Assessing the Use of Composted Two-Phase Olive Mill Wastes as Soil Improvers

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Abstract

Co-composting two phase olive mill wastes (TPOMW) with bulking agents – which provide nitrogen and aeration– with agricultural purposes is an appropriate strategy for the management of this by-product from both environmental and economic points of view. The aims of this work were to characterize two composts prepared by mixing TPOMW and fresh horse manure and to study the effects of the composts produced when applied to a calcareous soil fertilized with two mineral programs on radish, lettuce and green beans throughout two years, by emphasizing on crops productivity and soil chemical properties. The two mixtures subjected to composting evolved to materials with different properties, thus leading to differences in soil and crop responses to the resulting composts. After compost application radish root and leaf biomass were significantly higher when AL was added compared to AL+H, and similarly standard mineral fertilization (F1) showed higher values for these parameters than the reduced program F2. Regarding subsequent crops, compost application increased markedly lettuce and bean yields in comparison with the controls, especially treatments with the highest rate of compost and mineral fertilizers. Throughout the second year of the experiment, standard fertilization enhanced radish and lettuce productivity, whereas non significant variations in bean pods yield were scored; in addition, the residual effect resulted in a greater lettuce yield in compost-amended treatments with standard fertilization, especially when composts were added at 24 Mg ha^{-1}. Finally, compost application improved soil fertility, particularly by increasing total organic carbon, total nitrogen and available potassium contents with respect to controls.

INTRODUCTION

The olive oil extraction industry has a considerable socioeconomic importance in most Mediterranean countries. During the last two decades oil extraction technology has evolved from the three-phase to the two-phase centrifugation system, thus reducing substantially the production of highly pollutant wastewater and providing a more efficient use of natural resources. The introduction of a two-phase decanter entails the production of large amounts of an organic by-product, the two-phase olive mill waste (TPOMW), which is a material of semisolid consistency, with low porosity, sludgy texture and high humidity, and also containing water-soluble carbohydrates, fats and phenols. Since TPOMW cannot be used directly for agricultural purposes due to nitrogen immobilization risks and phytotoxic effects (Alburquerque et al., 2006), its management has become an important concern to minimize the environmental impact. In this context, co-composting TPOMW with bulking agents, which provide nitrogen and aeration, is an appropriate strategy for the reclamation of this residue. Compost addition to soils is considered an important strategy to increase soil organic matter content and to improve sustainable fertility in agrosystems, since it supplies the nutrients needed by crops, and also has beneficial effects on soil physical, chemical and biological properties, including the increase of carbon sequestration in the context of climate change.

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The aims of this work were to characterize two composts prepared from TPOMW and to study the effects of the composts produced when applied to a calcareous soil fertilized with two mineral programs on radish, lettuce and green beans during two years, by emphasizing on crop yields and soil characteristics.

MATERIALS AND METHODS

Materials: Composts and Soil

Two composts were prepared by co-composting two-phase olive mill waste and fresh horse bedding: compost AL and compost AL+H, whose composting piles were irrigated with tap water or with an animal fatty-proteinaceous waste from the pharmaceutical industry, respectively. These materials were produced in a pilot plant (Centro de Edafología y Biología Aplicada del Segura, Murcia, Spain) by a dynamic composting system with periodical pile turning during the bio-oxidative phase (which lasted 195 days), followed by 66 days of maturation.

The composts were applied to a calcareous soil (pH=8.4 and $CaCO_3$ (total, %) = 37.7, silty loam texture) located in Lliria (Valencia, Spain) – 39º45'04" in latitude and 0º41'10" in longitude.

Composts Characterization

To determine pH and electrical conductivity (EC), 1:5 (v:v) water suspension or extract was prepared, respectively, as indicated by the European standards (EN 13037, 1999; EN 13038, 1999). Cation exchange capacity (CEC) was determined according to Harada and Inoko (1980). Total organic matter was measured by loss on ignition following EN 13039 (1999), and total nitrogen (TN) and total organic carbon (TOC) were determined by automatic microanalysis (Navarro et al., 1991). Water-soluble phenolic substances were measured following Maestro Durán et al. (1991) procedure and water-soluble carbon (WSC) was determined using a Total Organic Carbon analyzer for liquid samples. Finally, P, K, Ca and Mg were measured by inductively coupled plasma-atomic emission spectrometry (ICP-AES) after aqua regia digestion (EN 13650, 1999).

Agronomic Evaluation Assays: Experimental Design and Analyses

Eight different treatments were comparatively tested using a factorial experiment conducted in a randomized block design, with the combination of 2 composts – AL and AL+H –, applied as a single amendment to the soil at 2 compost rates – 12 (R1) and 24 (R2) Mg total organic matter (TOM) ha^{-1}–, and fertilized with two mineral programs – standard (F1) and reduced (F2) for nitrogen (70% of F1) and potassium (no application). Mineral fertilized control soils, which did not receive any additional organic amendment, were also included. The mixtures were arranged in 35 L pots outdoors, where radish (*Raphanus sativus* L. 'Largo Rojo Escarlata'), lettuce (*Lactuca sativa* L. var. *longifolia* 'Romana de Valladolid') and green beans (*Phaseolus vulgaris* L. 'Contender') were successively grown during two years. At crop commercial stages plants were collected to determine total biomass and commercial yield estimated by: root mass, aerial biomass and pod mass for radish, lettuce and green beans, respectively.

After each year of the field experiment, selected soil properties were determined: total organic carbon content (MAPA, 1994), mineral N (Keeney and Nelson, 1982), total N (Kjeldahl procedure), available P (Olsen method) and available K (MAPA, 1994).

RESULTS AND DISCUSSION

Composts Characteristics and Composition

Composts AL and AL+H differed significantly in their agrochemical characteristics (presented in Table 1), due to the dissimilar mixtures prepared to carry out the composting process. A strongly alkaline pH value was observed in both materials, being higher in AL+H than in AL. Compost AL+H was also highly saline and showed a greater

EC value (806 mS/m) compared to compost AL (365 mS/m), whereas the latter had a higher CEC than AL+H (104.4 *vs*. 74.3 meq/100 g dry wt). Both materials were rich in organic matter and, as regards total organic carbon to total nitrogen (C/N) ratio, lower levels of total organic carbon and total nitrogen were recorded in compost AL+H than in compost AL, resulting in C/N ratios –10.6 and 11.9 for AL and AL+H, respectively– similar to typical values obtained in manures (Cegarra and Paredes, 2008). In addition, compost AL+H showed larger K and P levels than AL, particularly emphasizing a remarkable high K content found in both materials, whereas AL exhibited higher amounts of Ca and Mg. Water-soluble organic carbon and phenols determination revealed that the animal fatty-proteinaceous waste addition to AL+H increased significantly these compounds contents, which have been used widely to assess both the maturity and stability of composts, thus suggesting some potential phytotoxic effects.

Short-Term and Residual Effects of Composts Application to Soil

1. Influence of Composts on Crop Yield and Productivity. As shown in Table 2, after compost application both root and plant biomass of radish were significantly higher for AL than for AL+H. Standard mineral fertilization (F1) showed higher values for these parameters than the reduced program F2. Additionally, radish development and growth did not vary significantly or were higher in AL-amended treatments in comparison with un-amended, mineral fertilized controls, whereas AL+H addition produced lower biomass than the control samples (Table 3). This may be explained by a nitrogen immobilization effect observed in a short-term incubation assay previously carried out (data not shown) or/and by phytotoxicity inferred from AL+H chemical composition. Regarding subsequent crops – lettuce and green bean –, results disclosed no significant differences between both TPOMW composts, while the highest compost rate tested in the experiment (24 Mg TOM ha^{-1}, R2) and the standard fertilization (F1) increased lettuce and green bean growth and yield with respect to the lowest compost rate R1 and the reduced fertilization F2. Compost application markedly increased lettuce and bean yields in comparison with the controls, especially treatments which contained the highest rate of compost (R2) and mineral fertilizers (F1).

In relation to the second year, standard fertilization enhanced radish and lettuce productivity, whereas only slight variations in bean pods yield were observed. Furthermore, the residual effect (crops grown during the second year after composts application) resulted in greater lettuce yield and development in treatments with composts added at 24 Mg ha^{-1}. As a general trend, when compared with mineral fertilized controls, a significant yield decrease was recorded in the control that included the lowest mineral fertilizers application (F2).

The above mentioned results suggest that different responses of radish compared to lettuce and green beans during the first year of the field trial could be related with a differential evolution of the two composts after their application to soil. Nitrogen immobilization process and phytotoxicity found in AL+H could have been temporary and reversible, thus nitrogen mineralization began before lettuce establishment and remained during green bean crop. During the second year after compost addition, the statistical analyses showed a stronger effect of the mineral fertilizers rate on plant growth and production. Despite the fact that compost type and rate did not affect considerably radish and green bean yield, lettuce presented significant differences in compost rate, thus indicating that the residual effect may be related with the crop nutritional requirements.

2. Changes in Soil Properties Induced by Amendments Addition and Crops Growth. Treatments main effects on soil chemical properties after crops cultivation (data not shown) exhibited that compost AL increased total organic carbon content, while compost AL+H raised phosphorus and potassium levels in soil. Considering compost rate, total organic carbon, total nitrogen and available potassium concentration were larger when the highest compost application (24 Mg TOM ha^{-1}) was added. Standard mineral fertilization program increased potassium soil content, whereas reduced program increased mineral nitrogen and phosphorus contents. Soil composition of all treatments one year after

TPOMW composts application (Fig. 1) showed that total organic carbon, total nitrogen, available phosphorus and available potassium levels were enhanced in compost-amended soils in comparison to the un-amended, mineral fertilized controls. Compost addition increased markedly potassic edaphic fertility, especially with AL+H at 24 Mg TOM ha^{-1}, thus showing similar results to those reported by Walker and Bernal (2008).

After the second year of field trial, the study of treatment main effects (data not shown) disclosed that AL application significantly increased the total organic carbon and total nitrogen concentration compared to AL+H. When the highest compost dose (24 Mg TOM ha^{-1}) was applied, all selected chemical parameters contents were significantly higher than those obtained at 12 Mg TOM ha^{-1}. Also, standard mineral fertilization provided larger available potassium content than the reduced program. With respect to the controls (Fig. 1), compost addition brought about an increase of total organic carbon – particularly when the highest compost rate was applied –, as well as a total nitrogen rise, but only with the largest compost application. Finally, all treatments that contained standard mineral fertilization provided a significantly greater available potassium level than those amended with the reduced fertilization and, in addition, all compost-amended samples that also included the standard fertilization program had considerably higher potassium content than un-amended controls.

CONCLUSIONS

The field experiment to assess short-term and residual effects of two TPOMW composts as organic amendments of soil revealed that, although both materials differed in their evolution when applied to soil, they could be used appropriately to improve soil fertility and to provide an additional nutrient source for crops as a slow release fertilizer, thus being considered an adequate alternative to manage olive oil extraction residues.

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Tables

Table 1. Selected physico-chemical characteristics and composition of the TPOMW composts.

Parameter	AL	AL+H	*P*
pH	9.17	9.59	***
Electrical conductivity (mS/m)	365	806	***
CEC (meq/100 g dry wt)	104.4	74.3	*
Organic matter (g/kg dry wt)	667.9	716.7	*
Total organic carbon (g/kg dry wt)	400.3	381.1	**
Total nitrogen (g/kg dry wt)	37.6	32.1	***
C/N ratio	10.6	11.9	***
P (g/kg dry wt)	8.00	10.13	*
K (g/kg dry wt)	36.26	47.03	***
Ca (g/kg dry wt)	76.13	43.75	***
Mg (g/kg dry wt)	22.19	15.25	***
Water-soluble organic carbon (g/kg dry wt)	35.8	61.3	***
Water-soluble phenols (g/kg dry wt)	1.7	10.1	**

AL: Compost from two-phase olive mill waste; AL+H: Compost from two-phase olive mill waste and animal fatty-proteinaceous waste.
*$P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$.

Table 2. Treatments main effects (compost type, compost rate and mineral fertilization) on productivity and growth parameters of radish, lettuce and green bean grown during two years.

Main effect	Short-term effects (1st year after compost application)						Residual effects (2nd year after compost application)					
	Radish		Lettuce		Green beans		Radish		Lettuce		Green beans	
	Root (g/pot)	Plant biomass (g dw/plant)	Above-ground biomass (g/pot)	Plant biomass (g dw/plant)	Pods (g/pot)	Total biomass (g dw/plant)	Root (g/pot)	Plant biomass (g dw/plant)	Above-ground biomass (g/pot)	Plant biomass (g dw/plant)	Pods (g/pot)	Total biomass (g dw/plant)
A. Compost												
AL	432	2.56	804	24.9	253.5	28.9	295	1.79	944	25.0	568	56.4
AL+H	365	2.06	853	24.8	252.7	29.5	316	1.92	956	26.4	574	56.6
P	***	***	ns	ns	ns	ns	ns	ns	ns	*	ns	ns
B. Compost rate												
12 Mg TOM ha^{-1}	398	2.34	749	21.1	237.3	26.0	304	1.86	896	24.6	566	55.4
24 Mg TOM ha^{-1}	398	2.28	910	28.6	268.9	32.4	307	1.85	1004	26.8	576	57.6
P	ns	ns	***	***	**	***	ns	ns	***	***	ns	*
C. Mineral fertilization												
Standard	417	2.52	854	26.8	268.1	30.4	341	2.03	1052	27.5	580	57.6
Reduced	380	2.11	804	22.9	238.1	28.1	270	1.68	848	23.8	562	55.3
P	**	***	ns	***	**	**	***	***	***	***	ns	*
D. Interaction												
AxB	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
AxC	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*
BxC	ns	ns	ns	***	ns	ns	ns	ns	ns	*	ns	*
AxBxC	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

AL: Compost from two-phase olive mill waste; AL+H: Compost from two-phase olive mill waste and animal fatty-proteinaceous waste. R1: 12 Mg ha^{-1}; R2: 24 Mg ha^{-1}. F1: Standard fertilization; F2: Reduced fertilization.

ns: not significant; *$P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$.

Table 3. Productivity and growth parameters of radish, lettuce and green bean of the compost-amended treatments compared with un-amended, mineral fertilized composts.

Treatments	Short-term effects (1st year after compost application)						Residual effects (2nd year after compost application)					
	Radish		Lettuce		Green beans		Radish		Lettuce		Green beans	
	Root (g/pot)	Plant biomass (g dw/plant)	Above-ground biomass (g/pot)	Plant biomass (g dw/plant)	Pods (g/pot)	Total biomass (g dw/plant)	Root (g/pot)	Plant biomass (g dw/plant)	Above-ground biomass (g/pot)	Plant biomass (g dw/plant)	Pods (g/pot)	Total biomass (g dw/plant)
AL R1 F1	443a	2.92a	719c	21.2bc	254ab	27.3bc	336a	2.01a	999b	25.1b	587ab	57.6a
AL R1 F2	407ab	2.30b	755bc	21.4bc	218b	25.5bc	261bc	1.67abc	784d	22.8b	552ab	51.5bc
AL R2 F1	437a	2.58ab	891b	32.1a	285a	34.1a	326a	1.94ab	1096a	29.0a	559ab	59.6a
AL R2 F2	440a	2.44b	853bc	24.8b	258ab	28.8b	256bc	1.54bc	896c	23.2b	600a	56.7a
AL+H R1 F1	399ab	2.30b	794bc	21.3bc	257ab	26.5bc	357a	2.09a	988b	26.2b	581ab	57.4a
AL+H R1 F2	345bc	1.85c	728bc	20.3bc	221b	24.9c	263bc	1.69abc	815cd	24.3b	545ab	55.0ab
AL+H R2 F1	387abc	2.26b	1012a	32.1a	277a	33.6a	346a	2.09a	1124a	29.7a	591a	55.9ab
AL+H R2 F2	329c	1.83c	879b	25.0b	257ab	33.1a	299ab	1.83abc	899c	25.2b	553ab	58.0a
CO F1	365bc	2.63ab	545d	16.0d	171c	17.9d	331a	2.03a	828cd	23.7b	563ab	55.2ab
CO F2	366bc	2.45b	555d	19.6c	136d	14.9e	232c	1.44c	632e	19.8c	510b	49.9c
P	***	***	***	***	***	***	***	***	***	***	***	***

AL: Compost from two-phase olive mill waste; AL+H: Compost from two-phase olive mill waste and animal fatty-proteinaceous waste; CO: un-amended but mineral fertilized control. R1: 12 Mg ha^{-1}; R2: 24 Mg ha^{-1}. F1: Standard fertilization; F2: Reduced fertilization. *** $P \leq 0.001$. Values within a column followed by different letter differ significantly at $P \leq 0.05$ by LSD test.

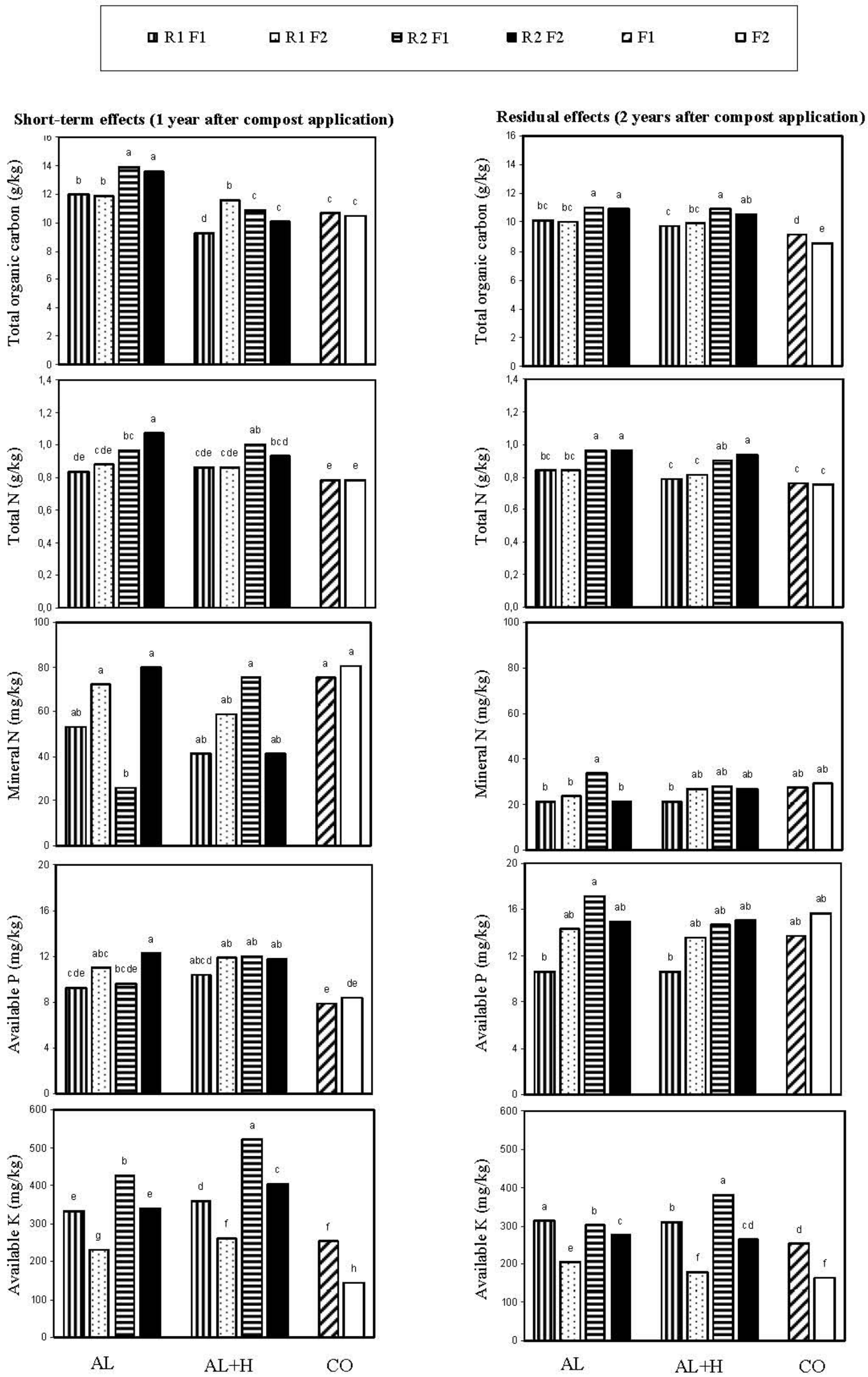

Fig. 1. Short-term and residual effects of compost application to soil on selected soil chemical parameters after radish, lettuce and green bean growth throughout two years, comparing the compost-amended treatments with un-amended, mineral fertilized composts. AL: Compost from two-phase olive mill waste; AL+H: Compost from two-phase olive mill waste and animal fatty-proteinaceous waste. R1: 12 Mg ha^{-1}; R2: 24 Mg ha^{-1}. F1: Standard fertilization; F2: Reduced fertilization. Vertical bars with different letter differ significantly at $P \leq 0.05$ by LSD test.