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RESEARCH ARTICLE

Olive Pomace Compost in Organic Emmer Crop: Yield, Soil Properties, and Heavy Metals' Fate in Plant and Soil

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Abstract

The effects of olive pomace (OP) compost application on yield and quality of organic emmer, on soil characteristics, and on heavy metals accumulation in plant and soil have been evaluated. The research was carried out in Mediterranean environment for four consecutive years comparing the application of OP compost in two doses and with the addition of a bio-activator. These fertilizing treatments were compared to a commercial organic amendment and an unfertilized control. The application of OP compost ensured both a comparable level of yield than the commercial fertilizer and a high content of protein in the grain, suggesting that it could be an interesting strategy of fertilization for organic emmer. No remarkable heavy metals' accumulation was found in the plant and soil. Low transfer coefficients and soil accumulation were recorded at the end of experiment, indicating that OP compost could be used as suitable soil amendment, ensuring at the same time an eco-friendly recycling of waste materials. It can optimize organic emmer yield production, sustain soil fertility, and reduce pollution risks linked to the landfill disposal. These results are interesting to develop nitrogen fertilizer strategies for emmer crop, which is an underutilized ancient cereal that well fits for organic production.

Keywords *Triticum dicoccum* L. · Olive pomace · Yield components · Soil fertility · Heavy metals · Bio-activators

1 Introduction

The olive (*Olea europaea* L.) oil agro-industry generates large amounts of wastes and by-products, mainly in the Mediterranean countries. In particular, olive pomace (OP) is a semisolid by-product, with high contents of water (56.6–74.5%), phenols, lipids, and organic acids, which is obtained from the two-phase extraction system (Chowdhury et al. 2013). The OP is characterized by seasonal accumulation, and its disposal by direct land-application could represent a potential threat to the environment (Canet et al. 2008). This is due to phytotoxic and bacteriostatic substances (e.g., polyphenols) and elevated salt concentration (Gigliotti et al. 2012). However, the aerobic degradation process of composting could drastically reduce the content of phytotoxic compounds content in olive mill by-products (Diacono et al. 2012). By mixing OP with bulking materials (e.g., cereal straw or pruning wastes) to produce compost, such by-product could be easily recycled in agriculture, since it contains high content of organic matter and nutrients (Montemurro et al. 2009).

In the southern regions of the Mediterranean area, soil organic matter content is extremely low. This is because of a fast soil mineralization process, due to climatic conditions, which determines soil fertility reduction and negative effects on physical, chemical, and biological properties of the soil (Montemurro et al. 2004; Cayuela et al. 2010). The proper recycling of the organic agro-industrial wastes as soil amendments, instead of the use of mineral fertilizers, may represent a solution either for their disposal, or to replace the losses of organic matter in soil, thus sustaining soil fertility and agricultural production (López-Piñeiro et al. 2011). The application of these materials is crucial in organic agriculture, where the level of soil organic matter is one of the most important issues.

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Nevertheless, despite several benefits, repeated applications of composted on-farm and industrial waste materials could induce adverse impacts on the environment, because they are often characterized by significant concentrations of heavy metals. The presence of heavy metals in organic materials can either increase the soil concentration of these toxic elements or cause accumulation in plants tissues (Karagiannidis 1999), with possible negative effects on human and animal health, therefore, they should be monitored.

The agricultural policy of the European Community solicits to reduce fertilizer N application in crop cultivation, due to the increased concern about the effects of intensive production systems on water resources, soil, and atmosphere. To this end, a possible solution is to use organic fertilizer bio-activators. Since several species of bio-activators have been isolated, many experiments have been conducted to test bacteria (*Mycorrhiza* and *Azospirillum* bacteria) as inoculants to enhance the performance of plants. For example, Adesemoye et al. (2008) found that a commercial plant growth-promoting rhizobacteria and arbuscular mycorrhiza fungi promoted corn plant growth and yield, by enhancing nutrient uptake, thereby removing more nutrients from the field. Scientific and industrial interests for these microorganisms derive from the possibility to reduce the application of mineral N fertilizers, due to improved N uptake from soil sources. In rice crop, bio-activators had potential to economize up to 25% of recommended dose of N, improving its use efficiency without compromising crop productivity (Prasad Babu et al. 2015).

Soil fertility management relies not only on recycling of organic wastes but also on crop rotation and cropping systems, according to best agronomical practices. Within this context, the organic production of cereals in crop rotations is not only important for feed and food, but also for contribution to soil fertility. According to Giuliani et al. (2009), emmer is an underutilized ancient cereal, suitable for development in marginal rural areas, particularly fitting for organic production because of its great adaptability.

However, in contrast with these findings already known, there is a lack of knowledge on how it is possible to quantify and assess the sustainability in terms of yield, soil fertility, and recycling the OP compost in organic agriculture, since its distribution can play a crucial role, to close the loop of production according to Circular Economy principles. To cover these deficiencies and based on the considerations above, the objectives of this field trial in an organic emmer crop were the following: (i) to investigate the effects of OP compost and commercial organic fertilizer (both pure or plus bio-activator), on emmer yield and quality parameters; (ii) to assess the impact of the tested experimental treatments on selected soil properties; and (iii) to evaluate the effects of OP compost on the heavy metals accumulation both in plant and soil.

2 Materials and Methods

2.1 Study Site

The study has been conducted in the research farm "Azienda Sperimentale Metaponto" of the Research Centre for Agriculture and Environment, Council for Agricultural Research and Economics (CREA-AA), Metaponto (MT), in southern Italy.

The site is characterized by an "accentuated thermomediterranean" climate (Unesco-FAO 1963), with winter temperatures which can fall below 0 °C, summer temperatures which can rise above 40 °C, and rainfall unevenly distributed during the year, being concentrated mainly in the winter months. The mean annual precipitation is slightly higher than 500 mm, while the mean annual pan evaporation rate reached 1700 mm. Soil is classified as a Typic Epiaquert, according to the Soil Taxonomy definition (Soil Survey Staff 1999), the clay and silt contents being 60 and 36%, respectively, and the average soil bulk density 1350 kg m^{-3}.

2.2 Composting Set-up

The OP was collected from two-phase centrifugation olive oil milling industries in southern Italy. A composting windrow of OP mixed with different organic residues was made in an open field. In particular, the compost mixture consisted of 82 kg 100 kg^{-1} of OP, 10 kg 100 kg^{-1} of poultry manure, and 8 kg 100 kg^{-1} of wheat straw. Homogenization and oxygenation were ensured through continual monitoring of composting mixture humidity and temperature, by turning over the material. The moisture ranged between 50 and 60%, whereas the temperature ranged between 50 and 60 °C in the thermophylic phase (40 days) and 35–45 °C in the mesophylic phase (150 days).

The main chemical characteristics of the obtained compost are the following: pH = 8.63; total organic carbon = 245.2 g kg^{-1}; total nitrogen = 23.44 g kg^{-1}; total phosphorus = 7053 mg kg^{-1}; Cu = 98.81 mg kg^{-1}; Zn = 202.5 mg kg^{-1}; Pb = 30.82 mg kg^{-1}; Ni = 5.55 mg kg^{-1}. Since the initial compost mixture was similar from year to year, we did not find significant differences among final composts.

2.3 Experimental Setup, Treatments and Measurements

Within a 4-year emmer-lentils rotation, the research on emmer (*Triticum dicoccum* L. cv. Lucanica) was carried out from 2009–2010 to 2012–2013 season. In the trial years, the field experiment was setup with the same experimental design and crop management. To study the cumulative effect on soil and to avoid the possible confounding effect of sites on treatments, the same plots were used in each season. Each plot consisted of 40 m^2 (5 × 8 m).

In a randomized complete block experimental design with three replications, the following treatments were compared: A = olive pomace compost applied as "amendment"; C = olive pomace compost applied as "fertilizer"; OF = commercial organic fertilizer allowed in organic farming (Fertil – ILSA) with 12.5% of organic N and 70% of organic matter; OF_b = commercial organic fertilizer plus a bio-activator containing a mixture of microorganisms, enzymes, and nutrients (Euroactiv agro, Eurovix s.r.l.); C_b = OP compost applied as "fertilizer" plus bio-activator. These treatments were also compared to an unfertilized control (N0).

For C and C_b treatments, the OP compost was distributed on the soil to allow an application of 50 kg ha^{-1} of N, in accordance with the fertilization local practices and, therefore, this distribution was indicated as "fertilizer." Considering the total N amount of OP compost (2.34%) and the percentage of its humidity (20%), 1.7 t ha^{-1} of compost for these two treatments was distributed. Conversely, for the A treatment, a fixed amount of 8 t ha^{-1} was applied, in accordance with the amendment local practices (distribution indicated as "amendment"). The organic materials were applied about 1 month before sowing, and immediately tilled into the soil (about 15 cm depth). The bio-activator composition was as follows: organic carbon 38% on dry matter basis; humified organic carbon (HA + FA)-C 10%, organic N 4%, C/N ratio 9.3, Cu max 70 p.p.m., Zn max 200 p.p.m., salinity 50 meq/100 g.

Emmer sowing occurred at the end of November—first decade of December, and harvest occurred since the first decade of June to the first decade of July. The emmer sowing rate was about 150 kg of seeds ha^{-1}. At harvest time, the grain yield (at 13% of humidity), total dry matter, number of stems m^{-2}, 1000 seeds weight, and number of seeds m^{-2} were determined in the middle of each plot. Total N contents of grain and straw were determined by elementary analyzer CHNS/O (Analyzer Flasch 2000 Thermo scientific) on 5 mg of milled sample, allowing the calculation of N uptake (N content × biomass dry weight). Moreover, for the agronomic quality assessment, the grain protein content was obtained by multiplying the grain N content by 5.70 (Baker 1979).

At the beginning (t0) and at the end of the experiment (tf), five soil sub-samples (0–30 cm layer) were taken from each elementary plot, pooled in one sample for replication and treatment, air dried, ground to pass a 2-mm sieve and then analyzed. The data at t0 were the mean of all treatments, since the replications were pooled in one sample. On samples, the following soil characteristics were determined: soil N-nitrate (NO_3^-, mg kg^{-1}) extracted by 2 M KCl (1:10, *w*/*v*) and measured by continual flow colorimetry according to Henriksen and Selmer-Olsen (1970); total organic carbon measured by Walkley-Black method to estimate organic matter (OM, g kg^{-1}) by using the conventional "Van Bemmelem factor" of 1.724, which is based on the assumption that the OM contains 58% carbon; total Nitrogen (N, g kg^{-1}) determined by the Kjeldahl method; available P by the Olsen and Sommers method (Olsen and Sommers 1982); exchangeable K extracted by $BaCl_2$ and triethanolamine according to Page et al. (1982) methodologies, and assayed by Inductively Coupled Plasma-Optical Emission spectrometry ICP-OES. Moreover, on soil, plants, and compost samples, the total heavy metals' (Zn, Cu, Ni, and Pb) contents were determined. The first step was the microwave digestion with hydrochloric/nitric acid solution, according to UNI EN 13346/2002; then, the heavy metals have been quantified by ICP-OES, according to EPA6010C/2007. Finally, the balance and the transfer coefficients of the heavy metals were calculated. The transfer coefficients were determined by using the plant and soil heavy metals content measured at the fourth experimental year. They were obtained by dividing the concentration of each heavy metal in the emmer plants by its content in the corresponding soil sample (Mantovi et al. 2003). For the metals balance, soil application and plant uptake parameters were calculated as the sum of the four trial years. In particular, soil accumulation was calculated by the difference between the final soil content and the sum of soil initial content, soil application, and seeds uptake.

The statistical analysis was carried out by using the general linear model procedures of the SAS package. Differences among the treatments were evaluated with the Duncan's multiple range test (DMRT) at the 0.05 probability level.

3 Results

3.1 Yield, Yield Components, and Quality Parameters

Grain yield value was higher in OF and C_b plots than N0, by 34.7 and 33.9% respectively, whereas A, OF_b, and C determined intermediate results (Table 1). In particular, the activated compost (C_b) increased the yield in absolute value by 20.6% than the simple C, while this enhancement was not found when the bio-activator was added to the commercial organic fertilizer. The seeds' number trend was almost the same of yield, showing that OF reached the highest value and N0 the lowest one. Conversely, no significant differences were found among the treatments for the other physiological (number of stems per square meter), productive (total dry matter), and qualitative (1000 seeds weight) parameters.

In absolute value, the N content of grain and the protein content were higher in the not activated compost treatment C compared to C_b (11.64 and 11.63%, respectively). Conversely, the application of bio-activator increased these parameters when it was applied in association with commercial organic fertilizer, whereas in N0, there was the lowest values. The control treatment also showed the lowest grain

Table 1 Emmer yield, yield components, and quality (4-year average)

Treatments	Grain yield (13% humidity)	No. of stems m^{-2}	Total dry matter	1000 seeds weight	No. of seeds m^{-2}	Grain N content	Plant N	Grain protein content	Grain N uptake	Total N uptake
	t ha^{-1}		t ha^{-1}	g		%	%	%	Kg ha^{-1}	Kg ha^{-1}
A	1.39ab	557	13.57	57.64	2444ab	1.60a	0.42	9.33a	22.24a	73.39
OF	1.59a	567	13.11	56.40	2861a	1.40ab	0.40	8.16ab	22.26a	68.30
OF_b	1.43ab	598	12.07	58.31	2458ab	1.57a	0.38	9.15a	22.45a	62.88
C	1.31ab	624	11.04	56.07	2354ab	1.63a	0.60	9.50a	21.35a	79.73
C_b	1.58a	626	12.29	58.66	2732ab	1.46ab	0.30	8.51ab	23.06a	64.83
N0	1.18b	655	12.80	55.04	2165b	1.35b	0.50	7.87b	15.93b	68.20

The values in the same column followed by different letters are significantly different at $p \leq 0.05$ (Duncan's multiple range test)

N uptake, which was lower by 39.8% than the average of all the other treatments, and these latter were not significantly different among them. Finally, no significant differences were found among treatments for both total plant N and total N uptake parameters.

3.2 Effect of Tested Treatments on Soil Fertility

Soil nitrate content at the end of the rotation was lower in OF and N0 than the other treatments (Table 2). In particular, the N0 value was lower by 74 and 73% than in the OF_b and C_b treatments, respectively, which showed the highest values. The A treatment determined the significantly highest value in OM, also being the only one that showed a higher OM content than the initial one. The OF and C treatments (both with and without bio-activator) showed intermediate values, while N0 had the lowest one. In particular, the compost applied as "amendment" (A) had a OM content higher by 16% than the average of the observed intermediate values. No significant differences were found among treatments in both total N and available P, even if the final values were higher than the initial level except for OF_b in total N, and OF and C_b in available P. The highest exchangeable K was found in compost applied as "fertilizer" (C), whereas both OF and OF_b showed lower values. Furthermore, A and C treatments increased N, P, and K values as compared to the initial levels.

Table 2 Soil chemical characteristics at the beginning (t0) and at the end of the 4-year trial period

Treatments	NO_3	OM	Total N	Available P	Exchangeable K
	mg kg^{-1}	g kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}
Values at t0		20.6	1.29	31.0	459
A	57.7a	21.5a	1.51	38.6	464a
OF	35.3b	17.9b	1.40	29.1	288b
OF_b	66.9a	17.3b	1.12	36.4	294b
C	54.6a	19.1b	1.46	39.0	592a
C_b	64.5a	19.7b	1.29	28.8	386a
N0	17.2c	16.1c	1.43	32.1	326b

The values in the same column followed by different letters are significantly different at $p \leq 0.05$ (Duncan's multiple range test)

3.3 Effect of Tested Treatments on Heavy Metals Fate

After 4 years of OP compost application, the mean values of Zn, Cu, Ni, and Pb in the soil were very similar to those of t0 (Table 3). No significant difference was also found among the treatments A, OF, C, and N0 in each heavy metal content, even if the A and C treatments showed higher values than OF, N0 for Cu, and C for Pb. The OF_b and C_b plots were not analyzed since they were different than OF and C only for the bio-activator application, which did not contain heavy metals. Similar results were found for emmer grain heavy metals content, since no statistical differences were recorded among treatments in all parameters. Furthermore, the mean of the absolute values in grain was substantially lower than those indicated as toxic levels for animal feeding.

According to Mantovi et al. (2003), the transfer coefficients of heavy metals from soil to emmer crop were calculated (Table 4). The values were obtained by dividing the content of each heavy metal in the grain emmer by its content in the corresponding soil sample measured at the fourth trial year. No significant differences were found for this parameter in Zn, Cu, and Pb contents among treatments, whereas the A treatment showed a significant increase of Ni (+ 25% in comparison with the mean of the other treatments).

Finally, in Table 5, the heavy metal balance for A, C, and N0 fertilizer treatments is reported. The initial and final soil levels of all the heavy metals were much higher than those of soil application obtained distributing OP compost in both doses (A and C treatments). Also, the emmer grain uptake (sum of the 4 years) for each heavy metal was very low as compared to the initial and final soil contents, and, as a consequence, the heavy metals soil accumulation showed the same behavior of the absolute values. In any case, positive values of soil accumulation were only recorded for Cu both in A and C treatments, while all other calculations showed negative responses.

Table 3 Heavy metals content in the soil (at beginning and end of trial field) and in the emmer grain (at the end of the trial field) compared to the toxic levels

	Soil contents				Grain contents			
	Zn_{tot}	Cu_{tot}	Ni_{tot}	Pb_{tot}	Zn_{tot}	Cu_{tot}	Ni_{tot}	Pb_{tot}
	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
A	85.2	23.4	29.9	41.6	25.7	5.8	26.9	10.5
OF	93.7	20.8	36.0	44.3	32.7	8.1	24.8	12.0
C	79.0	24.9	36.3	48.0	32.1	6.7	25.2	11.4
N0	87.0	19.1	33.6	37.9	28.2	7.5	26.6	11.4
Soil values at t0	87.3	22.3	35.9	45.0	–	–	–	–
Toxic level for animal feeding*	–	–	–	–	900	115	50	30

*National Research Council (1980)

4 Discussion

4.1 Yield, Yield Components, and Quality Parameters

The C_b treatment determined a higher yield than the compost both supplied as "amendment" and "fertilizer" (A and C plots), maybe due to the low temperatures that could have reduced their mineralization processes, whereas the presence of the bio-activator in C_b could have fostered the organic matter decomposition, due to selected microorganisms (Table 1). This finding confirmed the results of Prasad Babu et al. (2015) on another cereal, who reported that the bio-activator increased the efficiency of crop fertilization. Conversely, in our study, its application did not enhance yield quality.

The highest emmer yield was obtained by OF treatment (+ 14.39 and 21.37% in comparison with A and C treatments), while due to either a higher mineralization rate of this organic fertilizer (Canali et al. 2011) or a long cropping cycle of emmer, the protein content was lower than 14.34 and 16.42%, respectively. Therefore, the application of commercial organic fertilizer enhanced the N level during vegetative stages, increasing emmer production, but reduced the N availability at the end of cycle thus decreasing the quality of grain. This result should be taken into account in organic farming production, where the quality is at least as important as quantity (Diacono et al. 2012).

The yielding and qualitative parameters of N0 treatment confirm that the absence of fertilization is not a sustainable practice. This is true not only in conventional agriculture (Marino et al. 2016) but also in organic one, as the case of this study, in which emmer was included in a biannual rotation with a leguminous plant, specifically cropped to sustain soil fertility. However, the N0 treatment reached the same total N uptake, but showed the significantly lowest grain N uptake, indicating that the large amount of N uptake remains in the straw without the translocation in the grains. The good amount of total N uptake recorded in all treatments could be due to the leguminous crop in the rotation, studied in this experiment. The 1000 seeds weight showed no significant difference among treatments, while the significantly highest number of seeds per square meter was obtained in OF treatment, suggesting that the fertilizing strategies influenced the emmer crop fertility.

These findings suggest that the application of eco-friendly practices (OP, rotation, and bio-activator) in organic production, as promoted by the agricultural policy of the EU, should be earlier studied at the farming system level to avoid yield or quality reduction.

Table 4 Heavy metals transfer coefficient from soil to emmer plant, according to the fertilizer treatments

	Zn	Cu	Ni	Pb
A	0.30	0.25	0.90a	0.25
OF	0.35	0.39	0.69b	0.27
C	0.41	0.27	0.69b	0.24
N0	0.32	0.39	0.79b	0.30

The values in the same column followed by different letters are significantly different at $p \leq 0.05$ (Duncan's multiple range test)

4.2 Effect of Tested Treatments on Soil Fertility

Starting from the same soil chemical characteristics at the beginning of the experiment, the highest values of nitrate were found when OP compost (C and A treatments) and bio-activator (OF_b and C_b) were applied (Table 2). At the end of the cropping cycles, the highest amounts of nitrate were obtained by the fertilizing treatments as compared to the N0 one. These findings indicated that a share of N mineralized from the organic amendment remained in the soil, with the possibility to loss by leaching if there is not a subsequent crop that can take up this readily-available amount of N, as

Table 5 Heavy metals balance in the soil according to fertilizer treatments

	Zn			Cu			Ni			Pb		
	A	C	N0	A	C	N0	A	C	N0	A	C	N0
Initial soil content	353.6	353.6	353.6	90.3	90.3	90.3	145.4	145.4	145.4	182.3	182.3	182.3
Soil application	6.48	1.38	0.00	3.16	0.67	0.00	0.18	0.04	0.00	0.99	0.21	0.00
Grain uptake	0.124	0.117	0.106	0.028	0.026	0.024	0.130	0.123	0.110	0.051	0.048	0.043
Final soil content	345.1	320.0	352.4	94.8	100.8	77.4	121.1	147.0	136.1	168.5	179.4	153.5
Soil accumulation	− 15.1	− 35.1	− 1.3	1.3	9.8	− 13.0	− 24.6	− 1.5	− 9.4	− 14.8	− 3.1	− 28.8

suggested by Anwar et al. (2018). Our results highlighted that this share of nitrate present in the soil at the end of emmer cultivation, together with the estimation of N mineralization from organic materials, should be borne in mind when formulating fertilizer recommendations for the subsequent cultivations.

The application of OP compost as "amendment" (A treatment) determined statistically higher levels of organic matter and exchangeable K compared to the N0 and, even if without statistical difference, also for total N and available P. Furthermore, this treatment increased organic matter and total N of the 4.4 and 17.0%, respectively, as compared to the soil initial level. The same positive effects were recorded on soil characteristics for C treatment, indicating that the application of OP compost is important, at least in organic agriculture and considering a long-term period. The recycling of OP through its composting is also important to follow and close the loop of agricultural production applying the indications of the European Community on the action plan for the Circular Economy (EC 2015); therefore, the findings of this research can contribute to increase the knowledge on this aspect. The same results were found with the application of different organic materials in cereal and leguminous crops (Montemurro et al. 2015; Saleem et al. 2017). Conversely, the application of commercial organic fertilizer (OF) reduced the levels of organic matter, available P, and exchangeable K compared to the values of these parameters at t0, suggesting that, even if the yield of OF reached the highest performance, its sustainability is not the best for the long period time.

4.3 Effect of Tested Treatments on Heavy Metals Fate

The content of all heavy metals in the soil (Table 3), at the end of field experiment, showed no significant difference among treatments and were very similar to those recorded at the beginning of the experiment, except for Cu which showed a slight increase in the C and A treatments. These findings confirm the results obtained by Russo et al. (2015), who found that the determination of some biomarkers to pollutants and heavy metals of the OP excluded any kind of soil pollution in the medium-term period.

Similarly, the content of all heavy metals in the grain emmer at the end of trial field showed no significant difference among treatments and were substantially lower compared to the toxic level for animal feeding, which were indicated by the National Research Council (1980). Therefore, our results showed no accumulation in emmer grain, thus suggesting no negative effects on human or animal health. In any case, the level of heavy metals should be always monitored, since their presence could cause deleterious health effects in people that are exposed to soil-plant systems, as suggested by Zhang et al. (2018). The low level of heavy metals' accumulation in emmer plant was also confirmed by the transfer coefficients, which were always less than one unit (Table 4). However, the A treatment reached a significant increase of Ni by 20% than the mean of the other treatments, as a consequence of repeated large application of OP compost over 4 years. The other heavy metals showed both no significant difference among treatments and low values of transfer coefficient, indicating that emmer could be fertilized with organic materials, at least in the short-middle-term period.

No remarkable soil accumulation of heavy metals was found in the treatments at the end of field experiment (Table 5). The only positive values of soil accumulation were found in A and C for Cu, and this result was a consequence of either the mobility in the soil, due to organic matter degradation by soil micro-organisms (Quantin et al. 2002), or to sampling effects. Therefore, the accumulation in the soil of heavy metals after OP compost application could be observed only after a continuous application throughout the years on the same land, as suggested by Zhang et al. (2006). Furthermore, the heavy metals' accumulation in the soil was also low, because of their concentrations in the OP compost were always under the current limit values imposed by the Italian legislation (Legislative Decree No. 217 2006). The initial and final soil contents of heavy metals were much higher than both those applied with the OP compost and uptakes by emmer crop, even if the levels of heavy metals at t0 were relatively high. This behavior could be due to the low capability of this crop to accumulate heavy metals in the plant, since the accumulation can depend not only on the genotype but can be also as a consequence of many other parameters, i.e., soil characteristics, climatic factors, and agronomic managements.

Finally, the findings of this research showed no variation in the soil heavy metals' deficit as a consequence of repeated OP compost application. As suggested by Montemurro et al. (2010), the deficit should be equal to zero, which is the best compromise between crop uptake, soil application, and accumulation. Since the values found in this research were in this direction, it is possible to confirm the low bioavailability of heavy metals in the soil and emmer plant.

5 Conclusions

The results of this research indicated that the application of OP compost in organic emmer is an interesting strategy of fertilization, since its utilization ensures a good level of yield and a high level of protein content in the grain. The findings showed no substantial accumulation of heavy metals both in the soil and emmer crop, since the transfer coefficients and soil accumulation at the end of the 4-year field trial were very low. Therefore, the OP compost utilization could be used not only to provide a useful N source in organic farming, as it was observed in this study, but also to reduce the input of mineral fertilizers in conventional agriculture and to recycle waste in an eco-friendly way. However, since it is of utmost importance to protect the environment, it is always important to monitor plant and soil heavy metals' concentration, also calculating their balance and transfer coefficients, so giving information in middle-long term applications of organic materials.

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References

Adesemoye AO, Torbert HA, Kloepper JW (2008) Enhanced plant nutrient use efficiency with PGPR and AMF in an integrated nutrient management system. Can J Microbiol 54:876–886

Anwar Z, Ping A, Haroon B, Irshad M, Owens G (2018) Nutrients losses via runoff from soils amended with cow manure composted with leaf litter. J Soil Sci Plant Nutr 18(3):851–864

Baker D (1979) Report on cereal foods. J Assoc Off Anal Chem 62:36–370

Canali S, Di Bartolomeo E, Tittarelli F, Montemurro F, Verrastro V, Ferri D (2011) Comparison of different laboratory incubation procedures to evaluate nitrogen mineralization in soils amended with aerobic and anaerobic stabilized organic materials. Journal of Food Agriculture & Environment 9:540–546

Canet R, Pomares F, Cabot B, Chaves C, Ferrer E, Ribò M, Albiach R (2008) Composting olive mill pomace and other residues from rural south eastern Spain. Waste Manag 28:2585–2592

Cayuela ML, Sánchez-Monedero MA, Roig A (2010) Two-phase olive mill waste composting: enhancement of the composting rate and compost quality by grape stalks addition. Biodegradation 21:465–473

Chowdhury AKMMB, Akratos CS, Vayenas DV, Pavlou S (2013) Olive mill waste composting: a review. Int Biodeter Biodegr 85:108–119

Diacono M, Ferri D, Ciaccia C, Tittarelli F, Ceglie F, Verrastro V, Ventrella D, Vitti C, Montemurro F (2012) Bioassays and application of olive pomace compost on emmer: effects on yield and soil properties in organic farming. Acta Agric Scand Sect B - Soil Plant Sci 62:510–518

EC (2015) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Closing the loop - an EU action plan for the circular economy. COM (2015) 614 final

Gigliotti G, Proietti P, Said-Pullicino D, Nasini L, Pezzolla D, Laura R, Porceddu PR (2012) Co-composting of olive husks with high moisture contents: organic matter dynamics and compost quality. Int Biodeter Biodegr 67:8–14

Giuliani A, Karago¨z A, Zencirci N (2009) Emmer (*Triticum dicoccon*) production and market potential in marginal mountainous areas of Turkey. Mt Res Dev 29:220–229

Henriksen A, Selmer-Olsen AR (1970) Automatic methods for determining nitrate and nitrite in water and soil extracts. Analyst 95:514–518

Karagiannidis N (1999) Effect of industrial waste application on plant growth. Agrochimica 43:18–27

Legislative Decree No. 217 (2006) Suppl. Ord. G.U. n. 141, 20 giugno 2006

López-Piñeiro A, Albarrán A, Nunes JMR, Peña D, Cabrera D (2011) Cumulative and residual effects of two phase olive mill waste on olive grove production and soil properties. Soil Sci Soc Am J 75: 1061–1069

Mantovi P, Bonazzi G, Maestri E, Marmiroli N (2003) Accumulation of copper and zinc from liquid manure in agricultural soils and crop plants. Plant Soil 250:249–257

Marino S, Cocozza C, Tognetti R, Alvino A (2016) Nitrogen supply effect on emmer (Triticum dicoccum Schübler) ecophysiological and yield performance. Int J Plant Prod 10:1735–1735

Montemurro F, Convertini G, Ferri D (2004) Mill wastewater and olive pomace compost as amendments for rye-grass. Agronomie 24:481–486

Montemurro F, Diacono M, Vitti C, Debiase G (2009) Biodegradation of olive husk mixed with other agricultural wastes. Bioresour Technol 100:2969–2974

Montemurro F, Charfeddine M, Maiorana M, Convertini G (2010) Compost use in agriculture: the fate of heavy metals in soil and fodder crop plants. Compost Sci Util 18:47–54

Montemurro F, Fiore A, Campanelli G, Ciaccia C, Ferri F, Maiorana M, Diacono M (2015) Yield and performance and soil properties of organically fertilized fodder crops. J Plant Nutr 38:1558–1572

National Research Council (1980) Mineral tolerance of domestic animals. Subcommittee of Mineral Toxicity in Animals, National Academy of Science, Washington, DC., USA

Olsen RS, Sommers LE (1982) Phosphorus. In: Page AL, Miller RH, Keeny DR (eds) Methods of soil analysis, Part II (2nd Edn). American Society of Agronomy, Madison, WI, p 403427

Page AL, Miller RH, Keeny DR (1982) Methods of Soil Analysis. Part II. 2nd Edition. American Society of Agronomy, Madison, Wisconsin

Prasad Babu MBB, Gangaiah B, Latha PC (2015) Enhancement of rice productivity and nitrogen use efficiency through bioactivator™ treated nitrogen fertilization. Oryza 52:34–40

Quantin C, Becquer T, Rouiller JH, Berthelin J (2002) Redistribution of metals in a New Caledonia Ferralsol after microbial weathering. Soil Sci Soc Am J 66:1797–1804

Russo G, Vivaldi GA, De Gennaro B, Camposeo S (2015) Environmental sustainability of different soil management techniques in a high-density olive orchard. J Clean Prod 107:498–508

Saleem A, Irshad M, Hassan A, Mahmood Q, Eneji AE (2017) Extractability and bioavailability of phosphorus in soils amended with poultry manure co-composted with crop wastes. J Soil Sci Plant Nutr 17(3):609–623

Soil Survey Staff (1999) Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys. In: Agriculture Handbook 436. USDA-NRCS, Washington DC

Unesco-FAO (1963) Etude Écologique de la Zone Méditerranéenne. Carte Bioclimatique de la Zone Méditerranéenne (Ecological study of the Mediterranean area: Bioclimatic map of the Mediterranean sea). Paris-Rome. Available online: http://unesdoc.unesco.org/images/0013/001372/137255fo.pdf. Accessed Feb 2018. In French

Zhang M, Heaney D, Henriquez B, Solberg E, Bittner E (2006) A four-year study on influence of biosolids/MSW compost application in less productive soils in Alberta: nutrient dynamics. Compost Sci Util 14:68–80

Zhang Y, Yina C, Caobc S, Chengd L, Wua G, Guoe J (2018) Heavy metal accumulation and health risk assessment in soil-wheat system under different nitrogen levels. Sci Total Environ 622–623:1499–1508