Scientia Horticulturae 182 (2015) 145–155

Contents lists available at ScienceDirect

Scientia Horticulturae

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

Impact of organic no-till vegetables systems on soil organic matter in the Atlantic Forest biome

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ARTICLE INFO

Article history:
Received 25 August 2014
Received in revised form
25 November 2014
Accepted 1 December 2014
Available online 19 December 2014

Keywords:
Green manure
Labile and stable fractions
Soil health
Soil C balance

ABSTRACT

Soil organic matter is widely recognized as a strategy used to improve soil quality and reduce carbon emissions to the atmosphere. A field study was carried out to investigate the effects of cover crops in organic no-till vegetables systems on changes in soil organic matter and CO_2—C emissions, in dry and rainy seasons. We hypothesized that CO_2—C emissions are higher in conventional till as compared with no-till, and that no-till increases soil C sink. The crop rotation comprised a 3-year cropping sequence involving two crops per year—cabbage (*Brassica oleracea* L.) in winter and eggplant (*Solanum melongena* L.) in summer time. Treatments were no-till on dead mulch of grass (*Avena strigosa* Schreb. and *Zea mays* L.), leguminous (*Lupinus albus* L. and *Crotalaria juncea* L.), intercrop (grass and leguminous) and conventional till (no dead mulch) with rotary hoe arranged in a randomized block design on a clayey Oxisol (Typic Haplustox) at Domingos Martins-ES, Brazil. On 2012 and 2013, disturbed soil samples at three different layers (0–5, 5–15 and 15–30 cm) and undisturbed samples at 0–10, 10–20 and 20–30 cm, for chemical and organic matter characterization were taken. CO_2—C emissions and soil temperature were measured in situ on March, May, August and October 2012 and February 2013 (after 3 years of experiment). Conventional till site showed the lowest microporosity values and the highest macroporosity, followed by lower soil bulk density at 0–10 cm layer. Total organic C ranged from 34.94 to 50.48 g kg^{-1} in intercrop and 27.11 to 43.74 g kg^{-1} in conventional till. Total N ranged from 2.81 to 5.34 g kg^{-1} in grass and 2.54 to 4.51 g kg^{-1} in conventional till. Highest C stock was recorded in intercrop. Conventional till showed lower labile C values while recalcitrant C was higher in the intercrop treatment. The annual average of CO_2—C emissions (μmol CO_2 m^{-2} s^{-1}) followed the order: grass (15.89) > intercrop (13.77) > leguminous (13.09) > conventional till (11.20). Highest annual average of soil temperature was recorded in conventional till (23.95 °C). Lowest annual mean of soil water content, microbial biomass C, and highest metabolic quotient were recorded in conventional till. These results suggest that the use of cover crops and organic compost in pre-planting promote C increments. The contribution of organic residues increases the water holding capacity and reduces soil temperature. No-till reduces soil disturbance and promotes a positive balance of C. Organic no-till vegetable systems is a strategy to increase soil C and should be encouraged in order to increase soil quality in the Atlantic Forest Biome in Brazil.

1. Introduction

The Brazilian Atlantic Forest is now reduced to about 11.4 to 16% of its original cover of approximately 150 million hectares (Ribeiro et al., 2009). Most deforested areas are composed of agricultural systems on degraded soils. Anthropogenic activities lead to land misuse causing changes in the physical, chemical and biological attributes of soils (Reicosky et al., 1999; Powlson et al., 2011). This implies decreases in the storage of organic carbon and nutrients as well as in the productive capacity of soils, since C is an indicator used to assess soil quality (Silva and Mendonça, 2007; Ghosh et al., 2012).

It is widely recognized that soil organic matter is one of the most important indicators of soil quality and health (Lal, 2004; Ghosh et al., 2012). Increasing or maintaining soil organic matter is critical to achieve optimum soil functions and crop production (Ghosh

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http://dx.doi.org/10.1016/j.scienta.2014.12.002
0304-4238/

et al., 2012). When monitoring soil quality in the tropics, sensitive soil quality indicators need to be identified, mainly due the continuous and intensive vegetable production in these areas (Moeskops et al., 2012). Soil management can lead to higher decomposition rates of organic matter decreasing the concentration of this soil component (Silva and Mendonça, 2007). Agriculture can significantly contribute to elevate atmospheric CO_2 concentrations as a consequence of soil management (Powlson et al., 2011). These C losses to the atmosphere can be mainly reduced by minimizing soil disturbance, either with no-till or agroecological management (Silva and Mendonça, 2007). It is estimated that 89% of the potential for mitigation of greenhouse gases produced by agriculture relies on C sequestration (Smith et al., 2008). In addition, increasing the soil organic C content is an important strategy to deal with climate changes driven by C emissions to the atmosphere from agricultural lands.

No-till and organic agriculture increase soil C and N sequestration, and reduce the oxidation of soil organic matter (Bayer et al., 2009; Campiglia et al., 2014). Continuous input of plant residues and paucity of soil disturbance promote reductions in CO_2—C emissions through decreases in organic matter decomposition rates (Lal, 2004; Bayer et al., 2009). On other hand, conventional crop production intensify soil disturbance and, consequently, breakdown the soil aggregates (Bayer et al., 2009). Conventional tillage is the most common agricultural management for vegetable production in areas formerly occupied by the Atlantic Forest in Brazil. In addition, vegetable production is historically managed by family smallholders. Intensive farming or intensive soil preparation in horticulture degrades the soil–plant environment, mostly due to the reduction in concentration and quality of soil organic matter and the diversity of soil organisms (Tian et al., 2011). Degradation of soil organic matter leads to long-term decreases in horticultural productivity. Thus, sustainable tillage is preferable to attain a positive net balance of C in the highly weathered tropical soils (Mendonça and Rowell, 1996).

The use of cover crops represent a potentially valuable supply of organic residues (C source) when they are used in no-tillage systems and their residues are left on the soil surface (Campiglia et al., 2014). No-till systems can mitigate CO_2—C emissions. This is because crop rotation and organic residues on soil surface promote gradual decomposition of organic matter, favoring C incorporation (Bayer et al., 2009; Conceição et al., 2013). Physical protection of organic matter provided by stable aggregates under no-till reduce organic matter mineralization and lead to C accumulation (Six et al., 2004). However, there is a lack of information about C storage gains and CO_2—C soil emissions by organic no-till vegetable systems, especially in the areas formerly occupied by the Atlantic Forest biome, a well-known biodiversity hotspot (Myers et al., 2000). Here, we report the results of a long term field experiment conducted in dry and rainy seasons. We aimed to investigate the effects of cover crops in organic no-till vegetables systems on changes of soil organic matter and CO_2—C emissions, in dry and rainy seasons. We hypothesized that CO_2—C emissions are higher in conventional till as compared with no-till, and that no-till increases soil C sink, leading to improved soil quality.

2. Material and methods

2.1. Site location, characterization and land uses prior to the experiment

The study was carried out at the 2.5 ha organic agriculture experimental site of Incaper (Espírito Santo Institute for Research, Technical Assistance and Rural Extension), municipality of Domingos Martins-ES (20°22′SE 41°03′W) altitude of 950 m above the sea. The climate of the region is Aw (tropical climate and dry season in winter), precipitation ranges from 750 to 1500 mm per year, and all months of the year have average temperatures of 18 °C or higher. The region is characterized by dry winter and rainy summer (Köppen, 1923). Mean monthly precipitation and air temperature are presented in Fig. 1. Soil is classified as Red-Yellow Latosol, Brazilian Classification System (Embrapa, 2006) or as clayey Oxisol, Typic Haplustox (Soil Taxonomy, USDA classification). From 1990 to 2009, this area was cultivated with organic vegetables (mainly lettuce, cabbage and eggplant). Organic management was performed using 15 Mg ha^{-1} of organic compost (dry mass) amendments. The composting area followed the indore system (Miller and Jones, 1995) with alternating layers stacked forming cells that received manual eversion periodically in order to control humidity (50%) and temperature (60 °C). The method relies on aerobic activity, although portions of the pile can become anaerobic between turnings. Moreover, it provides better control of flies, more rapid and uniform decomposition rates and less problems regarding moisture control (Miller and Jones, 1995). The compost was prepared with a stacked mixture of: grounded green cameron grass (*Pennisetum purpureum* Schumach.), coffee husk, crop residues of maize and beans, and inoculation with chicken manure at the rate of 50 kg m^{-3}. Organic compost characteristics were (total amount): 52% organic matter, 16:1 carbon:nitrogen ratio, 7.3 pH, 2% nitrogen, 1.2% phosphorus, 1.2% potassium, 4.8% calcium, 0.5% magnesium, 54 mg dm^{-3} copper, 188 mg dm^{-3} zinc, 12,424 mg dm^{-3} iron, 793 mg dm^{-3} manganese, 25 mg dm^{-3} boron. More details of the organic vegetable cropping (1990–2009) can be found in Souza et al. (2012).

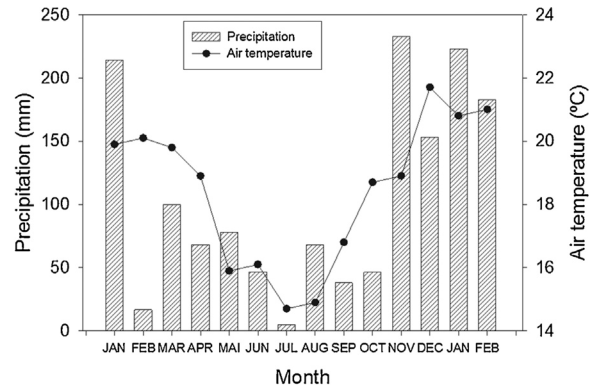

Fig. 1. Average monthly precipitation and air temperature of the municipality of Domingos Martins between January 2012 and February 2013. Data from Incaper.

2.2. Experimental design, cover crops and crop rotation

The organic no-till vegetables systems experiment was initiated in 2009. The experiment comprises four tillage systems, implemented on 4 m × 6 m plots, according to a Randomized Complete Block Design, with six replicates (totalizing 24 permanent experimental units) covering a total area of 576 m^2. Therefore, the effects of organic management accumulated over the years. Tillage treatments consisted of:

(i) No-till on dead mulch of grass (grass): black oat (*Avena strigosa* Schreb) was used as winter cover crop followed by maize (*Zea mays* L.) as summer cover crop.
(ii) No-till on dead mulch of leguminous (leguminous): white lupin (*Lupinus albus*, L.) was used as winter cover crop followed by Sunnhemp (*Crotalaria juncea* L.) as summer cover crop.