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ORIGINAL PAPER

Changes in Labile Fractions of Soil Organic Matter During the Conversion to Organic Farming

H. Abdelrahman[1,2] · C. Cocozza[3] · D. C. Olk[4] · D. Ventrella[5] · F. Montemurro[5] · T. Miano[3]

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Abstract
Organic farming can overcome the environmental consequences of intensive conventional farming. The objective of the work was to investigate the changes in labile soil organic matter (SOM) fractions during the conversion from conventional to organic farming in two Italian sites, namely Foggia (FG) and Metaponto (MT), which differed mainly in initial soil organic carbon (SOC) content. Fields were cultivated with lentil and wheat in rotation and treated with either compost or nitrogen or phosphorus (N/P) fertilizers in three field replicates. The SOM was sequentially fractionated into light fraction (LF), particulate organic matter (POM), and mobile humic acid (MHA) fraction. Isolated fractions were quantified and analyzed for C and N contents. Although total SOC responded to the fertilization treatments, the LF and POM fractions were yet more responsive. The MHA represented on average of 15% of SOC at both sites; however, the LF represented only 5–6% of the total SOC but was the most responsive to changes in soil management. Compost application contributed significantly greater quantities of LF, POM, and MHA than did the N/P fertilizers application. The initial SOC content can play an important role in determining the impacts of introducing organic farming practices on SOM fractions. Although both sites had an initial low SOC content, the MT site, with a lower SOC content, showed a substantial fractional C increment as compared to the FG site.

Keywords Light fraction · Particulate organic matter · Mobile humic acids · Compost · Crop rotation

1 Introduction

Conventional farming practices have increased food production to support increasing human demands (Zinati 2002) although, most of the time, they have shown excessive use of energy and agrochemicals, large water consumption and greenhouse gases emissions, and loss of soil fertility and productivity (Gomiero et al. 2011). In contrast, organic agriculture is a production system that sustains the health of soils, ecosystems, and people (Halberg 2012); therefore, soil of high quality is one cornerstone of sustainable agricultural systems such as the organic ones.

Organic farming includes a series of practices that enhance nutrient and energy use and minimize environmental pollution, such as crop rotations and crop diversity, different combinations of livestock and plants, application of organic amendments (Nandwani and Nwosisi 2016), green manure (de Jesus Souza et al. 2019), and symbiotic N fixation with legumes (Romanyà and Casals 2019). These practices are assumed to result in higher levels of soil organic C and N in the long run, even if their introduction could lead to a low N availability for crop uptake as soil biological activity might not be able to provide sufficient nutrients in the early growing season (Clark et al. 1999). Moreover, Karasawa et al. (2015) found that individual soil enzyme activities were promptly increased six months after switching to organic management,

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✉ C. Cocozza
claudio.cocozza@uniba.it

1 Soil Science Department, Faculty of Agriculture, Cairo University, Giza 12613, Egypt

2 Faculty of Organic Agriculture, Heliopolis University for Sustainable Development, Cairo, Egypt

3 Dipartimento di Scienze del Suolo, della Pianta e degli Alimenti, Università degli Studi di Bari “Aldo Moro”, 70126 Bari, Italy

4 National Laboratory for Agriculture and the Environment, USDA–ARS, Ames, IA 50011, USA

5 Centro di ricerca Agricoltura e Ambiente (CREA-AA), Consiglio per la Ricerca in Agricoltura e l’Analisi dell’Economia Agraria (CREA), 70125 Bari, Italy

albeit a period of 18–24 months was needed to reach a steady state of the various soil enzymes activities. Therefore, the introduction of organic practices requires specific periods of adaptation of all means in use: at least two years before sowing, or in the case of perennial crops other than grassland and at least three years before the first harvest of organic products (Commission Regulation EC No 889/2008). At the end of the conversion period, various changes occur to the soil, e.g., Briar et al. (2011) and Stamou et al. (2011) reported a clear shift of N from the mineral pools to the microbial biomass-N, while Santos et al. (2012) showed that organic farming practices increased the content of the humic fractions and 100–300% the soil microbial biomass.

Despite its great importance for soil fertility, the total soil organic carbon (SOC) could not reflect changes of the introduction of organic practices because it often takes years before shifts in agricultural management show detectable variations in SOC content (Clark et al. 1998; Yang et al. 2019). In contrast, the labile pools of soil organic matter (SOM) are sensitive to short-term changes in management and/or environmental conditions (Haynes 2005), especially the light fraction (LF), the particulate organic matter (POM), and the mobile humic acid (MHA; Abdelrahman et al. 2016, 2017; Marriott and Wander 2006). The LF is similar chemically to the original plant material, but a lesser amount of carbohydrates (Abdelrahman et al. 2016) and a greater quantity of sterols in the LF indicate the early stage of its decomposition in soil (Gregorich et al. 1996). The POM consists of partially decomposed plant litter, and it acts as a substrate and center for soil microbial activity, a short-term reservoir of nutrients, a food source for soil fauna, and loci for formation of water stable macroaggregates (Haynes 2005). The POM could be considered a larger contributor to total SOC as Mandal et al. (2019) showed a high positive correlation between POM carbon and SOC. The MHA is a labile fraction of humic substances rich in N, S, and H, characterized by phenolic moieties derived from the lignin residues, involved in short-term nutrients cycling (Olk 2006). Since conventional farming systems range from traditional cultures, low input, and environmentally friendly managements (e.g., minimum or zero tillage, integrated pest management, etc.) to intensive industrial monocultures (Gomiero et al. 2011), the introduction of strictly regulated organic practices can influence differently the labile fractions of SOM. Therefore, the objective of this work was to study the evolution of LF, POM, and MHA during the conversion period in two sites historically cultivated with wheat followed by a fallow period and managed with the same conventional practices, but different mainly for their initial SOC content. In particular, the work investigated the effects of the introduction of the lentil–wheat rotation and of the transition from the conventional fertilization to the one allowed in organic farming, from the conventional to the minimum tillage, and from the removal of aboveground crop residues to their return to soil, on the characteristics of LF, POM, and MHA.

2 Materials and Methods

2.1 Site Description and Experimental Design

The experimental stations at Foggia (FG; 41°27′35″ N and 15°30′18″ E) and Metaponto (MT; 40° 24′25″ N and 16°48′ 24″ E) in Italy have been cultivated for decades under conventional farming with wheat followed by a fallow period (July–September). The conventional tillage included moldboard plowing (35 cm deep) in late August and disk harrowing (15 cm deep) in November to prepare a proper seedbed. The crop was historically rainfed and fertilized with mineral fertilizers, typically about 200 kg diammonium phosphate (18 N, 46 P_2O_5) ha^{-1} before sowing, followed by about 100 kg urea (46 N) ha^{-1} at jointing stage. During the conventional farming, the wheat straw was removed from the plots and placed on the market for livestock.

These sites were converted to organic farming in response to the movement toward organic production in Italy and Europe and to study the changes in SOM under organic farming management. Soils at both sites are Vertisols belonging to the group of Calcixererts (Soil Survey Staff, 1999), and their main characteristics at the beginning of the trial are reported in Table 1. The climate at both sites was similar, with mean annual precipitation of 560 and 500 mm at FG and MT, respectively, mainly concentrated in autumn and winter. The mean annual temperature was 15.5 °C (annual temperature range 44/−10 °C) and 15.8 °C (annual temperature range 35/0 °C) at FG and MT, respectively.

The experiments started in 2009 and included a 2-year rotation of lentil (*Lens esculenta* Moench, cv Eston) with either durum wheat (*Triticum durum* Desf., cv Svevo) at FG or emmer wheat (*Triticum dicoccum*) at MT, and all crops were rainfed. Each experimental site was divided into 10 × 10 m plots distributed in a completely randomized block design with at least three replications for each treatment (supplementary material). Treatments were as follows: i) compost, ii) commercial organic fertilizer (N/P fertilizer), iii) compost applied at a rate of 13.3 Mg ha^{-1} (compost-A), respecting the N load limit (170 kg ha^{-1} yr^{-1}) defined by the EU Nitrate Directive (676/1991), and iv) an unfertilized control. Only the first two treatments were imposed at FG, and their application rate at both sites was calculated to meet crop requirement of 100 kg ha^{-1} N for a subsequent wheat crop (7.82 and 0.8 Mg ha^{-1} of compost and N fertilizer, respectively) or 30 kg ha^{-1} P_2O_5 for a subsequent lentil crop (3.55 and 0.2 Mg ha^{-1} of compost and P fertilizer, respectively). The compost applied annually to both wheat and lentil crops was prepared using olive pomace, olive pruning residues, and cattle manure enriched in straw bedding material. Either olive residual biomasses than cattle manure and bedding materials came from farms certified organic. For N/P fertilizer treatment, each new wheat crop received only N fertilizer and,

Table 1 Selected soil characteristics at the start of the conversion period in 2009

Site	pH (H_2O)	EC (dS m^{-1})	Clay g kg^{-1} soil	Silt	Sand	$CaCO_3$	OC	TN	P_{ava} mg kg^{-1} soil	K_{exc}
FG	7.8 ± 0.2	0.17 ± 0.05	455 ± 2.6	330 ± 5.6	215 ± 8.7	49.9 ± 3.1	14.3 ± 0.3	1.35 ± 0.01	16.4 ± 1.3	637 ± 33
MT	8.8 ± 0.1	0.18 ± 0.04	560 ± 1.9	360 ± 8.7	80 ± 5.6	91.5 ± 1.1	9.90 ± 0.6	1.30 ± 0.01	19.7 ± 2.1	759 ± 27

FG Foggia, *MT* Metaponto, *EC* electrical conductivity, *OC* organic carbon, *TN* total nitrogen, P_{ava} available phosphorous, K_{exc} exchangeable potassium

each new lentil crop received only P fertilizer. These applications were made annually in the autumn, between October and November depending on the weather conditions. Compost and N/P fertilizers were permitted in organic farming (Annex 1, Commission Regulation EC no. 889/2008). Soils were left bare after harvest (July) until September–October then the disc harrowing (15 cm depth) was applied for incorporating the crop residues and for preparing the soil for the subsequent crop.

2.2 Soil Sampling and SOM Characterization

Soils were sampled at the start of the conversion period (September 2009) to represent the initial soil conditions (T0) and after the harvest of each crop in 2010 (T1) and 2011 (T2). Soil samples were collected from the 0–30 cm depth from each treatment, air-dried, passed through a 2- mm sieve, and stored at room temperature in dark for subsequent analyses. At the end of each crop cycle, residues of wheat straw and lentil were collected from nine spots of 1 m^2 in each plot and weighed in order to estimate the quantity of crop residues left on each plot and treatment.

The total C and N contents of soil and SOM fractions were determined through automated combustion analysis (Fisons NA 1500 NC Series 2). Inorganic carbon was determined by the modified pressure-calcimeter (Sherrod et al. 2002) then the organic C was determined by the difference between total C and inorganic C.

Soils were sequentially extracted for the LF, the POM, and the MHA using a modified procedure by Cao et al. (2011). Each field replicate was extracted separately for these three SOM fractions. The LF of the whole soil was extracted by floating the soil in a 1.6 g cm^{-3} Na polytungstate (PT) solution. The bottles were shaken for 10 min on a reciprocal shaker at 200 rpm, transferred to 500-mL beakers and allowed to settle overnight. Afterward, the floating LF was removed from each beaker by vacuum suction and collected on a 20-μm-nylon filter and then transferred by PT washes into a 50-mL beaker and allowed to stand for 3 h. After 3 h, the floating material was removed from the 50-mL beakers by vacuum suction and collected onto the 20-μm-nylon filter, then washed by deionized water and transferred into preweighed drying tins. This material was dried overnight in a forced air oven at 58 °C.

Each soil sample replicate, remaining after the LF extraction, was dispersed by shaking in a Na-metaphosphate solution. Then the content of each bottle was poured through stacked 53 μm sieves so that clay and silt material were collected in an underlying shallow Pyrex pan. The > 53 μm POM fraction were refloated on 2.0 g cm^{-3} PT solution to obtain its light fractions, which was used for all further analyses. The Pyrex pan containing the silt plus clay was dried overnight in a forced air oven at 58 °C.

Following POM extraction, the dried silt plus clay material from each soil was evenly divided into two or three 500-mL centrifuge bottles. The contents of each bottle were extracted by 0.25 mol L^{-1} NaOH at a 1:10 (w:v) ratio. Specifically, the contents of each bottle were placed under an N_2 atmosphere by bubbling N_2 gas into each bottle for 5 min. Bottles were capped and shaken at about 200 rpm on a reciprocal shaker for 30 min every 2 h for a total of 20 h. The bottles were then centrifuged and the supernatants decanted and acidified (2 mol L^{-1} HCl) to pH 1.95–2.0 to precipitate the MHA. The soil was shaken overnight in 0.25 mol L^{-1} NaOH two more times and the resulting MHA was combined from all three washes. The silt plus clay was decalcified by 0.2 mol L^{-1} HCl washes with shaking for 10 min at about 200 rpm and centrifuging until the supernatant pH decreased to < 1.0. Excess HCl was then removed by one–two deionized water washings until the supernatant pH rose above 2.0, preferably between 2.5 and 3.0. The MHA fractions were then cleansed of soil contaminants by resolubilization in a KOH–KCl solution and by reprecipitation with 2 mol L^{-1} HCl (Swift, 1996), followed by a 24-h extraction with 0.2% HCl–0.2% HF and by 3 days of dialysis in successively weaker HCl solutions and at the end against water. Finally, the fractions were frozen and lyophilized.

2.3 Statistical Analysis

Each treatment was performed in three replicates. Experimental data were tested against the normal distribution using the homogeneity test; then data were analyzed using the general linear model procedure (SPSS 17.0, SPSS Inc.) with multivariable (fertilization treatment, crop, time, and their interactions) on the measured parameters for the LF, POM, and MHA.

3 Results

3.1 Crop Residue Masses

Crop residues are one of the main inputs of organic matter into soil. As the LF and POM are plant-like or partially decomposed materials (Gregorich et al. 2006), the input rate of crop residues into soil is an important consideration for understanding their cycling rates. The amounts of above-ground crop residues remaining after crop harvest did not differ among the treatments at either site; they were on average 7.05 Mg ha^{-1} and 10.65 Mg ha^{-1} after lentil and wheat, respectively. The belowground residues were not measured; however, they were estimated in about 0.8 Mg ha^{-1} and 3.7 Mg ha^{-1} after lentil and wheat, respectively, according to the root-to-shoot ratio (Arcand et al. 2013).

3.2 Soil C and N Contents

Total soil organic C increased by 2–14% and by 0.5–21% over the 2-year course in the FG and MT sites, respectively (Fig. 1a). At the FG site, SOC increased numerically with either compost or N/P fertilizer treatment compared to T0. The greater increase in SOC was reported at T2 after compost

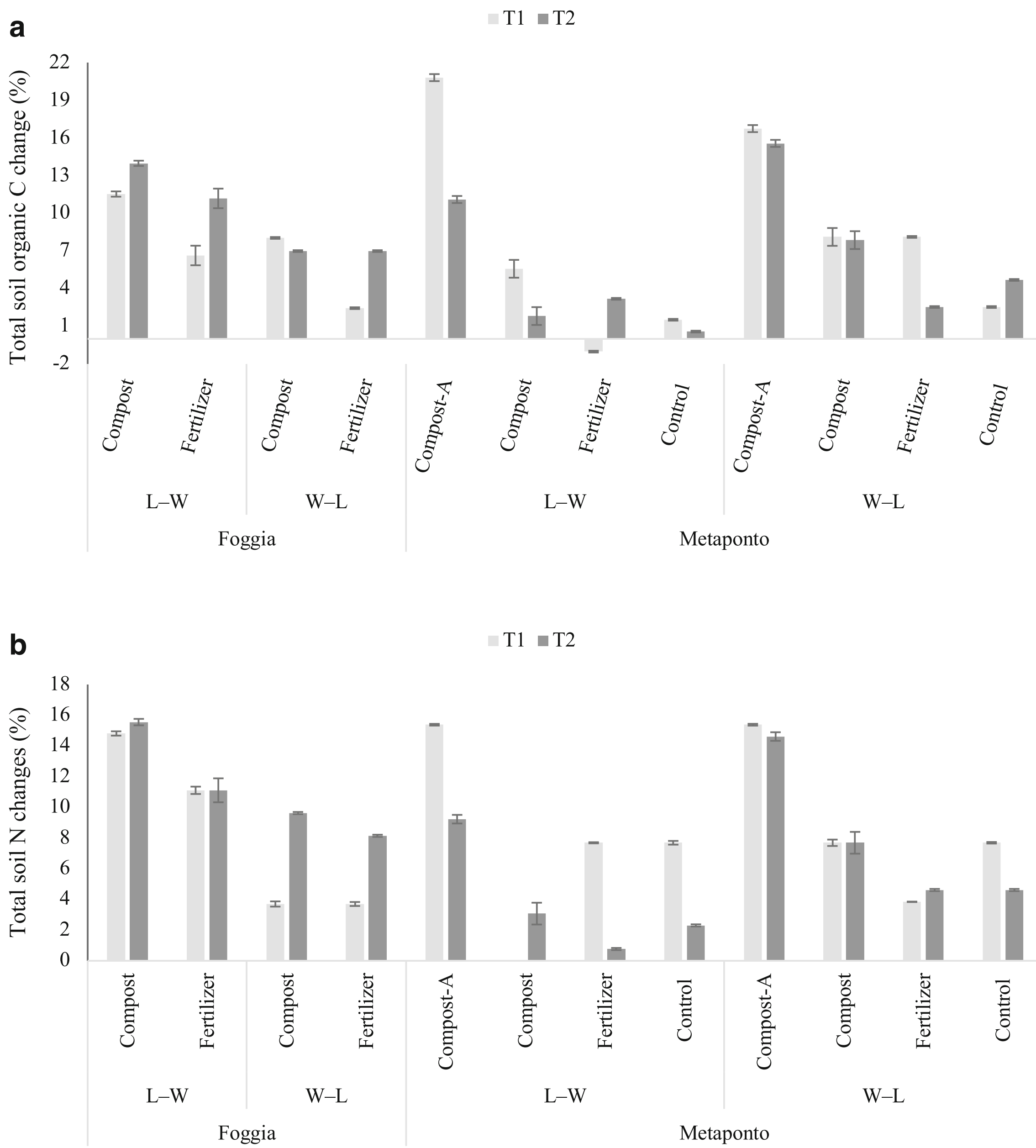

Fig. 1 Percent changes [(Tx-T0)/T0*100; where x refers to T1 or T2] in total soil organic C (**a**), and total soil N (**b**) after different fertilization treatments and rotations of lentil (L) and wheat (W) in 2010 (T1) and 2011 (T2) at the Foggia and Metaponto sites. Missing bar indicates a 0% change

and lentil–wheat rotation, however, neither crop ($P = 0.446$) nor fertilization treatment ($P = 0.486$) significantly affected SOC changes (Table 2). At the MT site, similar increases in SOC occurred after the fertilization treatments and were more evident after the compost-A treatment with either crop (Fig. 1a). Also, SOC at the MT site was not significantly (Table 2) affected by fertilization treatment ($P = 0.074$) or crop ($P = 0.276$).

At the FG site, larger numerical increases in soil N were reported after compost and fertilizer and after the lentil–wheat crop cycle at the end of the trial (T2; Fig. 1b). The latter result can be attributed to the lentil effect from T1 (Fig. 1b), even if the changes in soil N in FG were neither significantly affected (Table 2) by crop ($P = 0.267$) nor by fertilization treatment ($P = 0.302$).

At the MT site, soil N increased significantly ($P < 0.001$) after lentil at T1 with compost-A, fertilizer and control; however, no noticeable changes occurred after lentil at T2, except for control (Fig. 1b). Even the fertilization affected significantly soil N content (Table 2), with compost-A resulting in the largest percent variation (Fig. 1b).

3.3 Mass Distribution of SOM Fractions

The introduction of the organic farming management influenced the mass of the SOM fractions at both sites already at the end of the first crop cycle (Fig. 2a and b). At the FG site, mean LF mass with compost application was about 3 g kg^{-1} soil for either crop at T1 and T2. In general, the LF increased significantly ($P = 0.013$; Table 3) with either compost or N/P fertilizer treatment compared to the initial conditions (about 1.2 g kg^{-1} soil; Fig. 2a).

After lentil, the POM masses of all treatments were similar to the initial value (about 2 g kg^{-1} soil), while POM masses increased numerically (about 2.3 g kg^{-1} soil) after wheat and in the compost amended plots (Fig. 2a; Table 3). The compost treatment and the rotation wheat–lentil showed MHA masses similar to the initial value but numerically greater than the N/P fertilizer treatment. In addition, greater MHA masses were associated with lentil, for both compost and N/P fertilizer, than with durum wheat (Fig. 2a; Table 3).

At the MT site, compost-A treatment contributed significantly (Table 3) to the largest LF masses after either lentil or wheat (about 2.3 and 1.8 g kg^{-1} soil, respectively) at T1 and T2 (Fig. 2b). In general, the compost treatments contributed to greater LF mass with either crop with respect to the other treatments. Within the control treatment, LF mass was greater after wheat than after lentil (about 1 and 0.8 g kg^{-1} soil, respectively), reflecting the crop effect on the LF ($P = 0.009$; Table 3). At the end of each crop cycle, the POM was more abundant after the compost treatments with either crop than with the N/P fertilizer. The MHA masses were numerically greater ($P_{crop} = 0.103$, Table 3) after lentil than after wheat (about 2.3 and 1.8 g kg^{-1} soil, respectively) for all fertilization treatments. However, the unfertilized control showed MHA masses fairly similar to the initial soil endowment (about 1.65 g kg^{-1} soil).

Table 2 Levels of significance (P values*) for the effect of crop, fertilization treatment, time, and their interactions on the soil C and N fractions during 2009–2011 at the Foggia (FG) and Metaponto (MT) sites

Variable	FG		MT	
	C	N	C	N
Fertilization (F)	0.486	0.302	0.074	**< 0.001**
Crop (C)	0.446	0.267	0.276	**< 0.001**
Time (T)	0.002	<0.001	0.043	<0.001
F × C	0.365	0.899	0.885	0.309
F × T	0.871	0.728	0.686	**< 0.001**
C × T	0.161	**0.007**	0.736	**< 0.001**
F × C × T	0.695	0.674	0.999	0.922

*Actual P levels results of the multivariate general linear model analysis, $P \leq 0.05$ (in bold) is significant

3.4 Carbon Content in SOM Fractions

The fractional C content of a SOM fraction is the product of the fractional mass multiplied by its C concentration and it represents the contribution of a certain fraction to total SOC. At the end of the trial, fractional C concentration, averaged across crops and treatments, differed from LF (351 g C kg^{-1} LF) to POM (314 g C kg^{-1} POM) to MHA (411 g C kg^{-1} MHA) but did not differ greatly within the same fraction by fertilization treatment or crop, making the fractional C mainly a function of its mass.

The LF fractional C (LF-C) varied slightly among the fertilization treatments, primarily due to the fractional mass and it represented on average about 5.8% of total SOC at both sites at the end of the trial. At the FG site, the fertilization treatment had significant effects ($P = 0.007$; Table 4) on the LF-C as it increased by 5–150% after compost and N/P fertilizer treatments (Fig. 3a) and reached about 1 g C kg^{-1} soil. The LF-C significantly increased with time too ($P < 0.001$; Table 4), and the interaction between crop and time clearly induced a positive and significant effect on LF-C ($P = 0.009$; Table 4).

At the MT site, the greatest LF-C percent increase was recorded at T1 for compost-A after the lentil–wheat cycle (Fig. 3b). All compost-based treatments contributed to greater LF-C with respect to the N/P fertilizer or the control treatment with either crop cycle. Crop ($P = 0.022$) and fertilizer treatment ($P < 0.001$) significantly affected the LF-C at the MT site (Table 4).

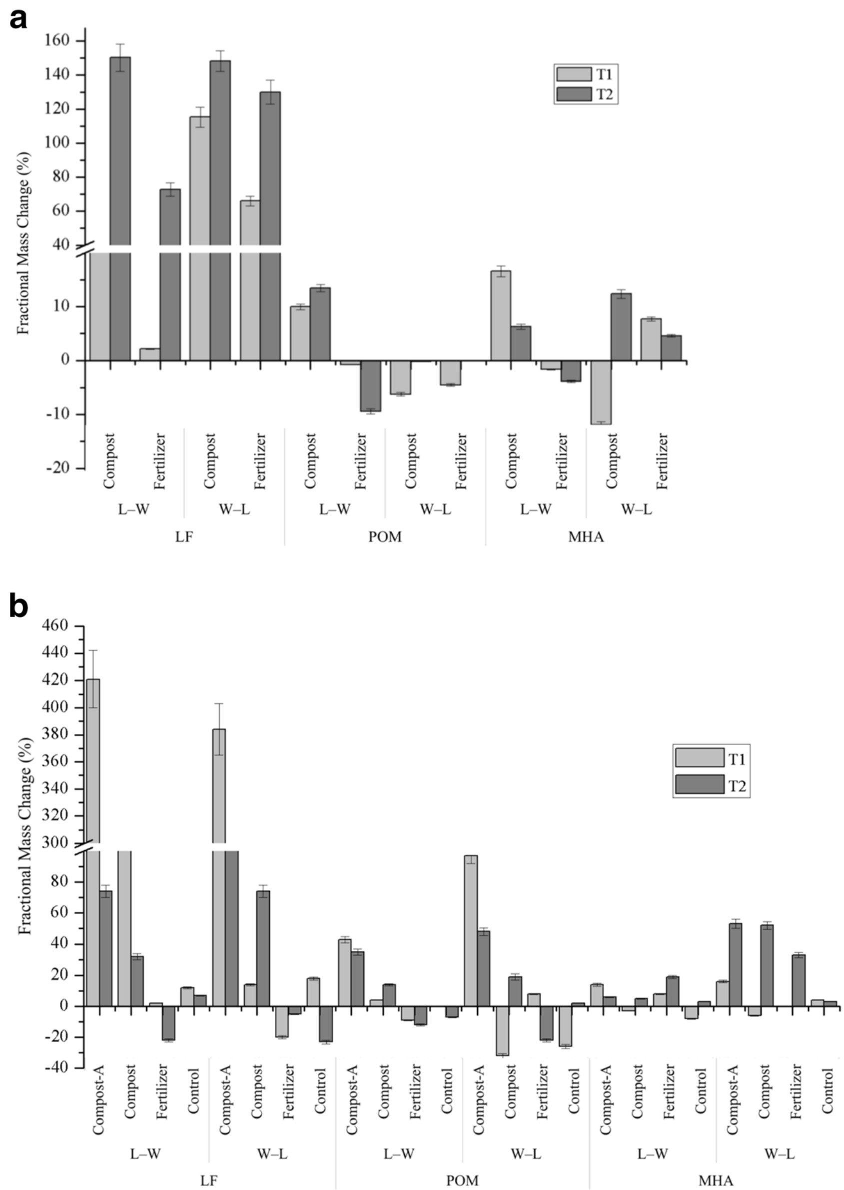

Fig. 2 Percent changes [(Tx-T0)/T0*100; where x refers to T1 or T2] in fractional mass of the light fraction (LF), the 500–53 μm particulate organic matter (POM) and the mobile humic acid (MHA) after different fertilization treatments and rotations of lentil (L) and wheat (W) in 2010 (T1) and 2011 (T2) at the Foggia (**a**), and Metaponto (**b**) sites. Missing bar indicates a 0% change

At the FG site, the POM fractional C (POM-C) increased significantly with time ($P < 0.001$; Table 4) regardless of rotation or fertilization (Fig. 3a). On the other hand, the POM-C, at the MT site, was significantly influenced by the fertilization ($P < 0.001$) and the time ($P = 0.001$; Table 4), reaching the highest value (about 0.92 g C kg^{-1} soil) already in T1 with the compost-A treatment after wheat. As per the LF-C, compost-A and compost treatments showed higher percentile increments of POM-C with respect to the other treatments, even if the compost treatment induced a substantial increase in POM-C only at the end of the trial (T2; Fig. 3b).

At T2, the POM-C represented 4% and 6% of SOC in the FG and MT sites, respectively, showing an increase over time, since POM-C accounted in 2009 for only 2.6% and 4.5% of SOC at the FG and MT sites, respectively.

The MHA fraction contained an average of 411 g C kg^{-1} fraction at both sites and represented on average 13.4% and 7.3% of total SOC in T2 at the FG and MT sites, respectively. At the FG site, the MHA-C increased during the experimental course after compost and lentil on one side, and after N/P fertilizer and wheat on the other side (Fig. 3a), reaching about 2.3 g C kg^{-1} soil, which was more than 15% of the total SOC. Despite the reported increases in the MHA-C, neither crop ($P = 0.167$) nor fertilization treatment ($P = 0.498$) had significantly affected the MHA-C (Table 4).

At the MT site, the MHA-C changes during the experimental course were significantly influenced by the crop ($P < 0.001$), the fertilization treatment ($P = 0.001$), and the time ($P < 0.001$; Table 4). The largest increase in the MHA-

Table 3 Levels of significance (*P* values*) for crop, fertilization treatment and time effects on the mass of the SOM fractions during 2009–2011 at the Foggia and Metaponto sites

Variable	Foggia			Metaponto		
	LF	POM	MHA	LF	POM	MHA
Fertilization (F)	**0.013**	0.390	0.770	**< 0.001**	**< 0.001**	0.094
Crop (C)	0.162	0.671	0.762	**0.009**	0.622	0.103
Time (T)	**< 0.001**	0.983	**0.023**	**< 0.001**	0.252	**< 0.001**
F × C	0.222	0.775	0.221	**0.024**	0.532	0.150
F × T	0.160	0.736	0.271	**< 0.001**	**0.001**	0.116
C × T	**0.004**	0.674	0.443	0.130	0.940	**0.003**
F × C × T	0.496	0.470	0.163	0.062	0.780	0.392

*Actual *P* levels results of the multivariate general linear model analysis, $P \leq 0.05$ (in bold) is significant

C was reported after the compost treatment and wheat–lentil rotation (Fig. 3b; 0.97 g C kg^{-1} soil).

4 Discussion

The results of the present study might provide insights into the response of SOM to the introduction of new agricultural practices such as crop residue retention, crop rotation, minimum tillage, and organic fertilization. The relatively small SOC content changes recorded during the conversion period from conventional to organic farming agree to the findings of Herencia et al. (2008) who reported numerical improvement of SOC in plots receiving organic treatments at the end of the conversion period; however the SOC increase became significant only after 4–5 crop cycles. In contrast, Gopinath et al. (2009) showed a significant SOC increment already at the end of a two-year transition period of a bell pepper crop. Generally, the increase in total soil C or in fractional C after organic amendment application tends to be more evident after long-term application (Yang et al. 2019).

Though SOC responded to introduction of the organic farming practices, the labile fractions of SOM were yet more responsive, but to a different extent in each site. At the FG site, the LF was the sole fraction that responded significantly to the new soil management showing an increase of its mass and fractional C content. At the MT site, both the LF and the POM showed significant variations of their mass and fractional C content, as well as the C content of the MHA. The greater content of the MHA-C recorded at the MT site, especially after lentil, might have been also due to greater activities of soil microbial communities in response to balanced C/N ratio of the lentil residues compared to the wheat ones (Gan et al., 2011; Le and Marschner 2018); such high-quality residues might lead to more microbial remains that can be stabilized in SOC (Cotrufo et al. 2013).

Since changes in SOM usually occur when the rates of C input and C loss (decomposition) diverge (Janzen et al., 1997), the recorded changes in SOC and especially in labile SOM fractions could have been promoted by the following different conditions: i) the crop residues were left on the ground and the distributed organic amendments contained high contents of C and were applied at high rates, compared to the previous soil management; ii) the minimum tillage, introduced to the study sites at T0, slowed the mineralization processes of the C deriving from crop residues and organic fertilization, and built SOM, as reported by Varvel and Wilhelm (2011) too; iii) the studied soils were depleted in SOM, which consequently heightens the effectiveness of the introduction of the new soil management. However, soils responded specifically different to the introduction of organic farming, which was possibly due to the diverse initial soil fertility level of the two sites (Table 1). Despite its higher clay and silt content, soil at MT was characterized by a dramatically lower SOC and since several authors (e.g., Hassink 1997; Trigalet et al. 2014; Frasier et al. 2019) have found positive linear correlations between the SOC and the silt plus clay contents, the larger and variable response to management at MT was possibly due to its higher soil degradation status. Bakken et al. (2006) found similar results studying three cropping systems after

Table 4 Levels of significance (*P* values*) for the effect of crop, fertilization treatment, time and their interactions on SOM fractional C content during 2009–2011 at the Foggia (FG) and Metaponto (MT) sites

Variable	FG			MT		
	LF–C	POM-C	MHA-C	LF–C	POM-C	MHA-C
Fertilization (F)	**0.007**	0.451	0.498	**< 0.001**	**< 0.001**	**0.001**
Crop (C)	0.194	0.331	0.167	**0.022**	0.735	**< 0.001**
Time (T)	**< 0.001**	**< 0.001**	0.223	**< 0.001**	**0.001**	**< 0.001**
F × C	0.098	0.544	0.085	0.078	0.536	0.187
F × T	0.112	0.088	0.395	**< 0.001**	**0.002**	**0.005**
C × T	**0.009**	0.592	0.532	0.240	0.971	**< 0.001**
F × C × T	0.420	0.049	0.044	0.146	0.773	**0.016**

*Actual *P* levels results of the multivariate general linear model analysis, $P \leq 0.05$ (in bold) is significant

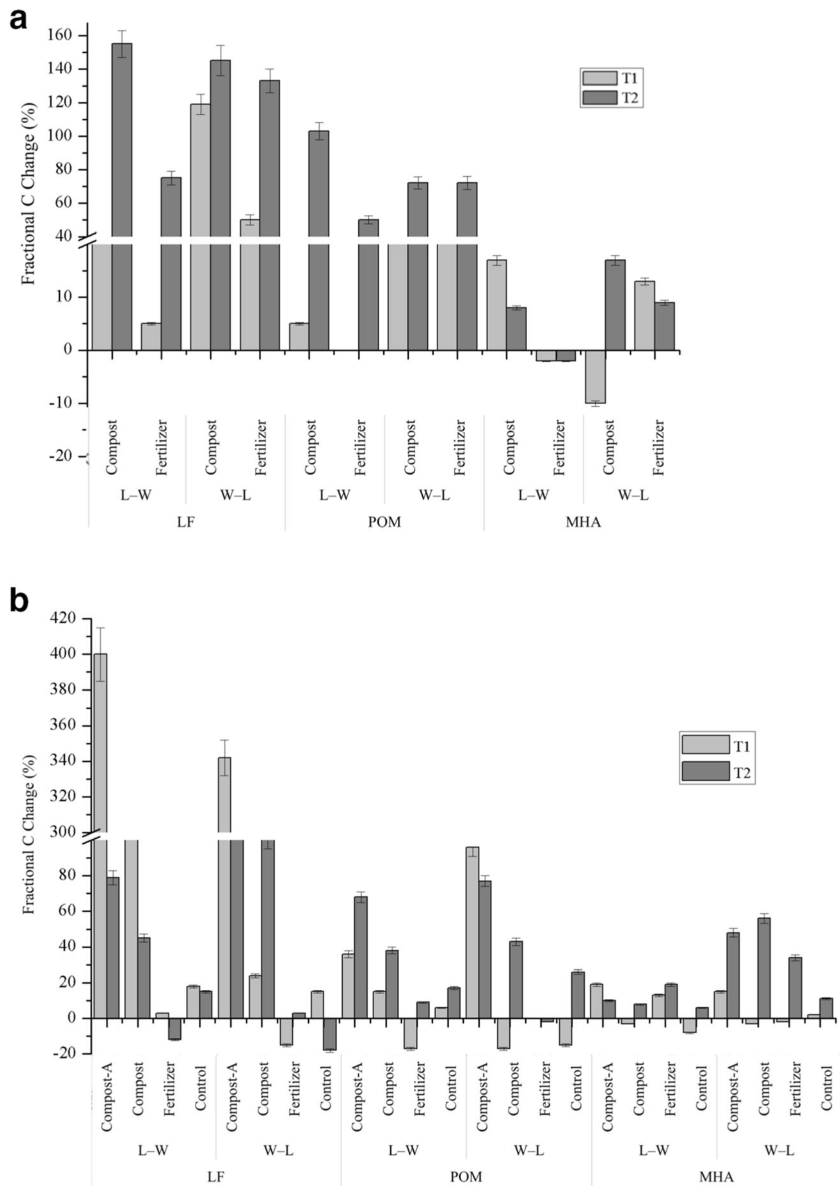

Fig. 3 Percent changes [(Tx-T0)/T0*100; where x refers to T1 or T2] in fractional C (fraction mass × fraction C concentration) in the light fraction (LF), the 500–53 μm particulate organic matter (POM) and the mobile humic acid (MHA) after different fertilization treatments and rotations of lentil (L) and wheat (W) in 2010 (T1) and 2011 (T2) at the Foggia (**a**), and Metaponto (**b**) sites. Missing bar indicates a 0% change

conversion from conventional to organic farming: physical and biological soil properties improved in the experimental site managed with all-arable cropping before switching to the organic practices, while sites characterized by fertility building leys preceding the introduction of the organic farming did not respond clearly due to their initial higher level of soil fertility. Furthermore, Six et al. (2002) suggested the existence of a storage capacity of soils with respect to C as many long-term field experiments exhibited a proportional relationship between C inputs and SOC content across treatments, while some trials in high C soils showed little or no increase in SOC content with two- to threefold increases in C inputs. For the same reasons, even the total soil N at MT showed a significant increase already by the end of the first year (T1), regardless of crop or fertilization. In addition, the unamended control treatment at MT had numeric accruals of total soil organic C and N and fractional C nearly as large as the corresponding increases in some of fertilized plots, indicating that the minimum tillage promoted the conservation and development of SOM deriving from crop residues and crop rotation in the unamended plots.

However, the soil degradation status, the amount of fertilizer applied, and the balanced root exudates could be the reasons for the percentage reduction of total SOC recorded at MT after the application of P fertilizer to legume the first year of experimentation (T1, Fig. 1a). In fact, legumes might have stimulated the microbial community activity resulting in an increased mineralization of native SOM (priming effect), as reported by De Mastro et al. (2019) too.

Generally, at the MT site the slightly more negative percentage variations of LF and POM fractional masses following the N/P fertilizer treatments with respect to the control suggest that the N/P fertilizers might have stimulated the mineralization process, especially at the detriment of the more labile fractions. The same behavior has been observed only for the POM at the FG site underlining the central role played by that fraction for the microbial activity with respect to the LF and MHA.

5 Conclusions

The introduction of organic fertilization, minimum tillage, crop residues retention, and crop rotation demonstrated that during a 2-year conversion period only the light fraction and its fractional carbon content respond unquestionably to the introduction of these organic farming practices, demonstrating a starting build-up of soil fertility. The other labile fractions studied respond mainly when the initial soil conditions are rather degraded.

The conversion period should start with the use of compost, applied at a rate to meet the nutrient requirements of the crop or, even better, as soil conditioner, since it had a notable benefit on masses of all separated fractions and their carbon content. Likewise, at the beginning of the transition period, the crop rotation should begin with a leguminous. It is, also, suggestive that the soils undergoing conversion to organic farming should not be left bare during summer especially in areas with hot weather. Any vegetal cover for soil during the hot weather period might be of high importance for conserving soil organic matter. Finally, the fractionation scheme used here successfully integrated uncomplexed physical fractions with humified chemical fractions to depict short-term carbon cycling in field conditions.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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