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Response of wheat crop during transition to organic system under Mediterranean conditions

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Abstract

Organic agriculture is an ecological production management system aimed at sustainable production of safe food, environmental protection and maintenance of soil health. The objective of this study was to evaluate, in a period of organic transition, the effects of different organic fertilizers on wheat yield, grain quality and soil characteristics. The research was performed in an experimental farm of Southern Italy (Foggia), over a three year period. An organic commercial fertilizer and compost, obtained from municipal wastes, with and without a commercial bioactivator, were compared in a randomized block design. Grain yield and quality and soil total organic carbon content (TOC) were measured. The Henin-Dupuis model was also tested to simulate soil organic C dynamics after organic fertilizer application. Among the years, significant differences were observed in grain yield and quality, indicating that wheat crop response was influenced by the weather conditions. The grain and straw yield was not significantly affected by the organic fertilizer used, though the compost resulted in significantly lower grain quality compared with the organic commercial fertilizer. In any case, at the end of the experimentation, the compost resulted in significantly higher TOC (+4%) compared to the organic commercial fertilizer. The results showed that the compost may be used as an alternative to sustain wheat productivity, feasible also from an economic point of view and to conserve soil fertility. Finally, under the local Mediterranean conditions, the soil organic C dynamics could be defined by the Henin-Dupuis model, also considering the C supply of annual root residues.

Keywords: Durum wheat; Organic fertilizers; Compost; Bioactivator; Yield and grain quality; Soil organic carbon dynamics.

Introduction

In many parts of the world, agriculture causes environmental concern in terms of land degradation, water use and greenhouse gas emissions (Wood et al., 2006).

The management practices adopted in conventional systems, though results in high crop yields, can lead to severe damage to soil structure and soil erosion and thereby reduced soil fertility. In the long-term, these effects can provide a less favorable environment for plant growth and as a consequence reduce productivity and profitability (Wells et al., 2000). Several studies highlight that conventional farming systems are also associated with decreased levels of total soil N and total soil C over time (Drinkwater et al., 1998; Wander et al., 1994).

Because of problems of environmental degradation and public health risk associated with the conventional farming systems, there is a growing interest in alternative farming systems, including those organically managed, as ways to improve overall soil health, agricultural sustainability and environmental quality (Poudel et al., 2002). Nevertheless, during the "organic transition" period, defined as the years after switching from conventional to organic management, crop yields are often lower than in conventional systems so the expectation of initially lower yields can be a strong deterrent to those farmers who may wish to make such a change (Martini et al., 2004).

Under the typical climatic conditions of Mediterranean environment (aridity, high temperature, etc.), excessive tillage, over-fertilization, luxury irrigation, complete removal of crop residues, monoculture and indiscriminate use of agro-chemicals can contribute to severe losses of soil organic matter and as consequence favor sensitivity to land erosion and deterioration of soil structure (Lal, 2008). Therefore, practices that return organic materials to the soil are necessary for maintaining or improving soil fertility as well as crop yields and quality and for developing a sustainable agroecosystem (Komatsuzaki and Ohta, 2007; Lal, 2008). Several kinds of wastes contain large amounts of organic matter that can be used in agricultural system thus solving the problem of disposal and reducing the use of chemical fertilizers. However, the use of organic wastes for fertilizing soils requires technologies (as composting) for processing the raw materials and prevent soil contamination by some toxic substances, pathogens, etc. Several studies have demonstrated that composting of by-products, such as crop and biodegradable agro-industrial residues, allows production of low-cost organic amendment or fertilizer, humified and sanitized (Alburquerque et al., 2009; Alfano et al., 2008; García-Ruiz et al., 2012). Besides, to recover degraded soils, characterized by low organic matter content and therefore low microbial activity, which ultimately hinders the plant growth, in the recent years, there has been increasing interest in the use of bioactivator, obtained from different organic materials, in agriculture. Soil application of these bioactivators could quickly improve the microbial population of the soil, promote the rapid mineralization of nitrogen and other micronutrients and thus support the development of plant cover (Tejada et al., 2011). These bioactivators, generally comprising peptides, amino acids, polysaccharides, humic acids, phytohormones, etc., are directly absorbed by soil microorganisms and plants, which spend a smaller amount of energy in the absorption process (García-Martínez et al., 2010).

Since soil organic matter management, for maintaining the soil fertility in future, is an important pre-requisite for sustainable agriculture, use of simulation models could represent a tool to study and understand the organic carbon dynamics in the soil, to forecast the fate of carbon additions to the soil and to establish the optimal agronomic techniques to be adopted for preserving soil fertility, even depending on climatic conditions and soil texture (Andriulo et al., 1999; Bayer et al., 2006; Bertora et al., 2009).

In the light of these considerations, a three year research was carried out on durum wheat, grown under Mediterranean conditions and in a transitional organic farming management, with the following aims: (1) to investigate the agronomic performance of a compost in comparison with an organic commercial fertilizer; (2) to study the effects of a commercial bioactivator on crop yield and some soil properties; (3) to evaluate the accuracy of a simple method to estimate the short-term soil organic carbon content variation, after annual applications of organic fertilizers. Finally, a synthetic cost-benefits analysis was performed considering the costs at farm level for purchasing and spreading the fertilizers.

Materials and Methods

Site and experimental design

The field experiment was carried out over a three year period (from 2009 to 2012) in Southern Italy (Foggia, 41° 27' N, 15° 03' E), at the experimental farm "Podere 124", of the Research unit for cropping systems in dry environments (CREA-SCA), on durum wheat cv Svevo. This is an early variety widely cultivated in Italy, characterized by taller size and higher productivity and good quality (Arduini et al., 2006).

The site is characterized by an alluvial vertisol, clay soil, classified as a Typic Epiaquert, in accordance with the Soil Taxonomy. The soil showed average contents of clay, sand and silt of 49.4%, 19.5% and 31.1%, respectively, an average bulk density of 1100 kg m^{-3}, a sufficient total nitrogen content (about 1.3 g kg^{-1}), a good organic matter (about 2.5 g $100g^{-1}$) and available phosphorus (Olsen) content (about 25 mg kg^{-1}), a high exchangeable potassium content (about 1000 mg kg^{-1}). The climate is "accentuated thermomediterranean", as classified by UNESCO-FAO (1963), with winter temperatures that can fall below 0 °C, summer temperatures that can rise above 40 °C, the rainfall is unevenly distributed during the year (550 mm), being concentrated mainly in the period from November to February (winter months). The monthly minimum and maximum temperatures and the rainfall, during the three experimental years, are illustrated in Figure 1.

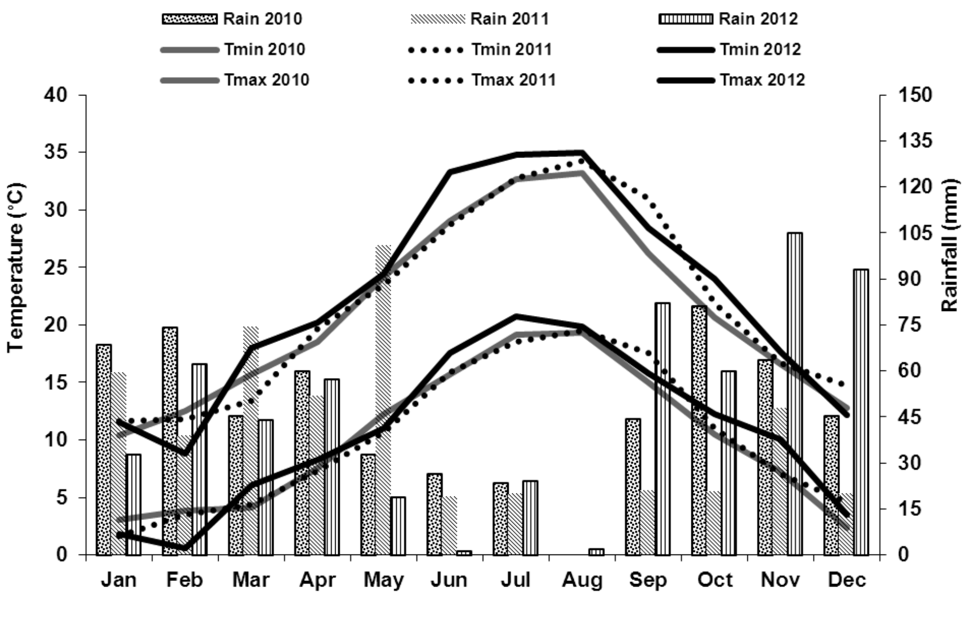

Figure 1. Mean monthly temperatures and rainfall during the three years of experimentation.

In a transitional organic system (the site was managed conventionally prior to the beginning of this survey), the following treatments were compared: (i) two organic fertilizers (F) with and without commercial bioactivator (A). The organic fertilizers were: an organic commercial fertilizer, allowed in organic farming (ORG); (ii) a compost, obtained from the organic fraction of municipal solid wastes, coming from the separate collection (MSW). A randomized block design, with a 2×2 factorial scheme (F×A) and three replications, was adopted. Every block was divided into four plots of 125 m^2 to study the effects of fertilizers and bioactivator application.

A N dose of 100 kg ha^{-1}, to supply the nutrient requirement of wheat, was applied, for both fertilizer treatments, in a single solution about two weeks before sowing. The amounts of compost and organic commercial fertilizer applied every experimental year were 4 and 0.8 t ha^{-1}, respectively, taking into account the N content of fertilizers and the crop needs. At the same time of fertilizing, the commercial bioactivator (10 kg ha^{-1}, as recommended by the producer) was also applied. The wheat sowing occurred in December in all experimental years. All agronomic practices were performed following the recommended organic management techniques.

The bioactivator, used in this experiment, is recommended in over exploited soils to reactivate the microbial component due to its high total extractable carbon/total organic carbon content ratio. The main chemical characteristics of the organic commercial fertilizer and bioactivator, provided by the manufacturer and compost are reported in Table 1. At the beginning of each experimental year, three samples of compost were randomly taken and analyzed. The total organic carbon (TOC) was measured by dichromate oxidation (Vitti et al., 2016). The total extractable C (TEC) was obtained by 0.1 M NaOH + 0.1 M $Na_4P_2O_7$ extraction, at 65 °C for 48 h and subsequently quantified as TOC content. Total nitrogen (N) was analyzed according to the Kjeldahl procedure, using a VELP heating block for sample digestion (in concentrated H_2SO_4 medium in the presence of a K_2SO_4 + $CuSO_4$ catalyst) and a VELP apparatus for steam distillation and finally titration with boric acid. The pH was measured in 1:10 (w/v) water soluble extraction at 24 ± 1 °C with a CRISON microTT 2050 pH-meter. Total phosphorus (P) and potassium (K) were determined by Inductively Coupled Plasma-Optical Emission spectrometry (ICP-OES) after digestion in HNO_3 65% in a pressurized microwave (ANPA Manuale 2001).

Table 1. The major chemical characteristics of compost (MSW), organic commercial fertilizer (ORG) and bioactivator (A).

	MSW	ORG	A
TOC (g kg^{-1})	380	400	400
N (g kg^{-1})	25	125	120
P (g kg^{-1})	3.7	-	-
K (g kg^{-1})	15.1	-	-
pH	8.4	4.5	-
TEC/TOC (%)	45	-	95

TEC/TOC = Total extractable carbon/Total organic carbon content ratio.

Plant and soil sampling and analyses

During the cropping cycles, the main phenological stages were identified from emergence to physiological maturity. At physiological maturity, about 200 days after sowing, harvesting was performed and the grain yield, straw yield, harvest index, test weight and grain moisture content were determined. Finally grain protein content, yellow and gluten index, were measured (Infratec 1241).

The wheat ears were threshed to obtain the grain weight (expressed at 13% of moisture). The harvest index (HI) was calculated as the ratio between grain yield and total aboveground biomass (straw, ear and grain). The moisture content of the grain at threshing was determined in laboratory after drying at 70 °C till constant weight.

Soil samples were taken from each plot at the beginning (T_0) and at the end of the experimentation (2012) at 0-0.40 m depth, air-dried, ground to pass through a 2 mm sieve and then analysed. The TOC and total N were analyzed according to the same procedures followed for the compost determinations. The available P was determined according to Olsen method; the exchangeable K was determined by extraction in a barium chloride–triethanolamine buffered solution (pH=8.2), followed by ICP-OES quantification (Page et al., 1982).

Besides, to describe the evolution of soil organic carbon content, the Henin-Dupuis model was used. Henin and Dupuis (1945) were the first to simulate mathematically the soil organic carbon dynamics with a simple model, according to the first order kinetics. The organic carbon stock ($C_{H\text{-}D}$), expressed in kg ha^{-1}, at t time (years) was described by the following equation:

$$C_{H-D} = C_0 \cdot e^{-K_2 t} + \frac{mK_1}{K_2}\left(1 - e^{-K_2 t}\right) \tag{1}$$

where C_0 is initial C soil reserves, m is the annual C application by organic fertilization, K_1 is the isohumic coefficient, which is defined as the quantity of humus formed from a unit in weight of fertilizer added to the soil (unitless), then it is characteristic of the specific organic material used, K_2 is the coefficient of mineralization (year^{-1}), which represents the amount of organic C that is mineralized every year. The annual mineralization coefficient was estimated on the basis of clay and limestone soil content and air temperature, as reported by Castoldi and Bechini (2006):

$$K_2 = \frac{1200 \cdot f_\theta}{\left[(200 + A) \cdot (200 + 0.3C)\right]} \tag{2}$$

where $f_\theta = 0.2 \cdot (T-5)$, is a temperature factor and T is the average annual air temperature (°C), A is clay content (g kg^{-1}), C is limestone content (g kg^{-1}).

Hence, the first component of the equation 1, $C_0 \cdot e^{-K_2 t}$, represents the fraction of C_0 still in the soil at time t. The second component, $\frac{mK_1}{K_2}\left(1 - e^{-K_2 t}\right)$, is the fraction of soil organic C pool derived from the humification of organic material additions, starting from T_0 (Di Bene et al., 2011).

The annual contribution of organic carbon released by root biomass (C_R) was evaluated as reported by Bolinder et al. (2007), considering that in grain crop the average C concentration was assumed to be 0.45 g g^{-1}, for all plant parts:

$$C_R = \frac{Y_P}{(S:R \cdot HI)} \cdot 0.45 \tag{3}$$

where Y_P is the dry matter yield of above-ground product (g m^{-2} yr^{-1}), *HI* is the harvest index, *S:R* is shoot/root ratio.

Thus, the overall soil organic carbon balance (C_{Tot}) at the end of the experiment was calculated as following:

$$C_{Tot} = C_{H-D} + C_{RH} \tag{4}$$

where C_{RH} represented the organic carbon pool derived from the humification of organic root residues and was estimated as following:

$$C_{RH} = C_R \cdot \frac{K_1}{K_2}(1 - e^{-K_2 t}) \tag{5}$$

considering the isohumic coefficient of wheat root residue, K_1, equal to 0.15 (Bartolini, 1986).

The C_{Tot} value was finally compared with the amount of soil organic carbon quantified at the end of the experiment ($C_{determined}$).

Statistical analysis

Data were analyzed using the SAS package (SAS Institute, 2012). Year was considered as a random effect (Leogrande et al., 2014). The effects of the treatments were assessed through the General Linear Model procedure. The means of the experimental treatments were compared using the Student–Newman–Keuls (SNK) test at $P \leq 0.05$.

Results and Discussion

Effects of years and treatments on wheat yield and quality

The effects of year (Y), type of fertilizer (F) and bioactivator (A) on wheat grain and straw yield, HI, test weight, protein content, yellow and gluten index are presented in Table 2. In the transitional organic system, all the parameters, except test weight, showed significant differences among years, indicating that the variability of the climatic conditions influenced the wheat crop response. The grain and straw yield was the highest in 2011, with significant increases of grain yield of 19% and 57% compared with 2010 and 2012, respectively. This behavior can be explained by the rainfall pattern during the whole cropping cycle and in particular in spring, during the ear filling stage, which favored the growth and development of plants and grain yield. In 2010 and 2012, during anthesis and ear filling stage, rainfall was negligible (8.40 and 4.20 mm, respectively) and the maximum temperature was higher (almost 5 °C) compared with 2011. Garrido-Lestache et al. (2004) noted that high temperatures and water stress in spring shorten the grain filling and maturing period, reducing grain yield. Other authors have emphasized the key importance of adequate available water at and after anthesis to optimize grain yield, observing a higher sensitivity of wheat to water stress from stem-elongation to grain-filling stage (Schillinger et al., 2008; Zhang and Oweis, 1999). In addition, Andersson and Holm (2011) reported that grain yields were significantly lower with high temperature at anthesis. During the third year (2012), HI value decreased significantly by 17% compared with the average HI value obtained in the other two experimental years (2010 and 2011), probably due to higher temperatures and lower amount of rainfall, during the last growing stage (May and June; Figure 1). Conversely, in 2012 the protein content, gluten and yellow index were significantly higher compared with previous years, indicating that grain quality was better in drier year. Our results are in agreement with Lopez-Bellido et al. (2001), who found that the weather strongly influenced grain protein content. In particular in drier years the protein content increased only when the grain yields were reduced, emphasizing a negative correlation between grain yield and grain protein content.

In the organic transition period, the fertilizers used did not affect grain and straw yields, HI and test weight (Table 2). So the compost, used as fertilizer, did not significantly reduce the yield compared with the organic commercial fertilizer. These results are in agreement with earlier studies on winter wheat and other crops, in which the positive effect of compost was highlighted (Abedi et al., 2010; Farhad et al., 2011; Lopedota et al., 2013). Significant differences were found for protein content, gluten and yellow index (Table 2), with higher values for the organic commercial fertilizer by 9, 6 and 4%, respectively, indicating that the grain quality was affected by the fertilizer used. Usually, the compost is characterized by slow mineralization rate in the soil, markedly affected by environmental conditions (soil moisture and temperatures). Thus, probably, in the treatment with compost, during grain filling stage, the nitrogen availability was lower than under organic commercial treatment. Hence, looking at the short-term, under the pedo-climatic conditions of the experimental field, compost did not fulfil the N needs of wheat crop, reducing the grain quality but not the yield.

No significant differences were observed with the addition of the bioactivator on the studied parameters, indicating that the soil of experimental field had a good fertility and probably a good microbial activity and hence the applied bioactivator did not provide any benefit (Table 2).

A significant Y×F interaction was observed for grain protein content (Table 2 and Figure 2). The grain protein content varied in the three years of experimentation. In particular, in the first year the lowest protein content was observed with no significant differences between the fertilizer treatments. In the second and third year significant differences were recorded between fertilizer treatments and the use of the organic commercial fertilizer increased the grain protein content compared with the compost. This finding confirms that even if the amount of soil available nitrogen represents the most important feature to optimize grain quality, the effect of N fertilization is governed by annual weather conditions and the grain protein content is the result of complex interactions between N and water availability, yield and temperature (Lopez-Bellido et al., 2001).

Overall, the average yield in the organic transition period did not decrease compared with the average yield recorded during the same period, in open field of the same experimental farm under a conventional management (about 4.2 t ha^{-1}). Further, in the last year (2012) the organic production system increased the yield by 29% compared with the conventional one (data not reported).

Table 2. Effect of years, fertilizers and bioactivator on wheat yield.

	Grain Yield (moisture 13%)	Straw Yield	HI	Test weight	Protein content	Gluten index	Yellow index
	t ha^{-1}	t ha^{-1}	%	kg hl^{-1}	%		
Years (Y)							
2010	4.33 ^{b}	6.51 ^{b}	39.24 ^{a}	84.54	11.29 ^{c}	25.54 ^{c}	14.93 ^{b}
2011	5.16 ^{a}	8.22 ^{a}	37.70 ^{a}	84.18	13.48 ^{b}	28.39 ^{b}	15.70 ^{ab}
2012	3.29 ^{c}	6.84 ^{b}	31.59 ^{b}	85.38	16.99 ^{a}	30.01 ^{a}	16.28 ^{a}
	**	*	**	ns	***	***	*
Fertilizations (F)							
MSW	4.13	7.08	35.88	84.99	13.32	27.48	15.31
ORG	4.38	7.35	36.31	84.40	14.52	29.06	15.97
	ns	ns	ns	ns	**	***	**
Bioactivator (A)							
No	4.28	7.36	35.71	84.67	13.93	28.42	15.60
Yes	4.23	7.05	36.49	84.72	13.91	28.12	15.68
	ns	ns	ns	ns	ns	ns	ns
Interactions							
F×A	ns	ns	ns	ns	ns	ns	ns
Y×F	ns	ns	ns	ns	*	ns	ns
Y×A	ns	ns	ns	ns	ns	ns	ns
Y×F×A	ns	ns	ns	ns	ns	ns	ns

*, **, *** Significant at the P≤0.05, 0.01 and 0.001 levels respectively, ns = not significant. Within years and treatments, the values in each column followed by different letters are significantly different according to SNK test at the P≤0.05.

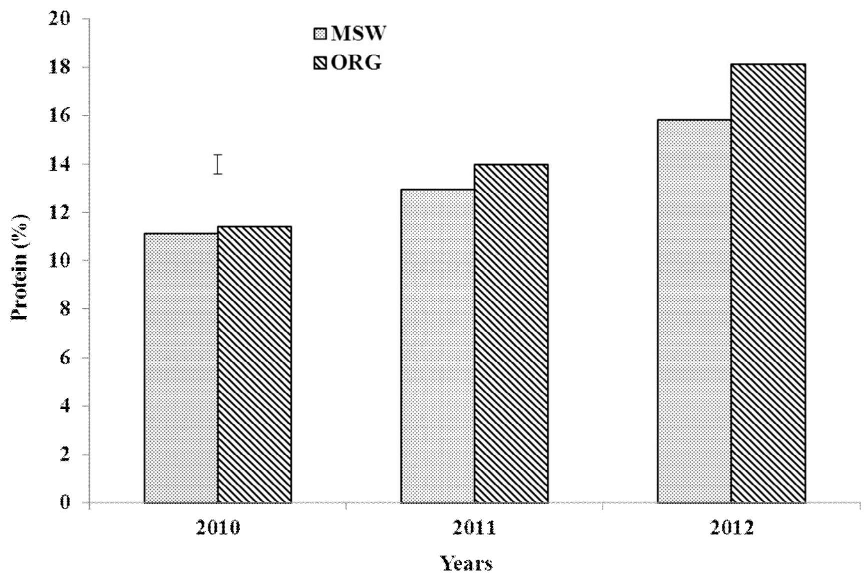

Figure 2. Effect of the Year × Fertilization (Y×F) interaction on grain protein content. The bar represents the Least Significant Difference (LSD).
MSW: compost coming from municipal solid organic wastes; ORG: commercial organic fertilizer; 2010, the first experimental year; 2011, the second experimental year; 2012, the third experimental year.

Changes in soil TOC content

After three years of compost and organic commercial fertilizer application, TOC content was on average higher than at the beginning of the experiment with increases of 6% for the treatments with compost and 2% for those with the organic commercial fertilizer (Figure 3). Therefore, the application of these organic fertilizers and of compost in particular, allowed to maintain the soil TOC level. This finding was in agreement with the results reported by other researchers who observed significant increments of organic carbon after repeated compost (or other organic amendments) applications (Albiach et al., 2001; Eghball et al., 2002; Leogrande et al., 2014). Moreover, at the end of experimentation, the MSW treatment showed a significant increase of TOC (+4%) compared with ORG treatment. No significant difference was observed with the application of the bioactivator (Figure 3) and for the interaction F×A. Soil total N, available P and exchangeable K at the end of the experimentation were not affected by treatments.

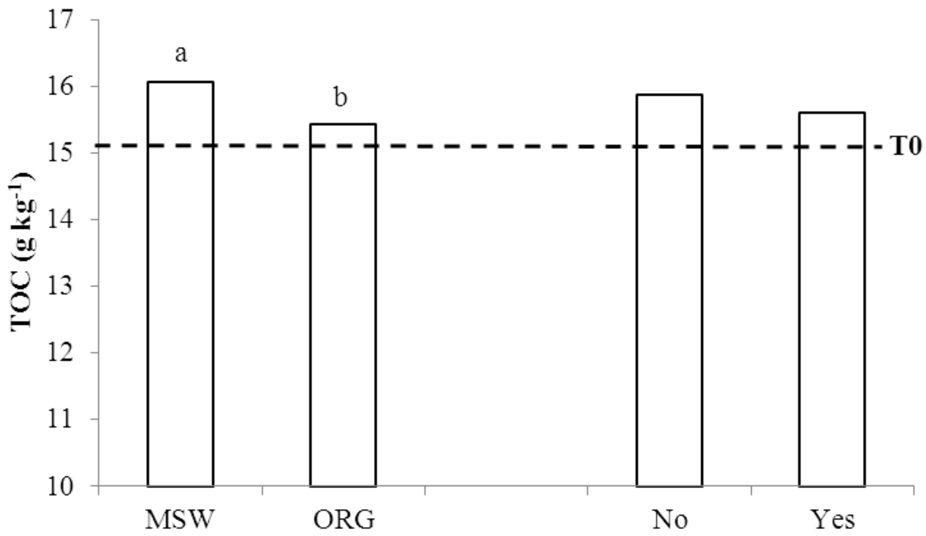

Figure 3. TOC content of the 0-0.40 m layer at the beginning (T_0, 2009) and at the end of the experimental years (2012) in the tested treatments, compost (MSW), commercial organic fertilizer (ORG), with and without bioactivator (Yes and No). The bars with different letters are significantly different according to SNK at the P≤0.05 probability level.

Soil organic carbon dynamics

All the parameters involved in the determination of soil organic carbon balance, after three years of compost and organic commercial fertilizer application, are presented in Table 3. The initial C soil reserves (C_0), determined at T_0 (at the beginning of the experiment, 2009), considering a soil depth of 0.40 m and an average soil bulk density of 1100 kg m^{-3}, were 66440 kg ha^{-1}. The mean annual C addition (*m*) was 1520 kg ha^{-1}, by compost, applied as fertilizer to overcome the wheat N need (100 kg of N ha^{-1}), while it was 320 kg ha^{-1}, by the organic commercial fertilizer. The mineralization coefficient K_2 was computed by equation 2, using calcium carbonate and clay contents of 70 and 494 g kg^{-1}, respectively and the mean annual temperature of

15.6 °C (Figure 1). The calculated value of this parameter reflected a reduced intensity of oxidative decomposition processes (Bayer et al., 2006), since, on the whole, 1.7% of the soil humus was mineralized each year. The isohumic coefficient (K_1) depends mainly on the chemical composition of the organic matter, so the waste rich in celluloses and lignins generate more humus than those rich in aminoacids and proteins, which decompose much easier (Patriche et al., 2012). Some authors found that the isohumic coefficient varied also with C/N ratio: in particular, it is very low for debris with low C/N ratio, such as materials of proteic origin (e.g. the isohumic coefficient of dried blood is 3.4), because there is a rapid mineralization of the excess nitrogen but the humification is very reduced. The isohumic coefficient, K_1, value for the compost used in this research was 0.32 as reported by Dono et al. (2005). For the organic commercial fertilizer, obtained through a process of thermal hydrolysis of the residues from the processing of the skins, with a very high protein content and collagen, K_1 was assumed to be 0.20. The annual organic carbon content released by wheat root (C_R) was estimated by the equation 3. As reported by several authors the *S:R* ratio is influenced by climate conditions, varieties and agronomic management (Andrews et al., 1999; Bolinder et al., 2007; Munoz-Romero et al., 2010; Williams et al., 2013). In this study, to estimate C_R, we considered a *S:R* ratio value of 5, typically used for annual crops but in any case effective also for wheat grown in Mediterranean conditions (Bolinder et al., 2007; Munoz-Romero et al., 2010; Williams et al., 2013). Finally, the humified fraction of root biomass, which annually remains in the soil, (C_{RH}), was calculated as reported in equation 5. $C_{H\text{-}D}$ and C_{Tot} were determined with equations 1 and 4, respectively and $C_{determined}$ was measured by laboratory analyses at the end of the experimentation. On the basis of our results, the estimated C value (C_{Tot}) and the measured one ($C_{determined}$) showed a high consistency, in fact the $C_{Tot}/C_{determined}$ ratio was very close to one (Table 3). Thus, the Henin-Dupuis model, taking into account the C supply of annual root residue also, seems to be an effective tool to quantitatively evaluate the organic carbon dynamics in soil, in the short term and in Mediterranean environment. This finding is in agreement with the results of other studies carried out in different agroecosystems and with several kinds of C inputs (Di Bene et al., 2011; Marraccini et al., 2012; Shibu et al., 2006).

Table 3. The parameters involved in the determination of soil organic carbon balance at the end of the experiment (after three years of compost, MSW and organic commercial fertilizer, ORG, application).

	C_0	m	K_1	K_2	C_R	C_{RH}	$C_{H\text{-}D}$	C_{Tot}	$C_{determined}$	C_{Tot}/ $C_{determined}$
	kg ha^{-1}	kg ha^{-1}yr^{-1}		yr^{-1}	kg ha^{-1}yr^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	
MSW	66440	1520	0.32	0.017	2524	1107	64559	65666	70708	0.93
ORG	66400	320	0.20	0.017	2524	1107	63324	64431	67892	0.95

Cost-benefit analysis

Although it was not the main objective of the research, a synthetic cost-benefits analysis was performed to assess the most economically and environmentally sustainable fertilization strategy.

To this aim, only the direct costs for purchasing and spreading the fertilizers were taken into account. In any case, although the production expenses of the two organic fertilizers were not considered, the compost is a low-cost product, coming from a natural transformation of organic matter by aerobic microorganisms, while the organic commercial fertilizer is obtained through thermal hydrolysis processes of wastes characterized by high management and environmental costs.

The average costs of fertilizers purchase and spreading are reported in Table 4. The costs of the fertilizers were calculated on the basis of the commercial price and the applied amounts; for compost the commercial price included also the transport costs ranging, in the study area, between 5.20 and 7.50 € t^{-1} (Dono et al., 2005). The costs of spreading were estimated considering an average price of fertilizer application of 40 € $hour^{-1}$ (taking into account the expenses for the agricultural machinery and worker) and the time required for its distribution of about 120 and 30 minutes for MSW and ORG, respectively. The results showed that the cost of fertilizing with compost was lower compared to the organic commercial fertilizer, mainly due the lower commercial cost. So, despite the costs for spreading were higher, the compost use could allow an economic saving of about 150 € ha^{-1}.

Overall, this synthetic cost-benefit analysis shows that the compost, in the short term and in the experimental area, may furnish also economic benefits and this could be considered a further reason to encourage its use.

Table 4. Costs analysis of the compost (MSW) and organic commercial fertilizer (ORG) application.

	Average cost of fertilizer	Applied amount of fertilizer	Cost of applied amount	Cost of fertilizer spreading	Total cost of fertilizing
	€ t^{-1}	t ha^{-1}	€ ha^{-1}	€ ha^{-1}	€ ha^{-1}
MSW	27.00*	4.0	108.00	80.00	188.00
ORG	400.00	0.8	320.00	20.00	340.00

* The commercial price included also the transport costs (Dono et al., 2005).

Conclusions

The results of this study showed that in Mediterranean environment, where cereals are extensively cultivated, in an organic transition period, the compost, coming from the organic fractions of municipal solid wastes, used as fertilizer, could be an alternative source of nutrients for the crops and a resource for maintaining and/or improving soil fertility. In comparison to the organic commercial fertilizer, the compost did not decrease wheat yield, though the grain quality was lowered. Furthermore, at the end of experimentation, the compost increased significantly the soil organic carbon content compared to the organic commercial fertilizer. Finally, a synthetic evaluation of the costs related to the application of the two fertilizers highlighted a higher economic benefit with compost use. The use of bioactivator, in our experimental conditions, did not bring any benefit on the wheat yield, grain quality and soil characteristics.

Moreover, in the Mediterranean agro-climatic environment and in the short-term, the variation of the soil organic carbon content could be described by the Henin-Dupuis equation, also considering the contribution of annual root residues; in fact the results of this simulation showed a high consistency between the organic C calculated by model and the amount quantified by laboratory analyses.

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