Applied Soil Ecology 73 (2014) 140–147

Contents lists available at ScienceDirect

Applied Soil Ecology

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

Soil carbon dynamics as affected by long-term contrasting cropping systems and tillages under semiarid Mediterranean climate

Vito Armando Laudicina, Agata Novara, Luciano Gristina, Luigi Badalucco*

Dipartimento di Scienze Agrarie e Forestali, Università degli Studi di Palermo, Viale delle Scienze, Edificio 4, I-90128 Palermo, Italy

ARTICLE INFO

Article history:
Received 1 March 2013
Received in revised form 29 August 2013
Accepted 4 September 2013

Keywords:
Labile carbon pools
Field CO_2 flux
Carbon stock
Wheat monoculture
Wheat–faba rotation
Tillage

ABSTRACT

In a dryland Mediterranean agrosystem (Sicily, Italy) a comparative study was carried out among two crop systems (wheat/wheat and wheat/bean) after 19 years under three most used tillage managements (conventional, dual layer and no-tillage), in order to ascertain the effects of those experimental factors, single and combined, on various soil organic C pools (total and extractable organic C, microbial biomass C, basal respiration). Field CO_2 fluxes from soil, throughout a year, were also determined. Moreover, C input and output were assessed, as well as microbial and metabolic quotients. Tillage management more than cropping system affected the soil organic C stored in the first 15 cm of soil. After 19 years, no-tillage caused a 3.6 Mg ha^{-1} increase of C content in wheat/faba rotation while of 5.6 Mg ha^{-1} in wheat monoculture. The higher soil total organic C content in wheat monoculture was ascribed to a lower quality of residues supplied (higher both C/N ratio and acid detergent fibre (ADF) content). Moreover, wheat/bean rotation increased soil microbial biomass C, basal respiration and microbial quotient, thus suggesting that crop rotation more than tillage management was the driving factor in improving soil biochemical indicators.

1. Introduction

Reduced tillage is regarded as one of the most effective conservation agricultural practices to decrease CO_2 emissions from soil and sequester C into it (Curtin et al., 2000; Laudicina et al., 2011; Luo et al., 2010). On the other hand, conventional tillage causes an increase in soil CO_2 evolution, although many authors (Roberts and Chan, 1999; Ellert and Janzen, 1999; Reicosky and Archer, 2007) noted that such an increase usually occurs for few days after machine operations. However, Luo et al. (2010) highlighted that the role of adopting no-tillage in sequestrating C is greatly regulated by cropping systems. As a consequence, it is important to emphasise on both quantity and quality of crop residue inputs, as well as on tillage management.

Long-term field experiments have shown a direct linear relationship between C added as residues and C matter accumulated in soil (Cole et al., 1993; Duiker and Lal, 1999). However, in semiarid environments, where quantitative differences in residues among cropping systems are low, their quality becomes a determinant for soil C dynamics (Yadav et al., 2008). Curtin et al. (2000) have demonstrated the advantage of cereals over legumes in achieving maximum soil C sequestration rates. Indeed, in a semiarid area of Canada, they found that annual C added to soil ranged from 1.6 Mg C ha^{-1} in average for the black lentil to 2–3 times that amount for wheat crop. Similarly, in Argentina soybean, which produced 1.2 Mg ha^{-1} residues, resulted in a net loss of soil C while corn, with 3.0 Mg ha^{-1} residues, significantly lessened the loss of soil C from the system (Studdert and Echeverria, 2000). Guo et al. (2009), comparing crop performance in soil CO_2 emissions, found leguminous crop residues having more potential than wheat, although they improved soil quality and crop productivity. Those results confirmed that the quality of residue inputs, which generally is inversely related to the residue C/N ratio, can strongly affect CO_2 emissions (Al-Kaisi and Yin, 2005) by changing the microbial decomposition rate of residues (Kuo et al., 1997; Sainju et al., 2002). Therefore, residue C to N ratio is crucial in soil organic matter decomposition modelling (Melillo et al., 1989). Moreover, recent studies (Dubeux et al., 2006; Stubbs et al., 2009) have demonstrated as also the acid detergent fibre (ADF) is useful to predict plant material decomposition rates. Long-term field experiments provide reliable opportunities to investigate directly the effects of management on soil quality properties that do not respond rapidly to change, such as soil organic C (SOC), but not confounded by land use and management changes themselves (Hopkins et al., 2011). Such experiments provide benchmark values against which the effect of wider environmental changes can be examined (Hopkins et al., 2009).

The objectives of the present study, carried out in a representative dryland agrosystem, were to evaluate the long-term (19 years) effects of two contrasting crop systems (wheat–wheat vs. wheat–faba) under three different tillage managements (conventional tillage, dual layer and no-tillage) on (i) soil organic C labile

---

* Corresponding author. Tel.: +39 09123897052; fax: +39 091484035
E-mail address: luigi.badalucco@unipa.it (L. Badalucco).

0929-1393/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.apsoil.2013.09.002

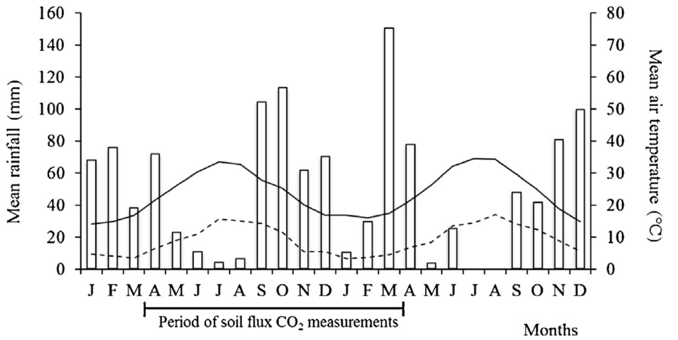

Fig. 1. Climatic trend from January 2008 to December 2009. Histograms are mean monthly rainfall, continuous and broken lines are, respectively, maximum and minimum mean monthly temperature. Soil CO_2 flux measurements were carried out from April 2008 to March 2009.

pools, and (ii) field and potential soil CO_2 emissions, to relate all them with both quantity and quality of residues input in cropped soils of the Mediterranean environment.

2. Materials and methods

2.1. Study site

The experimental work was carried out from April 2008 to April 2009 at the Pietranera farm of the University of Palermo, located in the central-southern Sicily, Italy, (37°30′N, 13°31′E), 178 m above sea level. The climate at the experimental area is semi-arid Mediterranean, with a mean annual precipitation of 552 mm and a mean annual air temperature of 15.9 °C. Climatic data were collected from January 2008 to December 2009 by a weather station located 500 m far from the experimental field (Fig. 1). The soil used was a fine-clayey, calcareous, mixed, xeric Chromic Haploxerert, with a slope of 7%. Main soil properties, determined before setting up the experimental field and referring to 0–15 cm depth, were: clay 471 ± 51 g kg^{-1}, silt 225 ± 26 g kg^{-1}, sand 304 ± 28 g kg^{-1}, total organic C 18.1 ± 0.5 g kg^{-1}, total N 1.3 ± 0.1 g kg^{-1} and pH 8.1 ± 0.1.

2.2. Experimental design

The experimental design, established in 1991, was a strip-plot with two replications. Since 1952 up to 1991, the experimental area was cropped with a durum wheat/vetch crop rotation under a deep ploughing regime. Two crop sequences (wheat monoculture and wheat/bean rotation) were assigned as horizontal treatments and three tillage systems as vertical treatments. The plot size was 370 m^2 (18.5×20.0 m). Tillage managements were: (i) conventional tillage (CT), consisting of ploughing to a depth of 30 cm followed by one or two shallow (10–15 cm depth) harrowing operations before sowing; (ii) dual-layer (DL), consisting of a chisel ploughing to a depth of 40 cm coupled with a mouldboard ploughing to a depth of 15 cm and followed by one shallow harrowing operation; (iii) no-tillage (NT). Although some studies suggest that soil C content across the profile could be driven by differences in incorporation depth of residues depending on tillage treatments (Sun et al., 2011), here only the 0–15 cm soil layer was investigated as most tillage operations involved the 0–15 cm soil layer, with conventional ploughing (up to 30 cm) more invasive than chisel plowing. To minimise the annual climatic variability effects, all crops had a yearly-based rotation. Seed density was 350 seeds m^{-2} in rows 16 cm apart for wheat (*Triticum durum*) and 40 seeds m^{-2} in rows 70 cm apart for faba bean (*Vicia faba*). Following normal farm practices, fertilisation was carried out every year by applying in wheat/bean (WB) rotation 92 kg ha^{-1} of P_2O_5 and 82 kg ha^{-1} of urea-N before seeding wheat, while 18 kg ha^{-1} of urea-N and 46 kg ha^{-1} of P_2O_5 before seeding faba. In wheat monoculture (WW), 92 kg ha^{-1} of P_2O_5 and 120 kg ha^{-1} of urea-N before seeding were applied. In WW monoculture, weed control was carried out by using in post-emergence Tribenuron-methyl herbicide (at the 3rd to 4th leaf stage). In no tilled plots of WB rotation, weeds were controlled prior to sowing by glyphosate [*N*-(phosphonomethyl) glycine]. Further details about experimental site and agronomic techniques are reported in Giambalvo et al. (2012).

2.3. Carbon and acid detergent fibre (ADF) input

During the 19 years since the experiment was established, the C inputs consisted mainly of root biomasses and marginally of shoots left after the harvest, both in wheat monoculture and in wheat/bean rotation. The cumulative C supplied by root biomass (CCRB) both for wheat and bean was calculated according to Kong et al. (2005) and Chung et al. (2008) as follows:

CCRB (Mg ha^{-1}) = 0.22 × CAB (Mg ha^{-1}) × root carbon (%), where CAB is the cumulative aboveground biomass and 0.22 is a conversion factor for root to shoot ratio used for both wheat and legumes, assumed as grains (IPCC, 2006).

The yield biomasses of both wheat and bean crops were estimated by weighing one square metre of aboveground biomass after the harvest for each plot. The C content of root and shoot residues was assumed for both species equal to 43% (Kong et al., 2005; Gan et al., 2009; Jensen et al., 2010). Root and shoot biomasses were also analysed for total N by Kjeldahl digestion (Bremmer, 1996) and for acid detergent fibre (ADF) content (Van Soest, 1963). Then, the ADF input was calculated by multiplying the C input by ADF content.

2.4. Soil sampling and analyses

Soils were sampled just after the harvest carried out in June 2009. Three soil samples (0–15 cm), each composed by five soil subsamples, were collected in each plot. Soil samples were sieved at 2 mm and split in two aliquots, the first being air-dried and the second remoistened to 50% of water holding capacity (WHC). Soil chemical analyses were carried out on air-dried aliquots whereas soil biochemical analyses on remoistened aliquots. Total organic C (TOC) was determined using a Carlo-Erba CHN analyser. Soil bulk density was measured using the tube core method (Blake and Hartge, 1986). Microbial biomass C was determined by the substrate (glucose) induced respiration method (SIR), according to Anderson and Domsch (1978). Briefly, 10 g soil aliquots, remoistened at 50% water holding capacity (HWC), were weighed into bottles and added with a glucose solution to have a final glucose concentration of 2 mg g^{-1} dry soil; the final soil moisture corresponded to 120% of WHC, in order to optimally spread the substrate within soil samples. The bottles with soil were conditioned for 0.5 h, sealed with butyl rubber stoppers, and incubated for 2 h at 22 °C. SIR was converted to microbial biomass C (MBC) using a conversion factor of 40 (Anderson and Domsch, 1978). The glucose concentration and the duration of the incubation period in the SIR assay, in order to reach the soil maximal linear respiratory response had been determined by previous tests. A short-term (36 days) aerobic incubation procedure was used to determine the potential of the soils to mineralise organic C (Nannipieri et al., 1990). Soil samples at 50% WHC were pre-incubated for a week at room temperature; then, readjusted the moisture by water addition, they were incubated at 22 °C in 200 cm^3 air-tight glass bottles. The CO_2 evolved was measured by sampling an aliquot of gas from the bottles by using a syringe and injecting it into a gas-chromatograph (Trace GC, Thermo Electron) equipped with a thermal conductivity detector (TCD). After air sampling, stoppers were removed for half hour to