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A simplified method for the assessment of carbon balance in agriculture: an application in organic and conventional micro-agroecosystems in a long-term experiment in Tuscany, Italy

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Abstract

Many research works propose sophisticated methods to analyse the carbon balance, while only a few tools are available for the calculation of both greenhouse gas emissions and carbon sequestration with simplified methods. This paper describes a carbon balance assessment conducted at farm level with a simplified methodology, which includes calculations of both CO_2 emissions and carbon sequestration in crop rotations. This carbon balance was tested in the Montepaldi Long Term Experiment (MOLTE) trial in central Italy, where two agroecosystems managed with two different farming practices (organic *vs* conventional) are compared. Both in terms of CO_2eq emissions and carbon sequestration, this simplified method applied in our experiment provided comparable results to those yielded by complex methodologies reported in the literature. With regard to the crop rotation scheme applied in the reference period (2003-2007), CO_2 emissions from various farm inputs were found to be significantly lower (0.74 Mg ha^{-1}) in the organically managed system than in the conventionally managed system (1.76 Mg ha^{-1}). The same trend was observed in terms of CO_2eq per unit of product (0.30 Mg kg^{-1} in the organic system and 0.78 Mg kg^{-1} in the conventional system). In the conventional system the sources that contributed most to total emissions were direct and indirect emissions associated with the use of fertilisers and diesel fuel.

Also the stock of sequestered carbon was significantly higher in the organic system (27.9 Mg ha^{-1} of C) than in the conventional system (24.5 Mg ha^{-1} of C). The carbon sequestration rate did not show any significant difference between the two systems.

It will be necessary to test further this methodology also in commercial farms and to validate the indicators to monitor carbon fluxes at farm level.

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Introduction

While, on the one hand, the agricultural sector contributes to greenhouse gas emissions, on the other it can also play a fundamental role in climate change mitigation through soil carbon sequestration. In particular, this is true for cropping systems which are based on specific conservation practices, such as minimum tillage, rotations and use of organic fertilisers (Robertson *et al.*, 2000; Six *et al.*, 2002; VandenBygaart *et al.*, 2003) or are managed with organic farming methods (Drinkwater *et al.*, 1998; West and Post, 2002; FAO, 2009).

Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the largest contributors to greenhouse gas (GHG) emissions from the agricultural sector (Snyder *et al.*, 2009). These gases are converted into a CO_2 equivalent, which expresses the relative contribution of a gas to the greenhouse effect (global warming potential, GWP) compared to carbon dioxide (CO_2) (Flessa *et al.*, 2002). In 2009, the GHG emissions from agriculture were 34.5 Mt CO_2eq. Since 1990, in Italy, GHG emissions dropped at a rate of approximately 15% compared with the total value for the entire period, mainly due to a decline in the number of livestock, the loss of cultivated areas, and particularly the reduction in the use of nitrogen fertilisers (ISPRA, 2012). In 2009, the agricultural sector was responsible for 7% of total GHG emissions (ISPRA, 2012), being therefore the second source after the energy sector (83%). Out of the three main greenhouse gases, N_2O is the largest contributor from agriculture (IPCC, 1996). Nitrous oxide emissions correspond to about 45% of the total global anthropogenic emissions from the agricultural sector (ISPRA, 2012). Most of N_2O emissions are produced in soils during nitrification and denitrification processes (Hutchinson and Davidson, 1993). The increase of N_2O in cultivated soils is mainly due to the use of N inputs in mineral fertilisers, animal wastes and biological N fixation (IPCC, 1996). In organic farming, a low nitrogen input in soils reduces potential nitrous oxide emissions (El-Hage-Scialabba and Müller-Lindenlauf, 2010).

In the literature there are a number of studies that investigate greenhouse gas emissions from agriculture. Audsley (1997), Ceuterick (1998), Kramer *et al.* (1999), Williams *et al.* (2006) and Warner *et al.* (2010) evaluated the emissions from different crops. Other authors estimated emissions from different farming system, such as Flessa *et al.*, 2002; de Boer, 2003; Cederberg and Mattsson, 2000; Haas *et al.,* 2001 who compared organic and conventional farming systems.

In two long-term comparative experiments with arable rotations, Niggli *et al.* (2007) and Nemecek *et al.* (2005) found that the global warming potential of all crops was reduced by 18% in organic cropping systems as compared to the conventional system. Küstermann *et al.*, (2008) and Robertson *et al.* (2000) reported an even higher reduction in greenhouse gas emissions, *i.e.* 53% and 64%, respectively.

The agricultural sector contributes significantly to carbon sequestration (FAO, 2009; Six *et al.*, 2002; Smith *et al.*, 2008; VandenBygaart *et al.* 2003; West and Post, 2002) by long crop rotations including legumes and organic fertilization (Leifeld and Fuhrer, 2010) and to the reduction of carbon loss as a result of conservative tillage systems (Roberson, *et al.*, 2000). Carbon sequestration in agriculture correlates with the farming system adopted. Several studies have demonstrated that organically managed plots have a higher soil carbon content than conventionally managed ones (Mariott and Wander, 2006; Müller-Lindenlauf, 2009; Stalenga and Kawalec, 2008; Küstermann *et al.*, 2008; Niggli *et al.*, 2009; Mondelaers *et al.*, 2009; El-Hage-Scialabba and Müller-Lindenlauf, 2010; Gattinger *et al.*, 2012).

Most of the above-mentioned research works were conducted using: i) complex methodologies, such as the life cycle analysis (LCA) Assessment to examine the contribution from different emission factors (Audsley, 1997; Ceuterick, 1998; Kramer *et al.*, 1999; Williams *et al.*, 2006; De Backer *et al.*, 2009; Warner *et al.*, 2010; Venkat, 2012); and ii) complex mathematical models to assess the carbon balance (Grace *et al.*, 2006; Küstermann *et al.*, 2008; Stockmann *et al.*, 2013). However, it is also possible to calculate GHG emissions using simplified methods (Flessa *et al.*, 2002; Lal, 2004). Simple empirical methods were also used to calculate carbon soil sequestration in terms of concentration of organic carbon, carbon stock and rate of carbon sequestration (Aguilera *et al.*, 2013). Furthermore, only a few studies are available on the effect of management practices on both carbon sequestration and CO_2 emissions (Küstermann *et al.*, 2008). This is probably due to the remarkable complexity of methods and databases used for each of these two indicators, which becomes even greater in combined analyses. In our study we evaluated the carbon balance of two agroecosystems (organic *vs* conventional) through a simplified set of indicators, which includes both carbon emissions (expressed as CO_2eq) and carbon sequestration of crop rotations. These indicators were selected within the framework of the SATREGAS project on the sustainability of farming systems and the promotion of crops with low CO_2 emission developed in Tuscany (Italy). In our study, the set of SATREGAS indicators was tested on the organic and conventional micro-agroecosystems of the Montepaldi Long Term Experiment (MOLTE) at the experimental farm of the University of Florence (Italy), using data from the 2003-2007 period.

Materials and methods

Study site

The Montepaldi Long Term Experiment (MOLTE) has been ongoing since 1991 (Migliorini *et al.,* 2013; Migliorini and Vazzana, 2007; Vazzana *et al.,* 1997) at the experimental farm of the University of Florence (Montepaldi, San Casciano, Val di Pesa, Long. 11° 09' 08'' E, Lat. 43° 40' 16'' N) in a slightly sloping area of about 15 hectares at 90 m asl. In the MOLTE experiment, three micro-agroecosystems were set up to investigate differences between organic, integrated and conventional management systems. In our study, we only considered data from the following two micro agroecosystems (Figure 1): i) the *Old Organic* (OldO) system of 5.2 ha, consisting of 4 fields under organic management since 1992 (EC reg. 2092/91 and following regulations; European Commission, 1991); ii) the *Conventional* system of 2.6 ha, consisting of 2 conventional fields managed with the farming techniques generally adopted by the local conventional farms.

The two agro-ecosystems are surrounded by ecological infrastructures, such as natural and artificial hedges, in order to avoid as much as possible any interaction effects and cross-contaminations among fields. The climatic conditions of the experimental area are typical of the Mediterranean sub-Apennine zone. The annual rainfall is about 770 mm with a peak in autumn and spring and a minimum in June-August. The annual mean temperature is 14.1°C with a maximum which can exceed 30°C in summer and minimum temperatures in January.

The MOLTE soil is composed of parent rock material derived from Pliocene sediments (slopes) and river Pesa fluvial deposits from the Holocene (plane), classified as Fluventic Xerochrepts (Lulli *et al.,* 1980). Based on the texture, this soil can be classified in between *silty clay loam* and *clay loam* with widespread gravel. Table 1 shows the main characteristics of the micro-agroecosystems analysed.

Data collection

In order to assess the soil organic carbon (SOC) concentration (mg kg^{-1}), soil samples were collected and submitted to specific chemical analyses (*i.e.* Springer-Klee method; Springer and Klee, 1954).

Each soil sampling was performed with a hand probe reaching a depth of 30 cm in 4 areas. For each area a soil sample was obtained by mixing three sub-samples collected in the same area after removing the crop residues from the soil surface. In total, we collected 24 soil samples each year. At harvest, crop yields were measured on the entire area of the fields, using four samples of harvested fraction and crop residues for each field. Each crop sample was obtained by collecting three sub-samples which were subsequently mixed.

In order to obtain the yield's dry matter, the yield values were adjusted

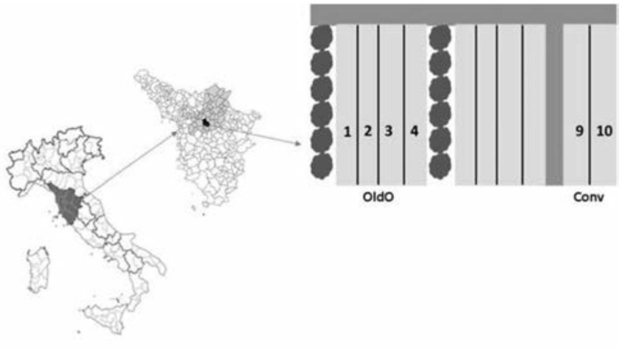

Figure 1. Location of the Montepaldi Long Term Experiment (MOLTE) on an organic (OldO) micro-ecosystem and a conventional (Conv) micro-agroecosystem close to Florence (Tuscany, Italy).

Table 1. Characteristics of the two agroecosystems analysed at Montepaldi Long Term Experiment (Florence, Tuscany).

Input	OldO	Conv
Soil texture	Silty clay loam and clay loam	Silty clay loam and clay loam
Crop rotation	I: Green manure + Corn II: Common/Durum Wheat or Barley + overseeding Clover III: Clover IV: Common/Durum Wheat	I: Corn II: Common/Durum Wheat or Barley
Tillage	2003-2007: plow/ripper (25 cm)/ disc arrow (2 times 20 cm)	2003-2007: plow/ripper (25 cm)/ disc arrow (2 times 20 cm)
Input	OldO	Conv
Fertiliser: nitrogen (kg ha^{-1})	9.9	81.0
Fertiliser: phosphorus (kg ha^{-1})	8.5	56.9
Fertiliser: potassium (kg ha^{-1})	1.7	0.0
Crop residues nitrogen (kg ha^{-1})	34.6	25.2
Herbicides (l ha^{-1})	0.0	4.1
Fuel (l ha^{-1})	146.5	144.1
Harvest (Mg ha^{-1})°	Barley: 4.0 Common wheat: 2.5 Durum Wheat: 3.2 Corn: 2.3 Clover: 3.9	Barley: 4.7 Common wheat: 6.2 Durum wheat: 3.5 Corn: 1.7

OldO, Old Organic; Conv, Conventional. °Annual average of the crop rotation.

on the basis of the humidity content. The biomasses of the crop residues (*i.e.* straw and root residues) were calculated using the harvest index [HI = 0.40 for maize; 0.45 for winter cereals (wheat and barley)] and shoot root ratio [We assumed the following shoot:root ratio: 5.60 for maize, 9.46 for wheat, 6.81 for barley, and 0.70 for annual clover.].

Statistical analysis

The experimental data collected from each system in the 2003-2007 period were processed by a univariate analysis of variance (ANOVA) with fixed model using SPSS 16.0 statistical software package.

Processing methods of global warming potential indicators

The GWP is defined as *the cumulative radiative forcing between the present and a selected time in the future, caused by a unit mass of gas emitted now* (IPCC, 1996). The three gasses, CO_2, CH_4 and N_2O are converted into a CO_2 equivalent value (CO_2eq) using the coefficients of 1, 25 and 298, respectively over a time span of 100 years (IPCC, 2006).

The GWP was calculated in terms of carbon emissions per unit of area (Mg ha^{-1} of CO_2eq) and per unit of product (Mg kg^{-1} of CO_2eq), using the following inputs: fuel (L ha^{-1}), herbicides (kg ha^{-1}), fertilisers [nitrogen (N), phosphorus (P), potassium (K); kg ha^{-1}] and farm machinery (hr ha^{-1}) (Table 1).

For the calculation of the GWP index (CO_2eq), the emission factors, defined as average emission rate of a given GHG for a given source relative to units of activity (IPCC, 1996), were derived from data on greenhouse gas emissions reported in the literature (Table 2).

Emissions due to loss of N_2O from fertilised soil and soil crop residues

The Intergovernmental Panel on Climate Change (IPCC, 2006) established a direct N_2O emission coefficient of 1% for nitrogen inputs of chemical fertilisers, organic fertilisers and the amount of N in crop residues. In terms of CO_2eq, this emission factor corresponds to 2.98 kg kg^{-1} (Table 2). While the nitrogen content of synthetic fertilisers can be inferred from the literature, for crop residues it was calculated using laboratory tests (Pregi/Dumas methods; Simon, 1962). The IPCC (2006) considered an indirect N_2O emission factor for evaporated ammonia and nitrogen (including the fraction emitted as N_2O) of 0.5 kg CO_2eq kg^{-1} and 3.5 kg CO_2eq kg^{-1}, respectively (Table 2).

Table 2. Emission factors used for the calculation of CO_2eq.

Emission factors	CO_2eq (kg kg^{-1})	Reference
N_2O direct application of nitrogen fertiliser	2.98	IPCC, 2006
N_2O direct application of crop residues	2.98	IPCC, 2006
N_2O indirect volatilization fertiliser	0.5	IPCC, 2006
N_2O indirect leached fertiliser	3.5	IPCC, 2006
N fertiliser production	2.86	Küstermann *et al.*, 2008
P fertiliser production	2.57	Küstermann *et al.*, 2008
K fertiliser production	0.73	Küstermann *et al.* 2008
Herbicide production	26.63	Audsley *et al.*, 2009
Diesel	3.17	IPCC, 1996
Manufacture machine	1.17	Doering, 1980

N, nitrogen; P, phosphorus; K, potassium.

Emissions from production of chemical fertilisers and herbicides

In this research the following emission factors were used for fertilisers: N fertilisers 2.86 kg CO_2eq kg^1, P fertilisers 2.57 kg CO_2eq kg^{-1}; K fertilisers 0.73 kg CO_2eq kg^{-1} (Küstermann *et al.*, 2008) (Table 2). The calculation of CO_2eq emissions from the production of fertilisers is then performed by multiplying the amount of fertiliser (kg) by the corresponding emission factors. Emissions of herbicides were calculated following Audsley *et al.* (2009), based on the quantity of product used (in terms of herbicide active ingredient) and an emission factor of 26.63 kg CO_2eq kg^{-1}.

Emissions from consumption of fuels and use of machinery

The CO_2eq emission was calculated (Flessa *et al.*, 2002) by multiplying the amount of fuel used (kg) by an emission factor of 3.17 kg kg^{-1} of CO_2eq (Table 2). Audsley (1997) argued that the only practical way to estimate CO_2eq emissions resulting from the use of agricultural machinery is to consider the energy required for producing them (expressed in MJ kg^{-1} of the machine's mass/weight) and converting it into kg CO_2eq. For these calculations, we first divided the machine's mass by the total hours of life of the machine itself (hourly charge of the machine's mass). Then, this value was multiplied by the hours needed to perform an operation for each crop and was subsequently converted in MJ kg^{-1} (Audsley, 1997). For the conversion we used Doering's coefficients (1980) of 14.6 MJ kg^{-1} for tractors and 8.6 MJ kg^{-1} for other farm machinery. Lastly, these values were converted into CO_2eq by multiplying them by a conversion factor of 0.074 kg MJ^{-1} (IPCC, 2006).

Carbon sequestration processing method

The calculation of carbon sequestration was performed using 2 indicators: the stock of SOC (Mg C ha^1) and the carbon sequestration rate (Mg C ha^{-1} $year^{-1}$), which were calculated as follows:

$$SOC_{stock} = BD \text{ x } SOC_{conc} \text{ x } D \quad (1)$$

where BD is soil bulk density (Mg m^{-3}), SOC_{conc} is the concentration of soil organic carbon (mg kg^{-1}), and D is the thickness of the soil layer (m). BD was estimated according to Post and Kwon (Post and Kwon, 2000):

$$BD = 100/[Om_{conc}/0.244 + (100\text{-}Om_{conc})/1.64] \quad (2)$$

where 0.244 is the bulk density of soil organic matter, 1.64 is the bulk density of soil mineral matter, and Om_{conc} is the concentration of soil organic matter (%), which was estimated according to Springer- Klee method (Springer and Klee, 1954).

The C sequestration rate (Mg C ha^{-1} $year^{-1}$) was calculated with the following equation:

$$\text{C sequestration rate} = (Ct_t - Ct_o)/t \quad (3)$$

where Ct_t and Ct_o represent SOC stocks (Mg C ha^{-1}) at the end and at the beginning of the experiment, respectively, and t refers to the duration of the experiment (years).

Results

Greenhouse gas emissions

With regard to the crop rotation applied during the reference period (2003-2007), the values of CO_2eq emissions for the OldO system (0.74 Mg ha^{-1}) were significantly lower than those of the Conv system (1.76 Mg ha^{-1}). In fact the emission level of CO_2eq from the organic system was 60% lower than that of the conventional system (Table 3).

The sources having the highest impact on total emissions in the Conv system were diesel fuel and the application and production of nitrogen fertilisers (Figure 2 and 3B). More than 55% of GHG emissions were attributed to the application and production of nitrogen fertilisers, while 25% was due to fuel combustion/use (Figure 3B).

In the OldO system the largest contribution to emissions (over 60% of the total emissions of CO_2eq) came from the use of fuel, while 30% of emissions were attributed to the production and application of nitrogen fertilisers (Figure 3A). Crop residues generated a higher loss of N_2O (*i.e.* 14% of the total emissions; Figure 3A) in the OldO system than in the Conv system. Nevertheless, these residues had a positive impact on the increase of the carbon sink in the soils under organic management. Also the CO_2eq emissions per unit of product were significantly different between the OldO farming system (0.30 Mg kg^{-1}) and the conventional system (0.78 Mg kg^{-1}) (Table 3).

Carbon sequestration

The carbon stock in the two farming systems was found to be statistically different: the carbon stock was 14% higher (27.9 Mg ha^{-1}) in the OldO system compared to the Conv system (24.5 Mg ha^{-1}) (Table 3).

The rate of carbon sequestration instead was not significantly different between the two farming systems (0.48 Mg ha^{-1} $year^{-1}$ in the OldO system and -0.54 Mg ha^{-1} $year^{-1}$ in the Conv system) (Table 3).

Discussion

Set of indicators for the calculation of the carbon balance

While various sophisticated methods for the carbon balance analysis at farm level have been developed (Venkat, 2012; Küstermann *et al.*, 2008), only a few tools are available for the calculation of both GHG emissions (CO_2eq) and carbon sequestration with simplified methods.

GHG emissions can be calculated using simple or more complex methods, such as for example the LCA analysis. There is currently a growing body of literature on LCA-based methods for assessing the environmental impact of single crops or production processes (Williams *et al.*, 2006; Meisterling *et al.*, 2009; Venkat, 2012).

These studies reported a reduction of CO_2eq emissions in organic systems as compared to conventional systems. This is in line with what we found in our investigation using simplified methods for indicator calculation. Only Nemecek *et al.* (2011) found a reduction of CO_2eq emissions in conventional systems.

In keeping with the results of Pelletier *et al.* (2008) and De Backer *et al.* (2009), we have shown that the reduction of CO_2eq emissions from organic farming depends on the application and production of fertilisers, even if we have observed a slightly higher use of fuel in

Table 3. Analysis of variance: average and significance of greenhouse gas emissions per unit of area (Mg ha^{-1}) and per unit of product (Mg kg^{-1}), soil carbon stock (Mg ha^{-1}) and carbon sequestration rate (Mg ha^{-1} $year^{-1}$) for each farming system depending on the source of variation in the 2003-2007 period.

Source of variation	Degrees of freedom	CO_2eq emission (Mg ha^{-1})	CO_2eq emission (Mg ha^{-1})	Soil carbon stock (Mg ha^{-1})	Carbon sequestration rate (Mg ha^{-1})
System (S)	1	**	**	**	n.s.
OldO	-	0.74+0.11	0.30+0.07	27.93+0.53	0.48+0.70
Conv	-	1.76+0.11	0.78+0.07	24.51+0.75	-0.54+0.99

**Significant with $P \leq 0.01$; *significant with $P \leq 0.05$. n.s. not significant; OldO, Old Organic; Conv, Conventional.

the organic micro-agroecosystem.

The changes in soil organic carbon can be estimated using a simple methodology or more complex soil carbon models. Küstermann *et al.* (2008) analysed carbon cycles in farming systems using a simulation model of carbon fluxes in the soil. In our study the calculated mean of C sequestration was 0.37 Mg ha^{-1} yr^{-1} for the organic system and -0.25 Mg ha^{-1} yr^{-1} for the conventional system. Rühling *et al.* (2005) reported similar results (a SOC increase by 0.18 Mg ha^{-1} yr^{-1} in the organic system and a SOC decrease by 0.12 Mg ha^{-1} yr^{-1} in the conventional system).

In line with those studies, also in our experiment we found a comparable SOC increase in the organic system as compared to the conventional system (0.48 Mg ha^{-1} yr^{-1} and -0.54 Mg ha^{-1} yr^{-1}, respectively).

Impacts of organic and conventional practices on carbon balance

On the basis of the results and the statistical analysis performed, we can note the effects of farm management on carbon balance. In our study we have shown that organic farming positively affects GHG emissions and SOC stock compared to the conventional farming system as reported in the literature by other authors (Mäder *et al.*, 2002; Nemecek, *et al.*, 2005; Niggli *et al.*, 2009; Leifeld and Fuhrer, 2010; El-Hage-Scialabba and Müller-Lindenlauf, 2010; Gattinger *et al.*, 2012).

CO_2eq emissions

In organic farming the CO_2eq emissions per unit of area and per unit of product are respectively 58% and 61% lower than in conventional agriculture. Various studies reported comparable results (Robertson *et al.*, 2000; Nemecek, *et al.*, 2005; Küstermann *et al.*, 2008). According to Küstermann *et al.* (2008), GHG emissions due to fuel consumption and use of machinery are nearly similar in both organic and conventional cropping rotations. On the contrary, in our experiment we have identified a large difference, which is mainly due to the contribution of N_2O to total GHG emissions (45% for the conventional system and 26% for the organic system) that can be ascribed to the synthetic-chemical C used in the conventional farming system.

The contribution in terms of GHG emission of N_2O was found to be the most important source of agricultural emissions (Flessa *et al.*, 2002; Mäder *et al.*, 2002, Olesen *et al.* 2006) and accounts for 38% of agricultural GHG emissions overall (El-Hage-Scialabba and Muller, 2010). In the organic farming system, both the ban on the use of mineral nitrogen and the addition of green manure in the crop rotations to improve the soil structure (Mathieu, *et al.*, 2006) reduced N_2O emissions by decreasing the concentration of readily available mineral nitrogen in the soil.

C sequestration

Gattinger *et al.* (2012) proved that both the SOC concentration and the SOC stock in soils under organic management are significantly higher than in non-organic farming management. In keeping with the

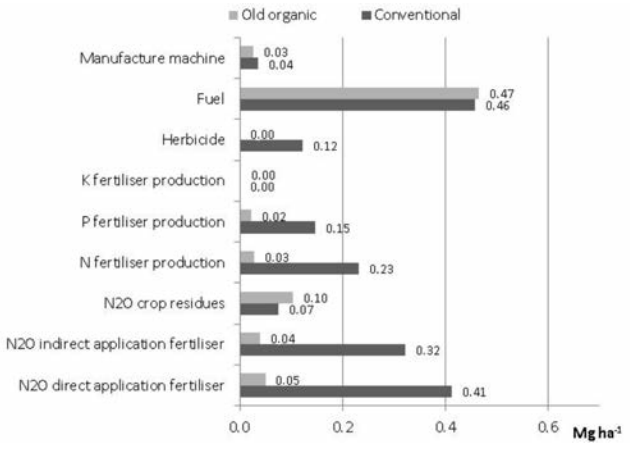

Figure 2. Average greenhouse gas emission (Mg CO_2eq ha^{-1}) of the organic micro-agroecosystem and the conventional micro-agroecosystem in relation to different types of activities in the 2003-2007 period.

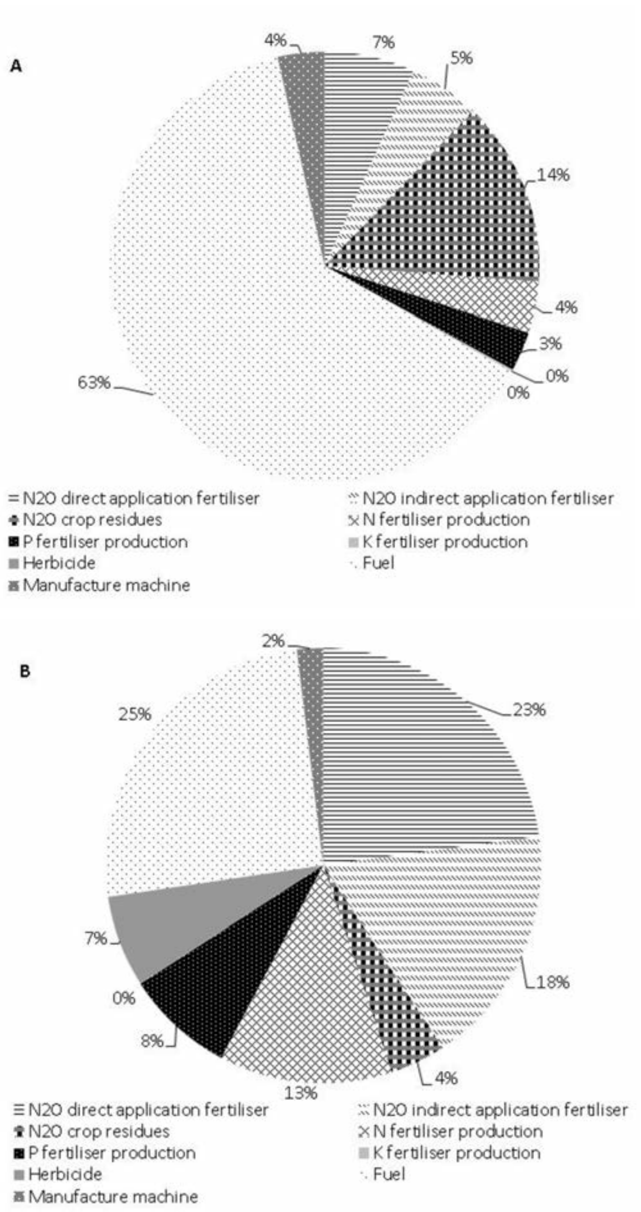

Figure 3. Greenhouse gas emissions (CO_2eq) for the organic micro-agroecosystem and the conventional micro-agroecosystem (percentage). A) Old organic; B) Conventional.

results of Gattinger *et al.*, also in our study we found that the soils under organic management stocked 3.4 Mg C ha^1 more than soils under conventional management. This value is derived by calculating the difference between soil carbon stocks in the organic system and in the conventional system, as described in Table 3). Instead, unlike Gattinger *et al.* (2012), we did not observe a significant difference in terms of carbon sequestration rate between the two farming systems. This result can be probably ascribed to the short period of our analysis. Ellert *et al.* (2001) argued that a period of 5 years is not sufficient to obtain statistically significant results in terms of carbon sequestration rate. Marriott and Wander (2006) reported that the increase of SOC sequestration by about 14% in organic systems *vs* conventional systems occurred on average after 10 years.

The same tillage used in the two management systems affected the carbon sequestration rate. Probably in the organic system the benefits in terms of carbon sequestration resulting from the application of carbon input (from cover crops, crop rotation and green manure) are partly lost due to the use of conventional tillage (for example ploughing) that accelerates the mineralisation process.

Even though it is widely acknowledged that different types of tillage affect the SOC concentration in soils under organic management, the results yielded by different research works are not univocal, because the effects can differ depending on the different pedoclimatic conditions (Alluvione *et al.*, 2013). Teasdale *et al.*, (2007) found a significantly higher carbon concentration in the organic system compared to the no-till system. Wells *et al.* (2000) and Küstermann *et al.* (2008) found a significantly higher organic carbon content in the organic system which did not involve the use of minimum tillage. Leifeld and Fuhrer (2010) and Robertson *et al.* (2000) emphasized the need to apply the carbon input to the soil with minimum or no-tillage.

Conclusions

In our study we have applied a simplified methodology to assess the carbon balance in a long-term experiment conducted in the MOLTE trial of the University of Florence.

Both in terms of CO_2eq emissions and carbon sequestration, the simplified methods applied provided comparable results to those found with complex methodologies reported in the literature.

Regarding CO_2eq emissions, the simplified methodology applied showed a reduction of GHG emissions in the organic system compared to the conventional system. Furthermore, the results indicate a minor involvement of the organic system in the emission of greenhouse gases per unit of area and per unit of product compared to the conventional one (58% and 61% less CO_2eq respectively).

Also in terms of carbon sequestration, the chemical tests for SOC calculation showed an increase of SOC in the organic system that is comparable to the results obtained with complex models for the calculation of soil carbon fluxes reported in the literature.

Organically managed soils have stocked 3.4 Mg C ha^{-1} (in five years) more the soils under conventional management. The carbon sequestration rate of the period under study did not show a significant difference between the two management systems. The same tillage used in the two farming systems, probably, affected this parameter.

These results are confirmed in numerous studies published recently (Küstermann *et al.*, 2008; Leifeld and Fuhrer, 2010; El-Hage-Scialabba and Müller-Lindenlauf, 2010; Gattinger *et al.*, 2012), which highlight that organic systems can have more positive effects on the carbon balance by reducing the use of inputs and increasing soil carbon sequestration.

In the future it will be important to validate the simplified set of indicators adopted in the MOLTE under different pedoclimatic conditions by comparing it with observed data and results of more complex simulation models, with the objective of extending its use to commercial farms.

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