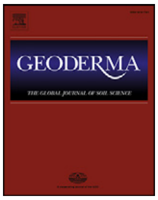
Geoderma 288 (2017) 213–221

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma



Does organic farming accumulate carbon in deeper soil profiles in the long term?

Humberto Blanco-Canqui *, Charles A. Francis, Tomie D. Galusha

Department of Agronomy and Horticulture, University of Nebraska-Lincoln, Lincoln, NE 68583, United States

ARTICLE INFO

Article history:
Received 24 September 2016
Received in revised form 17 October 2016
Accepted 18 October 2016
Available online 22 November 2016

Keywords:
Conventional farming
Diversified rotation
Green manure
Cattle manure
Soil organic C
Organic farming
Particulate organic matter

ABSTRACT

Organic farming systems provide the opportunity to deliver more soil ecosystem services than conventional practices. One such service could be soil organic C (SOC) accumulation, but recent debates suggest that this is unclear. Furthermore, organic farming potential to accumulate SOC for the entire soil profile is not well known. We quantified the cumulative SOC stocks, aggregate-associated SOC, and particulate organic matter (POM) concentrations for the 0–100 cm depth of the soil profile in a comparative crop rotation experiment in eastern Nebraska after >20 yr of management. We studied: 1) conventional farming, 2) conventional farming with diversified rotation, 3) organic rotation with alfalfa (*Medicago sativa* L.) as green manure, and 4) organic rotation receiving 37 Mg ha^{-1} yr^{-1} cattle manure. All the treatments had been managed for 40 yr except the organic rotation with green manure, which had been in place for 20 yr. Organic farming increased SOC stock, aggregate-associated SOC, and POM concentrations but only in the 0–15 cm soil depth. The SOC stock under organic cattle manure system was 19% greater than under conventional farming (33.1 Mg ha^{-1}) and 13% greater than under conventional farming with diversified rotation (34.8 Mg ha^{-1}). The SOC stock under organic rotation with green manure (36.6 Mg ha^{-1}) was 10% greater than in conventional farming. Results suggest that organic cropping systems accumulated SOC at 0.16 Mg C ha^{-1} yr^{-1} with cattle manure and 0.18 Mg C ha^{-1} yr^{-1} with green manure. Growing alfalfa for only two years in the 4-yr organic rotation probably limited its potential to increase SOC for the whole soil profile. Overall, in the long term, organic farming increases SOC stock but only in the upper 15 cm of the soil profile.

1. Introduction

Enhancing soil ecosystem services (regulating, provisioning, and supporting services) is a high priority in development of sustainable agricultural systems. Organic farming practices could maintain and provide more soil ecosystem services compared with conventional farming (Cavigelli et al., 2013; Williams and Hedlund, 2013; Reganold and Wachter, 2016). Organic farming systems differ from conventional farming systems because they exclude the use of synthetic fertilizers, pesticides, and genetic engineering (IFOAM, 2005). Organic farming primarily relies on ecological principles to maintain soil ecosystem services including biodiversity and natural soil fertility (Cavigelli et al., 2013; Reganold and Wachter, 2016).

One of the key ecosystem services from organic agriculture can be the accumulation of organic C in the soil relative to conventional farming systems. Increasing the amount of organic C stored in the soil, in general, is essential for improving soil fertility and productivity, soil physical, chemical, and biological processes and properties, belowground biodiversity, and filtration and degradation of non-point source pollutants, among others.

Agronomic, economic, environmental, and social benefits between organic and conventional farming practices have been widely compared and discussed (Gomiero et al., 2011; Seufert et al., 2012; Reganold and Wachter, 2016). However, effects of organic farming on SOC stocks and sequestration appear to remain unclear and controversial (Leifeld and Fuhrer, 2010; Gattinger et al., 2012, 2013; Leifeld et al., 2013; Kirchmann et al., 2016). Recent authors have argued that organic farming may (Gattinger et al., 2012; Cavigelli et al., 2013) or may not (Leifeld and Fuhrer, 2010; Gattinger et al., 2012; Kirchmann et al., 2016) have significant potential for storing SOC compared with conventional farming systems. For example, in a review of 32 publications, Leifeld and Fuhrer (2010) compared SOC stocks between organic and conventional farming and concluded that the higher SOC accumulation in organic systems is mainly due to the higher application of organic fertilizer compared with most conventional farming systems. The authors added that, in most studies, crop rotations and amount of external C inputs (i.e., animal manure) between organic and conventional farming differed, confounding factors that made SOC accretion comparisons difficult. In the few studies where crop rotation and organic fertilization

---

* Corresponding author.
E-mail address: hblanco2@unl.edu (H. Blanco-Canqui).

http://dx.doi.org/10.1016/j.geoderma.2016.10.031
0016-7061/

were similar, differences in SOC between the organic and conventional systems were unclear and inconsistent.

Another review of 74 studies by Gattinger et al. (2012) concluded that organic farming can accumulate more SOC compared with non-organic farming systems. The review found that organically farmed soils can sequester 0.45 ± 0.21 Mg C ha^{-1} yr^{-1} in the topsoil in temperate regions. Leifeld et al. (2013) posited that the greater potential of organic farming for accumulating SOC reported in the review by Gattinger et al. (2012) is mainly attributed to the application of large quantities of external organic C inputs such as animal manure, compost, and others relative to conventional systems that received little or no external C inputs. Leifeld et al. (2013) also stressed that application of animal manure to organic plots is simply a transfer from one location to another on the same farm or from nearby, and does not truly represent an additional C capture from the atmosphere. Kirchmann et al. (2016) highlighted some specific flaws, which can cause bias when comparing organic against conventional farming including higher rates of organic amendment application or inclusion of cover crops in organic systems relative to conventional systems.

The debate about the potential of organic farming for storing SOC warrants the need for more field experimental data of SOC stocks under different organic cropping systems and discussion of sources and causes for any differences in SOC stocks between organic and conventional farming systems. It is well recognized that organic cropping systems can vary with location and especially with the use of different fertility practices under the general umbrella of organic farming. Thus, the extent to which organic farming can accumulate SOC can vary with site-specific characteristics of soil type, management, and climate. For example, SOC accretion between organic farming with external inputs (i.e., animal manure) and organic farming with the use of semi-perennials and cover crops may differ.

Differences in tillage intensity, crop rotations, and input of organic amendments can be among the main drivers of SOC accumulation under organic farming (Gattinger et al., 2012). Some studies have suggested that diversifying crop rotations and reducing tillage intensity can enhance potential for organic farming systems to store more SOC and improve related soil properties compared with conventional farming systems (Cavigelli et al., 2013; Cooper et al., 2016). Other studies have suggested that without external C inputs, organic farming may reduce SOC stocks compared with conventional farming practices.

Long-term experiments are ideal settings to study changes in SOC accumulation and help us better understand the SOC storage potential of organic farming. However, data on SOC stocks from long-term organic farming experiments are scarce. The SOC accumulation is often slow and small, which requires the use of long-term experimentation to detect differences in SOC storage. Particularly, organic farming systems that rely on tillage for weed control may delay or reduce SOC accumulation due to soil disturbance (Williams and Hedlund, 2013).

It is also important to assess the distribution of SOC for at least 100 cm of the profile. Previous studies have collected data on SOC accumulation under organic farming only for near surface layers of the soil (<20 cm depth; Bell et al., 2012). The review of 74 studies by Gattinger et al. (2012) found that SOC concentration and stocks under organic farming in all studies were measured primarily for the 0 to 15 cm depth. Additional research assessing SOC stocks for greater depths of the soil profile is needed to better understand the potential of organic farming to promote deep SOC storage. Organic farming practices that include semi-perennials could store SOC at greater depths in the soil profile in the longer term. The objectives of this study were to quantify the cumulative SOC stocks and associated properties in organic and conventional cropping systems for the 0 to 100 cm depth in the soil profile after several decades of management in eastern Nebraska. We hypothesized that organic cropping systems would increase SOC stocks in deeper soil strata in the long term compared to conventional farming practices.

2. Materials and methods

2.1. History of treatments in the long-term experiment

This study was conducted on a long-term experiment of organic and conventional farming systems established in 1975. The experiment is located at the University of Nebraska-Lincoln's Agricultural Research and Development Center (ARDC) near Mead, Nebraska. The soil series is a Sharpsburg silty clay loam (fine, smectitic, mesic Typic Argiudoll) with 0–3% slope. The soil is deep, moderately well drained, and formed in loess. Mean annual precipitation is 748 mm and mean annual temperature is 9.9 °C.

The experiment is a randomized complete block design with four treatments replicated four times and managed under rainfed conditions. The four treatments were 1) conventional farming, 2) conventional farming with diversified rotation, 3) organic cattle manure system, and 4) organic green manure system. All treatments were in the field each year. The management of each treatment was slightly modified in 1996 (Table 1). Both conventional farming and conventional farming with diversified rotation have been receiving inorganic fertilizer and herbicide inputs since experiment initiation. Similarly, the organic cattle manure system has been receiving cattle manure since experiment initiation. However, the organic green manure treatment without inorganic fertilizers was initiated in 1996. In other words, the organic comparisons with cattle manure have a 40 yr history, while the more comprehensive comparisons that include green manure have a 20 yr history.

Note that the crop rotations in all four treatments were modified in 1996 (Table 1). Winter wheat (*Triticum aestivum* L.) replaced the oat (*Avena sativa* L.)/clover (*Trifolium* L. sp.) year. Alfalfa was added to the organic rotation with green manure treatment as a legume cash crop and source of green manure in 1996. As indicated earlier, the organic treatment with alfalfa green manure has been in place for 20 yr. Alfalfa is plowed before cereal planting. The average annual yield of alfalfa in this experiment is 7.41 Mg ha^{-1} (Wortman et al., 2011). Alfalfa is grown for two years in the 4-yr organic rotation for 20 yr, and there is a break before reseeding alfalfa in the same plots (Table 1). The organic rotation with green manure received no fertilizer at all except for alfalfa mulch. The N was supplied by the two years of alfalfa in the rotation.

In all treatments, the maize (*Zea mays* L.) plots in each corresponding crop rotation cycle were split into subplots of maize and grain sorghum [*Sorghum bicolor* (L.) Moench] in order to create two sequences

Table 1
Management and modification of the four treatments in 1996.

Nomenclature used	Management from 1975 to 1995	Management from 1996 to present
Conventional farming	Continuous maize (*Zea mays* L.) with inorganic fertilizer and herbicide inputs	4-yr conventional farming with maize-soybean-grain sorghum-soybean rotation with inorganic fertilizer and herbicides.
Conventional farming with diversified rotation	4-yr rotation (maize-soybean-maize-oat/clover) with inorganic fertilizer and herbicide inputs.	4-yr conventional farming with diversified maize-grain sorghum-soybean-winter wheat rotation with inorganic fertilizer and herbicides inputs.
Organic cattle manure system	4-yr rotation (maize-soybean-maize-oat/clover) with cattle manure amendment	4-yr organic cropping system with soybean-maize/sorghum-soybean-winter wheat receiving 37 Mg ha^{-1} yr^{-1} cattle manure as amendment.
Organic green manure system	4-yr rotation (maize-soybean-maize-oat/clover) with inorganic fertilizer inputs only	4-yr organic cropping system with alfalfa-alfalfa-maize-winter wheat rotation with alfalfa as green manure.