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RESEARCH

Crop and Soil Response to Organic Management Under Mediterranean Conditions

Rita Leogrande[1] · Carolina Vitti[1] · Alessandro Vittorio Vonella[1] · Domenico Ventrella[1]

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Abstract

Organic agriculture can contribute to maintain the long-term sustainability of the agroecosystems, preserve and improve soil quality and guarantee good quality food products. The objective of this study was to investigate the effects of different organic fertilizers and a biostimulant on crop performance and soil properties. The research was performed in an experimental farm in Southern Italy and covered a 2-year rotation of lentil and durum wheat for a period of 4 years. An organic commercial fertilizer and a compost, obtained from municipal wastes, with and without a commercial biostimulant, were compared in a randomized complete block design. The results showed that compost, as the only nutrient source, did not significantly decrease lentil and wheat grain yields, even though, in 2011 and 2012, wheat grain quality was better with the organic commercial fertilizer. Probably, the mineralization rate of compost, depending also on environmental conditions, and, consequently, the nutrient availability was not enough to meet the needs of wheat crop. Biostimulant significantly increased the straw yield of lentil by 20% and the weight of 1000 seeds of wheat by 4%. At the end of the experiment, the compost, applied at low doses, significantly increased soil TOC content (+3.4%) compared to the organic commercial fertilizers. Conversely, the biostimulant seemed to have no effect on the soil properties. Overall, under the local Mediterranean conditions, the compost may be used as an alternative nutrient source, with positive effects for lentil and wheat productivity, economic sustainability and soil fertility.

Keywords Durum wheat · Lentil · Organic fertilization · Biostimulant · Crop rotation · Yield stability

Introduction

Agricultural management can have substantial impacts on soil properties, biodiversity and biochemical processes. Conventional agriculture, characterized by excessive tillage, complete removal of crop residues, monoculture and indiscriminate or excessive irrigation and use of agro-chemicals (mineral fertilizers and pesticides), could cause negative effects on environmental sustainability of cropping systems increasing risks of soil degradation, water pollution, reduction of biodiversity, etc.

Due to serious environmental problems resulting from conventional agricultural practices, a growing interest towards alternative farming systems is encouraged, in order to improve overall soil health, agricultural sustainability and environmental quality (Poudel et al. 2002).

In this context, organic farming aims to reduce the environmental impact of agriculture by avoiding the use of synthetic compounds and promoting practices such as organic fertilization and crop diversification (Aguilera et al. 2015).

The issue of soil organic matter conservation is a key objective in organic farming systems for maintaining or improving soil fertility. Incorporation of crop residues, manure and organic amendments are essential strategies for returning organic matter to the soil. These agronomic practices are particularly recommended in warm and dry environments, as those in the Mediterranean area, characterized by low organic matter levels and consequently low nutrient availability and increased exposure to processes of structure degradation and soil erosion.

Among the organic amendments, compost (as those derived from several kinds of organic wastes, appropriately processed) is considered a valuable source of organic matter and nutrients (especially nitrogen and phosphorous). In

✉ Rita Leogrande
rita.leogrande@crea.gov.it

[1] Council for Agricultural Research and Economics, Research Centre for Agriculture and Environment (CREA-AA), Via C. Ulpiani, 5, 70125 Bari, Italy

agricultural soils, the compost is prevalently used as humic amendment (high dose application) in order to improve physical, chemical and biological properties, creating an enabling environment for plant growth (Pellejero et al. 2017). Therefore, from agricultural and environmental point of view, the application of composted organic wastes, as soil amendment, is a recommended practice to achieve the remediation of degraded soils and the nutrient supply to plants (Larney and Angers 2012).

Despite that several studies (Garcia-Gomez et al. 2002; Soumaré et al. 2003; Moldes et al. 2007) have shown that the application of mature compost improves plant growth and soil properties, the optimal rates for each crop should be investigated under field condition to have information on environmental impact, agronomic value and nutritional efficiency of compost. In fact, the compost is characterized by a slow mineralization rate in the soil since it contains more recalcitrant components (more stable organic matter), that may affect the fulfillment of crop nutrient requirement (Leogrande et al. 2014). Moreover, it is well known that soil temperature and moisture have a great importance in regulating the process of organic matter decomposition (Wang et al. 2016). Consequently, the mineralization rate depends not only on the organic matter quality but also on the wheather conditions and soil properties. Tejada et al. (2011) suggested that the soil application of organic biofertilizers, obtained from several organic materials by hydrolysis reactions (biostimulants), could support plant development. In fact, these products, currently available for agricultural use, generally contain peptides, amino acids, polysaccharides, humic acids, phytohormones, etc. (García-Martínez et al. 2010), that are easily assimilated by soil microorganisms. Consequently, microbial activities are quickly stimulated, promoting rapid mineralization of nitrogen and other micronutrients (Tejada et al. 2011). The interest in biostimulant use is increasing, since these organic products could be suggested as a useful strategy for speeding up organic matter decomposition and improving plant nutrition. In fact, due to environmental conditions and nature of organic compounds, the organic fertilizers, and in particular compost, release macro and micro nutrients slowly and gradually and their availability could not meet the needs of crops.

Crop rotations are recommended in all agricultural regimes because of several benefits regarding soil fertility, pest control, etc. However, crop rotation has to be specifically designed in space and time, with the choice of species that must depend on several factors: climate type (temperature, rainfall, relative humidity, global radiation, etc.), soil characteristics (texture, organic matter content, structure, nutrient availability, etc.), marketability and profitability, genetical adaptability. The basic concept of crop rotation is the need of diversification that is increasingly recognized as a crucial factor for a sustainable agro-ecological activity. In particular, legume crops, being a major biological nitrogen source, are a powerful option to reduce synthetic nitrogen fertilizer use and improve soil fertility (Bedoussac et al. 2015). Therefore, leguminous plants could be grown alternatively with non-leguminous plants to restore soil fertility and sustain crop yields. Then, the introduction of grain legumes in cereal cropping systems can increase the sustainability of farming systems, mainly due to the reduced use of nitrogen fertilizers, not only for the grain legumes but also for the following crops (Nemecek et al. 2008). Although the benefits provided by grain legumes have been known for a long time, in the last 50 years, the European arable land cultivated with grain legumes has declined from 4.7 to 1.8% with most of grain legumes used as fodder and only 13% for human consumption (Bues et al. 2013). The main reason of this decline could be the low and often unstable yield of grain legumes compared with other crops, like wheat.

Little and often conflicting information is available concerning the effect of compost, as the sole plant nutrient source, under arid and semi arid condition, which are typical for Mediterranean environment. We hypothesized that compost, although is characterized by slow mineralization, at low rates would be sufficient to produce acceptable yields of good quality, especially combined with a biostimulant. In the light of these considerations, a 4-year research of 2-year rotation of lentil and durum wheat was carried out under organic regime to evaluate the effects of organic commercial fertilizer and compost, obtained from urban wastes, both applied as fertilizer, on winter crop response and soil properties. For this reason, the organic rates for wheat and lentil were determined based on N and P compost content and crop requirements. Moreover, the influence of a commercial biostimulant, accepted in organic farming, was also investigated to evaluate the possibility to add this product to the fertilizers in order to improve the effects of fertilization.

Since many factors (differences in precipitation, temperature, pest outbreaks, weed pressure, soil fertility and agricultural management) could cause variability in crop productions across the years, for durum wheat a statistical analysis was performed to evaluate the effects of agronomic treatments on temporal yield stability.

Finally, since the economic profits address the farmers' choice, a synthetic cost–benefits analysis was carried out, considering the costs at farm level for purchasing and spreading the fertilizers and the income of crop production.

Materials and Methods

Site and Experimental Design

The field experiment was carried out over a 4-year period (from 2010 to 2013) in Southern Italy (Foggia, 41° 27′ N, 15° 03′ E, 90 m above sea level), at the experimental farm "Podere 124", of the CREA-AA. The experimental field was divided in two parts and in each part the cultivar "Svevo" of durum wheat (*Triticum durum*, Desf.) and "Eston" of lentil (*Lens esculenta*, Moench) were alternately cultivated. Svevo is widely cultivated in Italy, being an early variety characterized by tall size, high productivity and good quality (Arduini et al. 2006). Eston is an old lentil variety widely cultivated in central Italy and is characterized by low content of tannins and starch and relatively neutral flavor.

The soil is a clay loam of alluvial origin, classified by Soil Taxonomy-USDA as fine, mesic, Typic Chromoxerert (Soil Survey Staff 1992). At the beginning of the experiment, the soil organic matter, total nitrogen, available phosphorus (Olsen) and exchangeable potassium contents were on average 2.5 g 100 g^{-1}, 1.3 g kg^{-1}, 25 mg kg^{-1} and 1000 mg kg^{-1}, respectively. The experimental area has been conventionally managed (wheat monoculture and mineral fertilization, Stellacci et al. 2016) before the beginning of this study.

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 (autumn and winter months). The monthly minimum and maximum temperatures and the rainfall, during lentil and durum wheat cycle, are illustrated in Fig. 1.

To study the effects of organic farming system, the following treatments were compared: (1) two organic fertilizers (F) with and without commercial biostimulant (BS) application. The organic fertilizers were: commercial fertilizers (COF), allowed in organic farming (a nitrogen fertilizer for wheat and a complex fertilizer with a high P content for lentil); (2) a compost, obtained from the organic fraction of municipal solid wastes, after separate collection (COMP). A randomized complete block design, with a 2 × 2 factorial scheme (F × BS) and three replications, was adopted. Every block was divided into four plots of 125 m^2 to study the effects of fertilizers and biostimulant application.

A N dose of 100 kg ha^{-1}, for wheat, and a P dose of 30 kg ha^{-1}, for lentil, were applied in a single fertilization about 2 weeks before sowing. The amounts of compost and organic commercial fertilizer applied in each experimental year were respectively 3.19 and 0.20 t ha^{-1} for lentil and 4.72 and 0.83 t ha^{-1} for wheat, calculated taking into account the N and P content of fertilizers and the crop requirements. The biostimulant (10 kg ha^{-1}, as recommended by the producer) was applied at the same time of fertilizing. The biostimulant, used in this experiment, is recommended in over exploited soils to reactivate the microbial community. Its effect is due to the high total extractable carbon/total organic carbon content ratio. The main chemical characteristics of the organic commercial fertilizer and biostimulant, provided by the manufacturer, and compost are reported in Table 1.

Wheat and lentil sowings were carried out in December with a sowing density of 350 seeds m^{-2} (with plant spacing between rows of 0.15 m). All agronomic practices were performed according to the organic management approach.

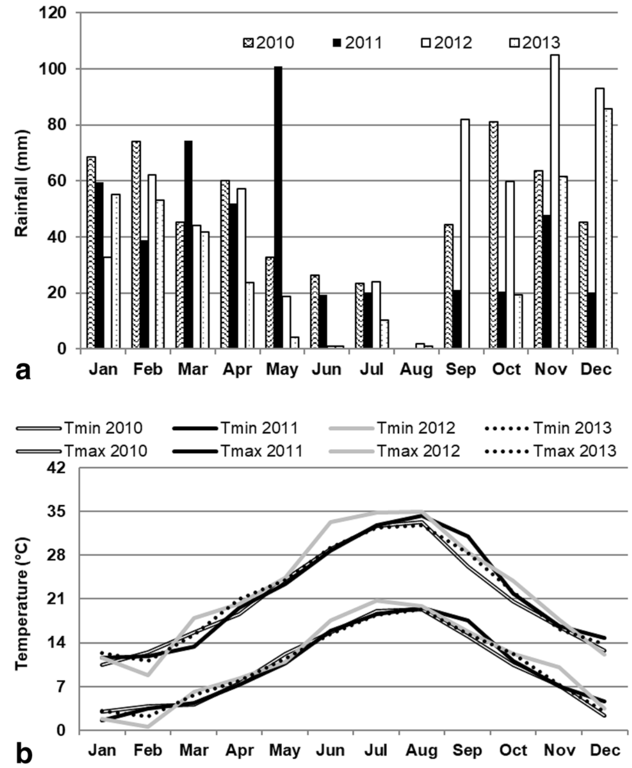

Fig. 1 Monthly rainfall (**a**) and minimum and maximum temperatures (**b**) during the 4-year period

Table 1 The main chemical characteristics of compost (COMP), commercial organic fertilizers (COF) supplied to durum wheat and lentil crops and biostimulant (BS)

	COMP	COF		BS
		Durum wheat	Lentil	
TOC (g kg^{-1})	380	400	200	400
N (g kg^{-1})	25	125	60	120
P (g kg^{-1})	3.7	–	70	–
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

Compost, Plant and Soil Sampling and Analyses

At the beginning of each experimental year, three samples of compost were randomly taken and analyzed. The total organic carbon (TOC) was measured on 0.2 g of finely ground material by Springer–Klee dichromate oxidation. 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 acidity (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).

Lentil and wheat harvestings were performed at physiological maturity, about 200 days after sowing. For both crops, the plants were handily harvested on two linear meters, then threshed to measure grain and straw yield and the weight of 1000 seeds and to calculate the harvest index (HI), as ratio between grain yield and total aboveground biomass. Finally, only for the wheat, grain protein content, yellow and gluten index, were measured (Infratec 1241).

Soil samples were taken from each plot at the beginning (t0) and at the end of the experiment at 0-0.40 m depth. The soil was air-dried, sieved at 2 mm diameter and then analysed. TOC content was quantified by Springer–Klee dichromate oxidation (Vitti et al. 2016) and total N were analyzed according to the same procedures followed for the compost. 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).

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 $P \leq 0.05$.

Stability Analysis

A comparative regression stability analysis of agronomic treatments involved in this study was carried out according to methodology recently adopted by Borrelli et al. (2014) and Ventrella et al. (2016a). The goal was to evaluate the variability of wheat yield across years. This analysis compared COMP and COF and other two treatments, Conservative and Conventional, included in other two experimental researches running in the same period in the experimental farm "Podere 124". Conservative treatment was based on a direct sowing of wheat, in a no tillage regime, whose crop residues (stubble and straw) were chopped and left on soil surface. Conventional treatment was based on crop residue incorporation with a previous fertilization of 100 kg ha^{-1} of N as urea (Ventrella et al. 2016b). Both for Conservative and Conventional, 100 kg ha^{-1} of N were applied as top dressing (NH_4NO_3). The annual average yield, protein content and test weight values, of each treatment were regressed against average annual values of COMP, COF, Conservative and Conventional treatments. The average annual values were considered "as an index of environmental variability under the assumption that it is impossible to separate the contribution of each factor involved crop productivity", as reported in Borrelli et al. (2014). The performance of individual treatments was evaluated by comparing the values of b, the slope of the linear regression function:

$$Y_i = a_i + b_i x$$

where Y_i is the average of treatment i with the correspondent intercept and slope (a_i and b_i, respectively) and x is the annual average.

The stability index (b_i) higher than 1 (with a negative intercept a_i) indicates that the performance of the treatment i is better in the high-yielding years, whilst a b_i value less than 1 (and positive a_i) indicates better performance in low-yielding years (Borrelli et al. 2014). The high- or low-yielding years are generally associated with years characterized by favorable or unfavorable weather conditions, above all in terms of rainfall and temperature.

Cost–Benefit Analysis

Although it was not the main objective of the research, a synthetic cost–benefits analysis was also performed to assess economical sustainability of the cropping system in study.

The average costs of the fertilizers (€ t^{-1}) were estimated based on the average commercial Italian prices; in particular, the compost commercial price also included 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 calculated considering an average price of fertilizer application of 40 € h^{-1} (taking into account the expenses for the agricultural machinery and worker) and the time required for distribution (about 30 min t^{-1}).

Lentil and durum wheat grain selling prices were estimated on the basis of average Italian market prices related to organic productions; the variable costs consist of the certified seed purchase (1300 € t^{-1} and 550 € t^{-1} for lentil and wheat seeds, respectively), cultivation costs, including also the fertilizer purchase and application, and average grain harvesting cost (about 70 € h^{-1}).

Results and Discussion

Effects of Years and Fertilizer Treatments on Lentil and Wheat Grain Yield and Quality

The effects of years (Y), type of fertilizer (F) and biostimulant (BS) on lentil and wheat are reported in Tables 2 and 3. For both crops, all investigated parameters showed significant variations among years. The amount and distribution of rainfall and temperature during the growing season (Fig. 1) likely affected the grain and straw yield and grain quality in agreement with several studies reporting the great impact of annual meteorological trend on lentil and wheat growth, development, therefore, yield and quality (Erskine and El Ashkar 1993; Zhang et al. 2000; Sarker et al. 2003; Lopez-Bellido et al. 2001; Garrido-Lestache et al. 2004). Sarker et al. (2003) stated that the variation in total seasonal rainfall accounted for 78.6% of lentil seed yield variability. In the current study, lentil grain yield was significantly higher in the wettest years (2010 and 2012) with an average rain of 573 mm, whilst the lowest yield was obtained in the driest year (2013), with a rainfall of 356 mm. Lopez-Bellido et al. (2001) and Garrido-Lestache et al. (2004) reported that the critical phenological phase of wheat was the grain filling stage. The Authors observed that water deficit and thermal stress during this stage could cause instabilities not only in grain yield but also in grain protein content and composition. In our study, the least productive year (2012) was characterized by the lowest average minimum temperature (2.8 °C) and the highest average maximum temperature (22.4 °C). In particular, during the grain filling stage (May 2012), the recorded minimum and maximum temperatures ranged between 7 and 15 °C and 13.7 and 31.8 °C, respectively. These differences of temperature could have an important impact on yield.

The significantly higher grain yield in 2013 of the current experiment (Table 3), after 4 years of organic management, could be explained by the combined effect of crop rotation and organic fertilization, that improved soil fertility and the plant nitrogen availability. Indeed, several researches showed that rotations, including a legume crop, improved wheat yield due to legume ability to fix atmospheric N_2, thereby increasing residual soil N content (Borghi et al. 1995; Debaeke et al. 1996; Lopez-Bellido et al. 1998). In fact, the N availability is a decisive factor for obtaining high yields and protein content (Borghi et al. 1995; Lopez-Bellido et al. 1998).

In the experimental conditions of this study, the biostimulant added to the compost had a positive effect on straw production of lentil. In fact, no significant difference was found between organic fertilizer treatments except for straw yield (significant interaction FxBS, Table 2), that increased significantly in the treatment COMP with biostimulant compared with COMP without biostimulant (+20%) and COF with biostimulant (+15%, Fig. 2). Such result was likely due to the action of biostimulant on soil microbial communities by boosting the mineralization rate of organic matter applied with compost, increasing nutrient availability for the crop (Chen et al. 2003). This greater nutrient availability provided a higher grain yield in COMP with biostimulant compared to COMP without biostimulant (+10%) and COF with biostimulant (+5%), but these differences were not significant. However, Parrado et al. (2008) observed that the biostimulant was not to provide nutrients, but rather to stimulate plant metabolism, stress reduction, etc.

As for durum wheat, the organic commercial fertilizer significantly increased grain protein content, gluten and yellow index compared to compost (Table 3). In particular, in the first and last years of the experiment (2010 and 2013), grain protein content was not affected by fertilization

Table 2 Effect of years, fertilizers and biostimulant on lentil yield

	Grain Yield	Straw Yield	HI	Weight of 1000 seeds
	t ha^{-1}	t ha^{-1}		g
Years (Y)				
2010	0.727 a	4.026 a	0.157 b	28.717 a
2011	0.580 bc	2.235 c	0.246 a	28.900 a
2012	0.658 ab	1.951 c	0.273 a	24.017 b
2013	0.480 c	2.948 b	0.143 b	21.433 c
	**	***	***	***
Fertilizers (F)				
COMP	0.604	2.840	20.036	26.046
COF	0.618	2.737	20.893	25.487
	ns	ns	ns	ns
Biostimulant (BS)				
No	0.605	2.680	20.776	25.987
Yes	0.618	2.897	20.153	25.546
	ns	ns	ns	ns
Interactions				
FxBS	ns	*	ns	ns
YxF	ns	ns	ns	ns
YxBS	ns	ns	ns	ns
YxFxBS	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

Table 3 Effect of years, fertilizers and biostimulant on durum wheat yield

	Grain Yield (moisture 13%) t ha^{-1}	Straw Yield t ha^{-1}	HI	1000 seeds weight g	Protein %	Gluten %	Yellow index
Years (Y)†							
2010	4.326 c	6.214 b	0.408 a	52.67 b	11.287 c	25.546 d	14.929 c
2011	5.159 b	8.219 a	0.377 a	56.00 a	13.478 b	28.377 c	15.701 b
2012	3.287 d	6.841 b	0.316 b	46.17 c	16.993 a	30.890 a	16.286 b
2013	6.871 a	8.911 a	0.402 a	52.26 b	13.429 b	30.008 b	17.415 a
	**	*	**	***	***	***	***
Fertilizers (F)							
COMP	4.729	7.383	37.046	52.170	13.305	28.062	15.822
COF	5.093	7.709	38.118	51.380	14.289	29.349	16.343
	ns	ns	ns	ns	***	***	*
Biostimulant (BS)							
No	5.002	7.801	36.956	50.840	13.803	28.831	16.064
Yes	4.819	7.292	38.21	52.710	13.791	28.579	16.102
	ns	ns	ns	**	ns	ns	Ns
Interactions							
FxBS	ns	ns	ns	ns	ns	ns	Ns
YxF	ns	ns	ns	ns	*	ns	Ns
YxBS	ns	ns	ns	ns	ns	ns	Ns
YxFxBS	ns	ns	ns	ns	ns	ns	Ns

†The data related to 2010, 2011 and 2012 were presented in the previous article by Leogrande et al. 2016

*, **, ***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

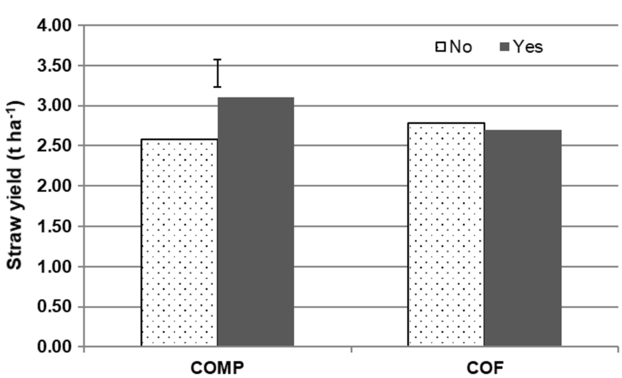

Fig. 2 Effect of the "Fertilization × Biostimulant" interaction on the straw yield of lentil. The bar above histograms represents the Least Significant Difference value (0.3447). *COMP* compost coming from municipal solid organic wastes, *COF* commercial organic fertilizer, *Yes* with Biostimulant, *No* without Biostimulant

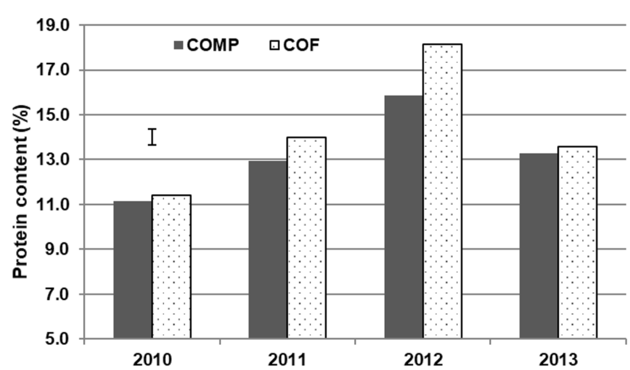

Fig. 3 Effect of the "Year × Fertilizer" interaction on grain protein content of durum wheat. The bar above histograms represents the Least Significant Difference value (0.7282). COMP: compost coming from municipal solid organic wastes; *COF* commercial organic fertilizer

treatments (Fig. 3); while, in 2011 and 2012 organic commercial fertilizer increased the protein content by 8% and 14%, respectively, compared with compost. During grain filling stage, the nitrogen availability was likely lower in the compost treatment than in organic one, also due to weather conditions (low temperatures and water availability) that compromised the decomposition of organic matter. Lopez-Bellido et al. (2001) showed that the wheat grain protein content is strongly dependent on the complex interactions between N and water availability, yield and temperature.

The biostimulant induced a significant increase in 1000 seeds weight (+4%) of wheat. The 1000 seeds weight, related to crop efficacy in storing photosynthates in the seeds, is greatly influenced by environmental conditions and soil nutrients (Hammad et al. 2011). Despite that the weight of grain is an important yield component and usually the major contributor to grain yield of wheat, in this study, it did not affect grain yield, that was slightly higher in treatment without biostimolant (Table 3), probably because the plants were stimulated to produce a lower number of grains but with greater size.

The findings of this research highlighted that compost, applied at low doses (3.2 and 4.7 t ha^{-1}) as the only nitrogen and phosphorous source, could be considered an effective strategy to maintain lentil and wheat yield, at least in particular environmental conditions, and consequently could replace the commercial organic fertilizer. Conversely, the combined application of compost and biostimulant did not show significant advantages on both crops yield and quality. Chivenge et al. (2011) stated that soil nutrient availability and associated yield benefits, derived from organic fertilization, depended on several factors (including climate, chemical and physical soil properties, organic fertilizer quality) and intricate interactions among these factors. Several studies reported that to maintain or enhance the crop yields, the compost should be combined with chemical fertilizers (Xin et al. 2017; Geng et al. 2019); in fact, the sole application of compost or other organic fertilizers (manure, crop residues, etc.), decreased yields, especially after few application and low doses (Giannakis et al. 2014). Decreased yield in crops grown in MSW-compost amended fields was due to low essential nutrient availability and to compensate this low availability, arising from low N mineralization rates and N immobilization by microbial biomass, elevated rates of compost (50 and 100 t ha^{-1}) are commonly used in agriculture (Giannakis et al. 2014).

Stability Analysis

Figure 4 and Table 4 report the statistical results of stability analysis for yield, protein content and test weight of wheat submitted to COMP, COF and other two treatments in conventional and conservative regime.

For yield, COMP and Conventional showed a higher annual variability (average R^2 of 0.6) than COF and Conservative (average R^2 of 0.9). A similar result was found also for protein content although with higher R^2 values than yield. The annual values of test weight were affected by a very low variability under Conventional (R^2 of 0.99) while COF was characterized by the largest one (R^2 of 0.6).

Examining the parameters of the yield regression lines, it resulted that, in a short-term, COMP, COF and Conventional treatments were characterized by linear trends not very different from the 1:1 line, thus showing similar productive responses in the unfavorable and favorable years. On the contrary, Conservative performances tended to be better in unfavorable years, probably due to the higher soil water retention which could be particularly advantageous in years with low rainfall during the autumn and winter. Other long-term studies highlighted that organic crop systems had lower yield variability and higher cropping system stability than comparable crops conventionally managed (Smolik et al. 1995; Lotter et al. 2003).

Due to the higher nitrogen fertilizations compared to other treatments, under Conventional the protein content was always higher than the other treatments, even if, in 3 years out of four, the values nevertheless falled into the first quality class (values > 14%, Fig. 4). Also for this parameter, Conservative showed a better performance in unfavorable years.

The linear functions of the test weight were quite different from the previous ones, with COMP and COF that presented higher values, compared to Conventional and Conservative, and linear regression function quite parallel to the 1:1 line. In any case, all the values were in the first quality class (values greater than 80 kg hl^{-1}).

Effects of Organic Management on Soil Properties

After 4 years of organic management (crop rotation and organic fertilizer applications), TOC content was on average higher than at the beginning (t0) of the experiment. The increase was about 12% in the treatments with compost and 9% in that with the organic commercial fertilizers (Fig. 5). This finding was in agreement with the results reported by other authors who observed significant increases of organic carbon after repeated compost (or other organic amendments) applications (Albiach et al. 2001; Eghball 2002; Leogrande et al. 2014). Moreover, at the end of experiment, the COMP treatment showed a significant increase of TOC (+ 3.4%) compared to COF treatment. Therefore, within the cropping system in study and the environment of Southern Italy, the annual application of compost increased total organic carbon stock in soil, mainly due to the nature of organic compounds of compost that are more resistant to the decomposition or are slowly mineralized by soil microorganisms. The issue of soil organic matter decline is recognized as a significant cause of degradation, especially in arid and semi-arid regions, rendering soils more vulnerable to erosion and desertification and less productive (Viaud et al. 2010). The results of this study highlight that the compost, also applied at low doses (3.2 and 4.7 t ha^{-1}), can contribute to restore/maintain the soil quality and to improve its long-term productivity. No significant difference was observed with the application of the biostimulant (Fig. 5). Total N content, at the end of the experiment, was on average higher than t0 with increases of about 9% in compost treatments and 5% in organic commercial fertilizer (Fig. 5). Furthermore, no

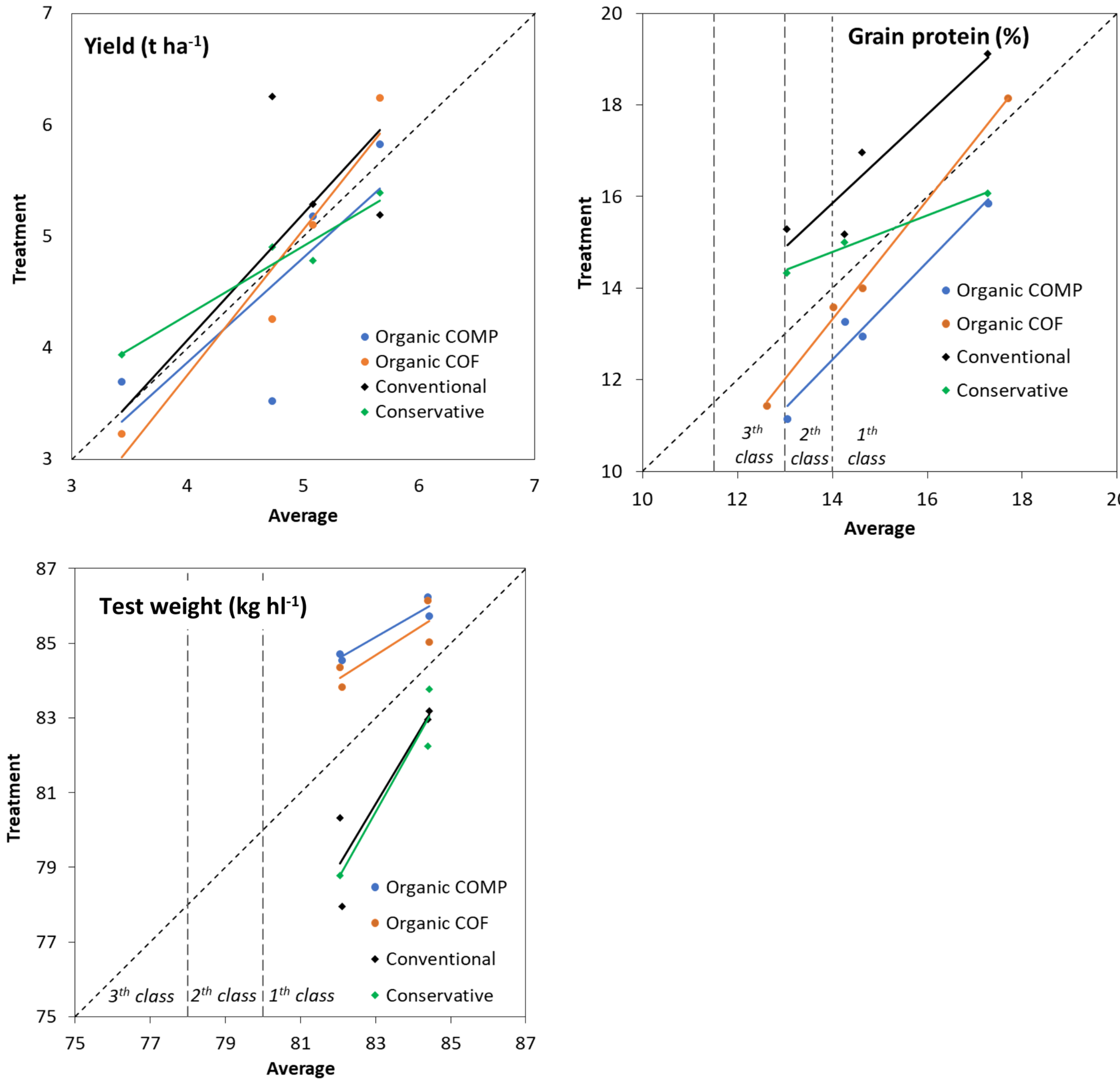

Fig. 4 Stability analysis for wheat yield, grain protein content and test weight, obtained by four treatments from 2009/2010 to 2012/2013. The statistical parameters and linear equation coefficients are reported in Table 4. The vertical dashed lines separate three quality classes for grain protein and test weight. The 1:1 diagonal dashed lines are reported for each response variable

significant difference was observed among all treatments compared.

Finally, at the end of the experiment, the available P and exchangeable K were not affected by treatments and did not show differences compared with the initial soil contents.

Cost-Benefit Analysis

This study considered only the direct costs for purchasing and spreading the fertilizers. In any case, although the production expenses of the two organic fertilizers were not taken into account, the compost can be considered a low-cost product, since 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 fertilizer purchase and spreading are reported in Table 5. The results showed that for lentil crop the cost of compost application was higher (+17%)

Table 4 Statistical parameters and coefficients of linear regressions showed in Fig. 4

Treatment	R[2a]	Pr > |F|	a	ES	t	Pr > |t|	b	ES	F b = 1	Pr > |F|
Yield (t ha^{-1})										
Organic COMP	0.621	0.2119	0.12	2.49	0.05	0.9672	0.94	0.52	0.01	0.9176
Organic COF	0.927	**0.0373**	− 1.46	1.24	− 1.18	0.3609	1.31	0.26	1.39	0.3602
Conventional	0.560	0.2517	− 0.47	3.42	− 0.14	0.9024	1.14	0.71	0.04	0.8661
Conservative	0.942	**0.0294**	1.82	0.52	3.50	0.0730	0.62	0.11	12.30	0.0726
Protein content (%)										
Organic COMP	0.966	0.1187	− 2.32	2.99	− 0.78	0.5795	1.06	0.20	0.09	0.8170
Organic COF	0.998	**0.0259**	− 8.88	0.95	− 9.31	0.0681	1.57	0.06	78.70	0.0715
Conventional	0.910	0.1942	2.00	4.61	0.43	0.7390	0.98	0.31	0.01	0.9527
Conservative	0.988	0.0702	9.20	0.66	13.92	**0.0457**	0.40	0.04	185.40	**0.0467**
Test weight (kg hl^{-1})										
Organic COMP	0.878	0.2274	41.16	16.57	2.48	0.2436	0.53	0.20	5.60	0.2544
Organic COF	0.613	0.4275	41.98	34.34	1.22	0.4365	0.52	0.41	1.39	0.4483
Conventional	0.996	**0.0401**	− 15.05	6.13	− 2.45	0.2463	1.16	0.07	4.91	0.2699
Conservative	0.918	0.1850	− 68.09	44.78	− 1.52	0.3703	1.79	0.54	2.18	0.3792

[a]Regression coefficient (R^2), intercept (a) and slope (b). ES is the standard error; Pr > |t| and Pr > |F| represent the t and F test, respectively, as results from analysis of regression

The tested hypothesizes are a = 0 and b = 1. The bold numbers indicate that the correspondent parameters are statistically different from 0 (R^2 and a) or 1 (b)

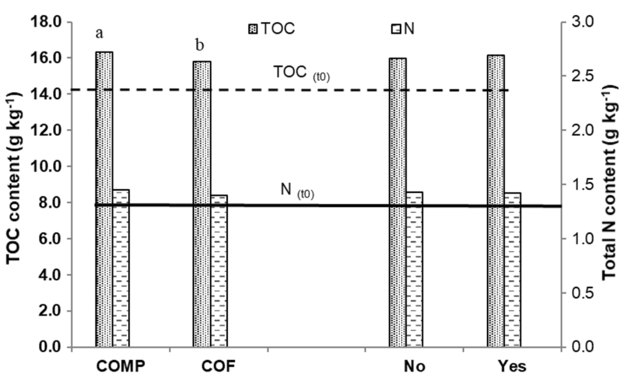

Fig. 5 TOC and N content of the 0–0.40 m layer at the beginning (t0) and at the end of the experiment for compost (COMP), commercial organic fertilizer (COF), with and without biostimulant (Yes and No). The bars with different letters are significantly different according to SNK at the P ≤ 0.05 probability level

compared to the organic fertilizer, mainly due to the higher amount of compost applied (3.2 t ha^{-1}) that increased the spreading costs. In fact, since the P content of compost was low (3.7 g kg^{-1}, Table 1), the compost rate applied was 16 times higher than commercial fertilizer one. As for wheat the cost of compost application was lower compared to the organic fertilizer, with an economic saving of about 120 € ha^{-1}, mainly due to the lower price of compost.

In order to evaluate the agricultural profitability of the two crops under organic regime, Table 6 showed the costs analysis of lentil and wheat productions. The results highlighted that the wheat profitability was not affected by fertilization, whereas lentil profitability decreased with compost fertilization by 25% compared to commercial fertilizer, due to higher costs of compost distribution and lower grain yield. In any case, durum wheat profitability was higher than lentil,

Table 5 Costs analysis of the compost (COMP) and commercial organic fertilizer (COF) application in lentil and durum wheat crops

	Average cost of fertilizer € t^{-1}	Applied amount of fertilizer t ha^{-1}	Cost of applied amount € ha^{-1}	Cost of fertilizer spreading € ha^{-1}	Total cost of fertilizing € ha^{-1}
Lentil					
COMP	27.00*	3.2	86.40	60.00	146.40
COF	550.00	0.2	110.00	15.00	125.00
Durum wheat					
COMP	27.00*	4.7	126.90	95.00	221.90
COF	400.00	0.8	320.00	20.00	340.00

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

Table 6 Costs analysis of lentil and durum wheat production with the compost (COMP) and commercial organic fertilizer (COF) application

	Average selling price[a] € t^{-1}	Average Yield t ha^{-1}	Selling income € t^{-1}	Variable costs[b] € t^{-1}	Profit
Lentil					
COMP	1000.00	0.58	580.00	343.40	236.60
COF		0.64	640.00	322.00	318.00
Durum wheat					
COMP	270.00	4.84	1306.80	400.90	905.90
COF		5.17	1395.90	519.00	876.90

[a]Lentil and wheat selling prices were calculated as the average of the Italian market prices related to organic products

[b]The variable costs include the certified seed purchase (1300.00 € t^{-1} for lentil and 550.00 € t^{-1} for wheat), cultivation costs and the average harvesting costs

mainly due to the higher wheat productivity. In fact, it is well known that wheat yield is at least twice that of grain legume (Bues et al. 2013; Preissel et al. 2015) and such yield level makes the crop more profitable when compared with grain legume such as lentil. Therefore, despite the price of grain lentil was almost 4 times higher than that of wheat, the low productivity of the lentil did not compensate wheat profitability. This is likely one of the main reasons for grain legume decline and current low cultivation (Bues et al. 2013). The explanation for the low yields of grain legumes is probably a trade-off related to the ability of legumes to fix nitrogen, because this biological process needs high amounts of energy which limits the potential of the plant to produce high yields (Bues et al. 2013). Our results showed that lentil cultivation was still profitable, leading to a sustainable improvement in the livelihoods of the farmers.

Overall, this synthetic cost-benefit analysis showed that the compost application may also furnish economic benefit and this could be considered a further reason to encourage these agronomic practices in cropping systems, particularly in the farms organically managed.

Conclusions

Agriculture should meet the twin challenge of feeding a growing population and simultaneously minimizing its environmental impact. In Mediterranean environment, where cereals are extensively cultivated, the legume cultivation, breaking the wheat monoculture, and the compost fertilization could be profitable practices not only to sustain the crop yields and product quality but also to maintain and/or improve soil fertility. The results of this mid-term research showed that the compost, applied at low doses (3.2 and 4.7 t ha^{-1}) and not as amendment, compared to the organic commercial fertilizer, did not decrease lentil and wheat yield. A multiyear comparison, involving other treatments under conventional and conservative regime, confirmed the positive effect of compost on durum wheat yield.

At the end of the experiment, after 4 years of repeated applications, the compost increased significantly soil organic carbon content compared to the organic commercial fertilizers. Conversely, the biostimulant did not show any significant effect on soil properties. Moreover, the biostimulant was not effective for both crops, in fact yield did not show any improvement, except for weight of 1000 seeds of wheat, and, when added to compost, for straw yield of lentil. Therefore, in experimental conditions, the addition of biostimulant to organic fertilizers (compost and commercial one) could have negligible benefits on crop response and soil properties.

Finally, a synthetic cost evaluation related to the purchase and application of the compost and commercial organic fertilizers highlighted higher economic benefit of compost when applied to the wheat crop.

Overall, this mid-term study highlighted that the organic management, adopting a crop rotation of lentil/wheat and compost as the only source of plant nutrients, could have a positive impact on farming productivity and profitability as well as on soil fertility. In any case, since the fertilization is a vital agronomic practice, the compost, obtained by several kinds of wastes and characterized by high organic matter levels and valuable nutrients, should be put to good use of managed properly in order to improve the plant nutrition status during the growth seasons without any risks for environment. Moreover, further studies should be carried out to better understand the role of biostimulant in the regulating soil nutrient mineralization and availability in order to optimize the organic management systems.

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