	2.6	4.5	0.33	270	51.9	20.5	57.5	283	413	3870	6.51	35.0	1.22
OrgC-S-O/A-A	24.8	2.5	3.8	0.23	296	52.1	19.7	34.0	251	407	3831	6.41	41.2	1.21
OrgC-S-C-O/A	24.7	2.5	4.3	0.28	362	52.2	16.7	27.4	203	479	3866	6.34	45.4	1.13
LSD$_{0.05}$	1.4	0.1	1.1	NS	42	7.1	NS	12.7	50.9	50.1	161	0.19	7.4	0.08

[1] Results from five randomly-located soil cores (0-15 cm), composited, and removed from each plot after fall harvest, prior to any tillage. Conv = conventional; Org = certified organic; C = corn; S = soybean; O = oats; and A = alfalfa. SOC = soil organic carbon; TN = total nitrogen; POM-C = particulate organic matter-carbon; POM-N = particulate organic matter-nitrogen; MBC = microbial biomass carbon; NO$_3$-N = nitrate-nitrogen; P = phosphorus; K = potassium; Mg = magnesium; Ca = calcium; Aggs = aggregate stability; BD = bulk density; LSD = Least Significant Difference at $p<0.05$; NS = not significant.

Economic returns mirrored those previously reported at other sites, with the organic rotations garnering, on average, twice the returns of the conventional rotation (Delate et al., 2013), and lower costs than conventional crops during transition (Delate, Duffy, Chase, Holste, Friedrich, & Wantate, 2003; Delate, Chase, Duffy, & Turnbull, 2006). Results from the LTAR experiment have been similar to other long-term trials, although LTAR organic yields have often exceeded those reported in the literature. Higher than usual yields during the transition phase could be attributed to the overall fertility of the Mollisols at the site and the high level of weed management experience, which has been a key aspect of success. Despite the equivalence in net C input, the soil under organic management holds significantly more C than the soil under conventional management, and over the coming decade, we will continue to monitor resulting changes in soil edaphic and biotic characteristics including soil microbial community structure and function under the various cropping systems.

8. Conclusions

The six long-term organic comparison sites examined in this review have contributed to an invaluable understanding of the mechanisms underpinning higher soil quality in organic systems, particularly enhanced C and N storage, leading to competitive economic returns. All experiments were transdisciplinary in nature; analyzed comprehensive system components (productivity, soil health, pest status, and economics); and contained all crops within each rotation and cropping system each year, a critical factor for analysis across years. Plot size ranged from 0.1 to 0.3 ha–an area of sufficient size to utilize farm-scale machinery and provide an accurate portrayal of typical farmer experience–often lacking in research station plot research. While, ideally, on-farm sites with larger fields should be employed as comparators to field station experiments to allow a minimum comparison of 5 to 10 years since conversion from conventional farming, as promulgated by Sir Albert Howard (1946), oftentimes, long-term on-farm sites are difficult to obtain and manage. Comparisons with organic grain yields reported from organic farmer surveys in Iowa showed a reduction of 17-20% in organic corn and soybean yields, but returns comparable to the 2X results demonstrated in the long-term trials (Chase, Delate, Liebman, & Leibold, 2008). Organic yield performance was improved in four of the six sites with increased experience and timely weed management, while two sites (FSP and LTAR) with experienced farm managers reported adequate weed control and concomitant equivalent organic and conventional yields early in the long-term site's history. The addition of manure, along with legume forages/cover crops, in the organic fertility scheme has proven essential for sufficient soil quality to support optimal yields across all sites. The scientific rigor under which these sites were operated has provided strong evidence supporting the viability of organic cropping systems for farmers and policymakers alike. Wherever organic farmer involvement in experimental design and feedback was explicit, and organic certification was obtained, organic comparison sites appeared to be more successful in terms of engagement and dissemination of results.

With organic product supply lagging behind the expanding market demand, partially owing to the perceived obstacles to successful transition to organic production (Dimitri & Oberholtzer, 2009), these sites provided sufficient evidence of the potential for successful organic transition. Adoption of land management strategies that foster C sequestration in agricultural soils will be important over the next several decades as we develop new mitigation strategies and technologies to reduce C emissions (Smith, 2004). Agricultural land management options currently recommended to foster C sequestration nearly always include some reduction in tillage intensity, which has been the on-going, or second-phase research, of four of the long-term sites (FST, SAFS, FSP; now VICMS), and implementation of integrated, multifunctional cropping rotations that include cover crops/forage legumes, small grains, and animal manure/compost soil amendments, as demonstrated by all long-term sites. Water quality enhancement, by reducing NO_3-N loss through the adoption of organically managed extended rotations that include small grains, forage legumes and pasture (see Cambardella & Delate, this issue), is considered an integral part of the next phase of many of the long-term trials. These results suggest that organic farming practices have the potential to reduce nitrate leaching, foster carbon sequestration, and allow farmers to remain competitive in the marketplace. Institutional support for these long-term comparisons is critical for successful organic farming demonstrations for area farmers and policymakers.

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