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Short term effects of synergistic inorganic and organic fertilization on soil properties and yield and quality of plum tomato

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ABSTRACT

Tomato is one of the most important crops in the world and its cultivation is usually based on a great use of inorganic fertilizers applied as broadcast fertilization and with several fertigations. For a more sustainable agriculture authors studied the synergistic effects of the application of two different composts, combined with an inorganic fertilizer, on the main chemical-physical soil properties and on the yield and qualitative parameters of a plum tomato variety. Two composts, obtained mixing sewage sludge or the organic fraction of the municipal solid wastes with pruning residues, grape marc, and exhausted olive pomace, were tested at 2 or 4.5 t ha^{-1} in a field experiment, replacing a part of the inorganic fertilization and respecting the N crop requirement.

From an environmental point of view, the addition of composts to the soil caused an increase in the total and available heavy metals content, even if no soil pollution has been recorded. The yield of tomatoes resulted higher with the combined application of amendments and inorganic fertilizer with respect to the sole inorganic fertilization. The quality of tomatoes was apparently not affected by the fertilization and, although certain heavy metals tend to increase their tomato concentration with the application of composts, their concentrations did not exceed the legal thresholds.

1. Introduction

The introduction and diffusion of the door-to-door collection system of the municipal solid wastes has increased the quantity and the quality of the organic fraction of wastes produced by municipalities. This great amount of food and garden wastes, together with residual biomasses deriving from farms and agri-food industries and possibly residential and no harmful sewage sludges should be valorized to obtain high quality soil amendments. In fact, the recycling of the organic waste in agriculture is considered one of the principles of the sustainable agriculture, in which the reduction of synthetic fertilizers and the development of healthy and biologically active soils are main goals (Neeson, 2004). From this point of view, the biological process of composting is an established and widely used method for the re-use of products virtually harmful to the environment and expensive to dispose of. Composts provide a wealth of available nutrients for plants (Boldrin et al., 2009), improve soil physical, chemical, and biological properties (Zhang et al., 2006), and facilitate the proliferation of beneficial microorganisms (Hagreaves et al., 2008) so promoting higher yields of crops and the reduction of use of fertilizers and pesticides. Furthermore, the soil amendment with organic biomasses supplies organic matter and promotes carbon sequestration (Favoino and Hogg, 2008). This contribution is very important in the Mediterranean environment and in regions where warm and dry seasons and inadequate crop management have reduced the organic matter content of soils (Cala et al., 2005).

However, compost soil amendments could present some problems concerning the increase of salts and heavy metals content deriving from the composition of raw materials (Hargreaves et al., 2008). Therefore, the quality of final composts and their commercial and agronomic value depend mainly on the quantity and quality of their organic matter in terms of stability and absence of toxicity.

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crop (Savić et al., 2008) with an extensive worldwide distribution and a massive economic value (FAOSTAT, 2015). The yield and quality characteristics of tomato crops are affected by fertilization, of course. Bilalis et al. (2018) reported an increase of the parameters related to the yield with the inorganic fertilization, while colour, total soluble solids and total soluble solids to titratable acidity ratio were significantly higher in tomatoes cultivated with organic fertilization. Hernández et al. (2014) found that the combined application of compost and inorganic fertigations improved some biochemical soil parameters and resulted in tomato yield and fruit quality similar to the sole inorganic fertigated control, suggesting that the inorganic fertilizers can

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be reduced by about 40%.

The aim of this work was to reduce the broadcast inorganic fertilization and eliminate the fertigations during the crop cycle of a plum tomato variety. The hypothesis was to study the synergistic effects of the application of two different composts, combined with an inorganic fertilizer, on the main soil properties and on the yield and qualitative crop parameters, in a perspective of sustainable agriculture and biomass recycling.

2. Materials and methods

2.1. Compost preparation and characterization

The first compost (SSC) was obtained mixing pruning residues (25% w/w), grape marc (20% w/w), exhausted olive pomace (20% w/w) and sewage sludge (35% w/w) deriving from the treatment of residential wastewaters, while the second compost (FWC) was prepared with the same raw materials and ratio, substituting the sewage sludge with the separately collected organic fraction of municipal solid wastes. The composting process was performed at an industrial composting facility preparing two piles (about 2.5 m height, 5 m width, 50 m length each). The temperature inside the heaps was kept at > 55 °C for at least 3 days by turning and irrigating them periodically to obtain the pasteurization of the biomasses. After 4 weeks, the temperature of the piles decreased naturally to a value of about 45 °C, indicating the conclusion of the active phase of composting. During the curing phase, less frequent turnings were made and after 120 days the two composts were sieved at 1 cm. Thirty samples were collected randomly alongside and from the top to the bottom of each pile at the end of the composting process. All samples of the same pile were mixed and, successively, separated into three samples for their characterization.

The composts were analysed for their moisture and ash content, pH (1:5, w/v) and electrical conductivity (EC, 1:5, w/v), P, organic and inorganic N content according to the methods by Trinchera et al. (2006). Organic carbon was analyzed using the Springer-Klee based method by Ciavatta et al. (1989). For their elemental characterization (total K, Mg, Fe, S, Cd, Cu, Ni, Pb, Zn, and Cr), the microwave-assisted acid digestion method was performed adding a suprapure HNO_3:H_2O_2:HCl mixture (6:1:1, v:v:v) to each compost sample. At the end of the digestion, the samples were cooled and diluted with distilled water Milli-Q Reagent grade into 25-mL volumetric flask, filtered through Whatman No 42 filter paper, and, finally, analyzed by using an inductively coupled plasma mass spectrometer (ICP-MS; NexION™ 300D, Perkin Elmer).

2.2. Field experiments

The field experiment was conducted in an open field of a private farm located at Brindisi, Apulia Region (Southern Italy), latitude 40°37′55″ North and longitude 17°56′09″ East. The soil of the experimental field was divided into 20 x 20 m plots, each separated by a 0.5-m buffer zone. Plots were distributed in a completely randomized block design with three replications for each treatment, for a total of 15 plots. The Apulian good agricultural practices suggest applying maximum 120 kg inorganic N ha^{-1} for the cultivation of tomato with an estimated production of about 70-80 t ha^{-1}, and in this trial the amount of N applied in each treatment was about 100 kg ha^{-1}. The treatments were: (i) Control, fertilized with 700 kg ha^{-1} of 10-10-15 fertilizer (10% N, 4.4% P, 12.5% K) one week before transplanting, fertigated with 3 kg ha^{-1} of a hydrolyzed animal epithelium based fertilizer containing 13% organic N and 50 kg ha^{-1} of 10-30-15 fertilizer (10% N, 13.1% P and 12.5% K) soon after transplanting, fertigated twice with 100 kg ha^{-1} of calcium nitrate (15.5% N and 18.5% Ca) during the fruit swelling; (ii) SSC 2, plots amended with SSC at a dose of 2 t ha^{-1} two weeks before transplanting, and fertilized with 700 kg ha^{-1} of 10-10-15 fertilizer one week before transplanting (iii) SSC 4.5, plots amended with SSC at a dose of 4.5 t ha^{-1} two weeks before transplanting, and fertilized with 300 kg ha^{-1} of 10-10-15 fertilizer one week before transplanting; (iv) FWC 2, plots amended with FWC at a dose of 2 t ha^{-1} two weeks before transplanting, and fertilized with 700 kg ha^{-1} of 10-10-15 fertilizer one week before transplanting; (v) FWC 4.5, plots amended with FWC at a dose of 4.5 t ha^{-1} two weeks before transplanting, and fertilized with 300 kg ha^{-1} of 10-10-15 fertilizer one week before transplanting. Composts were incorporated into the soil at about 20 cm depth by rotavation. The variety of tomato used in the experiments was Taylor F1, a long plum one. Five weeks old tomato seedlings were transplanted into the plots in paired rows (0.4 m apart) spaced at 1.7 m, with the plants at a distance of 0.4 m apart along each single row. The planting density was about 24,000 seedlings ha^{-1}. The transplanting occurred at the end of April and the tomatoes were harvested in September. The drip irrigation system consisted of a polyethylene pipeline in the middle of each paired row. The first irrigation was performed soon after the transplanting for the rooting and establishment of the plants. The following irrigations were carried out when water lost by evapotranspiration (ET) reached the 40% of available water depletion in the soil, according to Allen et al. (1998). The ET was calculated utilizing daily values of a class A pan evaporation and following the FAO evapotranspiration procedure (Allen et al., 1998).

Weed control was performed using herbicides containing the active ingredients Aclonifen and Metribuzin, applied before the transplanting. The tomato downy mildew was controlled using metalaxyl-M and mancozeb at early stage and, successively, zoxamide and cymoxanil. Finally, the moths were controlled using emamectin benzoate based insecticide.

2.3. Soil sampling and analyses

Soil samples were collected in triplicate before the transplant and after the harvest. Each soil sample was taken from 0 to the abundant root apparatus depth (about 20 cm) using an auger and was a composite of 13 cores collected from each replicate of each treatment following a X scheme, avoiding the borders. Soil analyses were performed on air-dried and 2-mm sieved samples. Particle-size distribution was determined by the pipette method after removing carbonates and organic matter, and the textural class of the soil was identified by the USDA soil textural classification system (Soil Survey Staff, 2014). Soil samples were analyzed also for pH (1:2.5, w/v), electrical conductivity (1:2, w/v), total organic carbon (Walkley and Black method), total nitrogen (Kjeldahl method), available phosphorous (Olsen method) and total carbonates (calcimeter method). The exchangeable potassium was extracted with a $BaCl_2$ and triethanolamine solution buffered at pH 8.2 and determined using the ICP-MS spectrometer. The total content of heavy metals (Cd, Cu, Ni, Pb, Zn, Cr) was determined as described for compost samples. The available fractions of heavy metals were extracted with diethylenetriaminepentaacetic acid (DTPA), filtered through Whatman No 42 filter paper, and quantified using the ICP-MS spectrometer (Page et al., 1982).

2.4. Tomatoes analyses

The yield of each plot was measured at the end of the crop cycle and about 50 marketable tomatoes were sampled randomly from the harvest of each plot and analyzed for the following parameters: (i) size (equatorial and longitudinal diameter), measured with a caliber; (ii) pH of the tomato juice (ISO, 1842:, 1991ISO, 1991ISO, 1842:, 1991); (iii) soluble solids content (°Brix: ISO, 2173:, 2003); (iv) dry matter content, determined drying samples at 105 °C to constant weight. The content of heavy metals in fruits was quantified as described for compost samples.

2.5. Statistical analysis

All analyses performed on soils and tomatoes were conducted at

Table 1
Physico-chemical characteristics of the two composts (on dry matter).

Parameter	SSC	FWC	Italian Legal Limits (D.L. 75/2010 and subsequent amendments)
Moisture content (%)	36.6 ± 3.8	33.3 ± 3.6	< 50
Ash content (%)	37.9 ± 4.5	39.5 ± 3.9	–
pH H_2O (1:5)	7.7 ± 0.6	7.8 ± 0.5	6 ÷ 8.5
Electrical conductivity (1:5) (dS m^{-1})	8.2 ± 0.2	8.5 ± 0.8	–
Organic carbon (g kg^{-1})	343 ± 25.6	336 ± 31.4	> 250
Total N (g kg^{-1})	24.0 ± 2.3	27.4 ± 3.4	–
Organic Nitrogen (g kg^{-1})	21.3 ± 1.8	25.2 ± 2.4	–
N-NH_4^+ (g kg^{-1})	1.8 ± 0.3	1.4 ± 0.3	–
N-NO_3^- (g kg^{-1})	0.9 ± 0.2	0.8 ± 0.1	
C/N ratio	14.3	12.3	< 25
Total P (g kg^{-1})	5.3 ± 0.7	5.6 ± 0.9	–
Total K (g kg^{-1})	9.8 ± 1.1	9.1 ± 1.2	–
Total Mg (g kg^{-1})	3.3 ± 0.4	2.8 ± 0.3	–
Total Fe (g kg^{-1})	16.7 ± 2.3	14.4 ± 2.8	–
Total S (g kg^{-1})	12.0 ± 1.4	6.1 ± 0.8	–
Total Cd (mg kg^{-1})	0.6 ± 0.02	0.2 ± 0.01	1.5
Total Cu (mg kg^{-1})	101 ± 6.9	65 ± 4.9	230
Total Ni (mg kg^{-1})	36 ± 3.7	24 ± 2.8	100
Total Pb (mg kg^{-1})	104 ± 9.5	42 ± 3.4	140
Total Zn (mg kg^{-1})	361 ± 33.8	180 ± 24.5	500
Total Cr (VI) (mg kg^{-1})	0.1 ± 0.01	< 0.1	0.5

SSC: Sewage sludge based compost.
FWC: Organic fraction of municipal solid wastes based compost.

least in triplicate. Experimental data were tested against the normal distribution using the Shapiro-Wilk's test, and against the homogeneity of variance using the Levene's test. Results normally distributed and showing homogeneity of variance were subjected to ANOVA and Tukey's test. Data not normally distributed or showing heterogeneity of variance were subjected to Kruskal-Wallis's test and Dunn's test. All statistical analyses were executed using the R software version 3.2.3.

3. Results and discussion

3.1. Composts

The characterization of the two composts at the end of the composting process is reported in Table 1. The pH was within the range established by the Decreto Legislativo 75(2010) (6.0–8.5), as well as the organic carbon content that was > 250 g kg^{-1}. The C/N ratio represents a very important index for the evaluation of the qualitative and quantitative transformations of the materials during the composting process. The law establishes for this parameter, in the final compost, a maximum value of 25, widely respected in composts under evaluation.

The raw materials of the two composts influenced other parameters: It is noteworthy that both amendments showed a high EC value due to the presence of sewage sludge for SSC and the salt of the foodwaste for FWC. Further, the heavy metals content was higher in the SSC with respect to the FWC, as reported in literature (Smith, 2009). However, both composts respected the legal threshold of those elements (Table 1).

3.2. Soil properties

The main properties of the soil samples examined are reported in Table 2. The soil showed a sandy loam texture according to the Soil Taxonomy USDA (Soil Survey Staff, 2014), with a content of sand, silt and clay of 520, 151 and 329 g kg^{-1}, respectively. The pH in aqueous suspension was between 8.0 and 8.3, and EC ranged from 1.0 to 1.55 dS m^{-1}. The EC values appeared slightly greater in amended soils, especially after the addition of composts at the highest dose, even if the differences were not significant. The organic carbon content increased significantly ($p \leq 0.001$) at the end of the trial in soils amended with the highest dose of composts. This result was related to the high amount of organic carbon applied and possibly to the relatively short period of investigation. The total Kjeldahl nitrogen (TKN) showed a slight significant increase ($p \leq 0.05$) after the amendments and this result, in the short term, was found by Liu et al. (2012) too. Apparently, the inorganic N fertilization of the control, based on the local good agricultural practices, maintained the initial soil TKN content, while the same amount of N applied in inorganic and organic form resulted in a slight increase of the soil TKN content. The available phosphorus content was reduced in the soils amended with the lower dose of both composts with respect to the control soil, whereas remained almost constant in soils amended with the higher dose of both composts. The incorporation of OM in soils increases the P availability to plants due to i) the competition for the sorption sites between P and the decomposition products of OM, especially organic acids, and ii) the mineralization of the organic P added with amendments. Sources of organic acids in soils are also rhizodeposition and microbial activity (Guppy et al., 2005). Control plots were fertilized only with inorganic P that readily precipitated as Ca phosphates due to the alkaline pH of the soil (Sposito, 2008). After the transplanting of tomato seedlings, a raise of organic acids content occurred because of root exudation and microbial synthesis, helping the desorption of P. In contrast, plots amended with composts promptly increased the P availability in proportion to the amount of OM applied and regardless of crop. Therefore, tomato seedlings benefited from a higher available P content, with the result of

Table 2
Mean values of chemical properties of soils at time 0 and at the end of the experiments, and analysis of variance.

Sampling Time	Treatment	Parameter						
		pH (H_2O) (1:2.5, w/v)	EC (dS m^{-1}; 1:2)	OC g kg^{-1} DM	TKN	C/N	P_{ava} mg kg^{-1} DM	K_{exc}
T0	All fields	8.2 a (0.1)	1.0 a (0.4)	4.1 a (0.1)	0.7 a (0.01)	6.2	102.4 bc (3.3)	234.0 a (6.7)
T1	Control	8.3 a (0.1)	1.0 a (0.3)	4.4 a (0.4)	0.7 a (0.02)	6.7	99.6 b (7.3)	225.3 a (13.2)
	SSC 2	8.3 a (0.2)	1.1 a (0.3)	5.6 a (0.3)	0.75 ab (0.06)	7.6	72.0 a (6.9)	239.3 a (26.0)
	SSC 4.5	8.0 a (0.1)	1.55 a (0.3)	8.7 b (0.7)	0.9 ab (0.19)	10.1	111.7 c (9.2)	235.6 a (2.3)
	FWC 2	8.1 a (0.1)	1.4 a (0.1)	5.6 a (0.4)	0.9 ab (0.08)	6.5	73.5 a (4.4)	229.3 a (13.2)
	FWC 4.5	8.2 a (0.2)	1.35 a (0.5)	8.7 b (1.1)	0.95 b (0.03)	9.3	95.5 b (3.5)	252.7 a (31.8)
		n.s.	n.s.	***	*		***	n.s.

SSC 2: Sewage sludge based compost at 2 t ha^{-1}; SSC 4.5: Sewage sludge based compost at 4.5 t ha^{-1}; FWC 2: Organic fraction of municipal solid wastes based compost at 2 t ha^{-1}; FWC 4.5: Organic fraction of municipal solid wastes based compost at 4.5 t ha^{-1}; EC: electrical conductivity; OC: organic carbon; TKN: total Kjeldahl nitrogen; $CaCO_{3tot}$: total carbonates; P_{ava}: available P; K_{exc}: exchangeable K. DM: dry matter. The standard deviations are reported in parentheses.
n.s.: not significant. The values in each column followed by a different letter are significantly different according to Tukey's test. * Significant at the $P \leq 0.05$ ** Significant at the $P \leq 0.01$; *** Significant at the $P \leq 0.001$.

Table 3
Total and available heavy metals of soils at time 0 and at the end of the experiments (T1).

Sampling Time	Treatment	Total heavy metals content						Available heavy metals content					
		Cd mg kg^{-1} DM	Cu	Ni	Pb	Zn	Cr	Cd † mg kg^{-1} DM	Cu	Ni	Pb	Zn	Cr †
T0	All fields	1.2 a (0.2)	46.6 a (4.1)	32.1 a (2.9)	32.0 a (4.1)	63.3 a (4.2)	49.0 a (1.6)	0.08 a (0.02)	4.9 a (0.3)	0.35 a (0.04)	1.4 a (0.1)	1.6 a (0.5)	0.03 a (0.02)
T1	Control	1.5 a (0.2)	48.4 a (3.8)	33.1 a (2.9)	33.1 a (3.4)	62.3 a (2.6)	49.6 a (2.1)	0.09 a (0.02)	4.9 a (0.2)	0.36 a (0.04)	1.5 a (0.04)	1.7 a (0.3)	0.03 a (0.02)
	SSC 2	1.2 a (0.1)	51.4 a (3.6)	42.9 bc (2.2)	41.1 b (2.1)	72.6 b (3.0)	60.6 b (1.2)	0.09 a (0.01)	6.5 b (0.4)	0.64 b (0.06)	2.0 ab (0.1)	2.9 b (0.2)	0.055 ab (0.01)
	SSC 4.5	1.2 a (0.3)	53.3 a (4.4)	49.0 c (1.1)	46.9 b (1.9)	81.9 c (3.5)	69.2 c (1.0)	0.25 b (0.06)	8.1 c (0.2)	0.74 bc (0.05)	2.4 bc (0.4)	3.4 b (0.5)	0.065 b (0.01)
	FWC 2	1.4 a (0.4)	54.7 a (1.6)	41.6 b (3.8)	42.3 b (2.7)	71.8 b (3.5)	60.5 b (2.5)	0.10 a (0.01)	6.6 b (0.6)	0.60 b (0.06)	1.9 ab (0.1)	2.8 b (0.1)	0.053 ab (0.01)
	FWC 4.5	1.3 a (0.4)	53.6 a (4.3)	48.7 c (2.0)	47.3 b (1.8)	80.1 bc (2.1)	70.2 c (2.9)	0.28 b (0.09)	8.9 c (1.2)	0.80 c (0.09)	2.6 c (0.4)	3.2 b (0.4)	0.061 b (0.01)
		n.s.	n.s.	***	***	***	***	*	***	***	***	***	**

SSC 2: Sewage sludge based compost at 2 t ha^{-1}; SSC 4.5: Sewage sludge based compost at 4.5 t ha^{-1}; FWC 2: Organic fraction of municipal solid wastes based compost at 2 t ha^{-1}; FWC 4.5: Organic fraction of municipal solid wastes based compost at 4.5 t ha^{-1}. DM: dry matter. The standard deviations are reported in parentheses.
The values in each column followed by a different letter are significantly different according to Tukey's test or Dunn's test (†).* Significant at the $P \leq 0.05$; ** Significant at the $P \leq 0.01$; *** Significant at the $P \leq 0.001$; n.s.: not significant.

Table 4
Mean values of qualitative and quantitative parameters of tomatoes fruits at the end of the experiments and analysis of variance.

Treatment	Parameter											
	Yield t ha^{-1}	Major axis mm	Minor axis mm	DM %	pH	° Brix	Cd mg kg^{-1} DM	Cu	Ni	Pb	Zn	Cr
Control	57.5 a (7.4)	75.6 a (1.3)	39.4 a (0.3)	6.2 a (0.1)	4.4 a (0.07)	6.6 a (0.4)	0.06 a (0.02)	14.5 a (2.6)	1.4 a (0.03)	0.8 a (0.2)	20.4 a (1.2)	0.42 a (0.02)
SSC 2	66.6 b (13.0)	78.2 a (4.3)	40.6 a (1.1)	6.0 a (0.2)	4.5 a (0.02)	6.6 a (0.3)	0.10 a (0.02)	16.0 a (1.2)	1.6 ab (0.2)	1.0 a (0.1)	23.2 ab (2.0)	0.45 ab (0.03)
SSC 4.5	66.6 b (4.8)	77.5 a (1.4)	41.0 a (1.5)	6.0 a (0.6)	4.3 a (0.05)	6.6 a (0.5)	0.39 b (0.08)	18.1 a (3.1)	2.0 c (0.08)	1.1 a (0.1)	24.8 b (1.3)	0.48 b (0.02)
FWC 2	72.1 b (9.6)	74.8 a (1.8)	38.5 a (0.3)	6.2 a (0.4)	4.4 a (0.03)	6.6 a (0.4)	0.08 a (0.02)	15.2 a (1.8)	1.5 ab (0.2)	1.1 a (0.2)	22.7 ab (1.5)	0.43 ab (0.03)
FWC 4.5	83.8 c (3.8)	79.6 a (0.8)	40.8 a (1.5)	6.2 a (0.7)	4.3 a(0.1)	6.6 a (0.6)	0.40 b (0.10)	17.6 a (1.9)	1.8 bc (0.1)	1.2 a (0.2)	24.5 b (1.4)	0.44 ab (0.04)
	***	n.s.	n.s.	n.s.	n.s.	n.s.	*	n.s.	**	n.s.	*	*

SSC 2: Sewage sludge based compost at 2 t ha^{-1}; SSC 4.5: Sewage sludge based compost at 4.5 t ha^{-1}; FWC 2: Organic fraction of municipal solid wastes based compost at 2 t ha^{-1}; FWC 4.5: Organic fraction of municipal solid wastes based compost at 4.5 t ha^{-1}. DM: dry matter. The standard deviations are reported in parentheses.
n.s.: not significant. The values in each column followed by a different letter are significantly different according to Tukey's test. * Significant at the $P \leq 0.05$; ** Significant at the $P \leq 0.01$; *** Significant at the $P \leq 0.001$.

a better yield of plots treated with composts with respect to the control ones. No significant change was observed in the exchangeable K content among all treatments. This result was in contrast with those of other authors (García-Gil et al., 2004; Kaur et al., 2008; Ros et al., 2006; Weber et al., 2007) who found the increased availability of nutrients due to the increased cation exchange capacity following the addition of organic matter by composts. Our result could be reasonably ascribed to the short period considered, but also to the equilibrium between the non-exchangeable pool and the exchangeable one of K in soil, since the K release from soil is a diffusion-controlled exchange (Arienzo et al., 2009).

Table 3 reported the values of the total and available heavy metals in soil samples. The total content of Cd and Cu was not influenced by the treatments while the total content of Ni, Pb, Zn and Cr increased significantly ($P \leq 0.001$) after the amendment with both composts, especially at the highest dose. Pichtel and Anderson (1997) found a similar trend for the total metals concentrations in soil amended one-time with foodwaste or sewage sludge based composts. The available Cd increased significantly ($P \leq 0.05$) with respect to the control soil only with the application of the highest dose of the two composts, whereas all other heavy metals availability raised significantly (Cu, Ni, Pb and Zn: $P \leq 0.001$; Cr: $P \leq 0.01$) after the amendments, especially at the highest dose applied. This result disagrees with the capacity of compost to reduce the solubility and bioavailability of metals reported by several authors (García et al., 1995; Nomeda et al., 2008; Smith, 2009). Possibly, the composts applied were relatively fresh and characterized by light and soluble molecules more suitable in chelating and solubilizing metals with respect to the more recalcitrant and less soluble moieties of more mature composts (Senesi et al., 2007), since metals availability decreases with the composting and maturation time (Smith, 2009). The soils amended with the same dose of composts did not show significant differences in terms of total and available heavy metals content, even if SSC was characterized by higher heavy metals content in comparison to FWC (see Table 1). Therefore, the quality of compost organic matter could have played a major role in the availability of metals rather than their quantity applied. In fact, the heterogeneity of the organic matter of municipal solid wastes with respect to the sewage sludge could have influenced the corresponding final compost.

3.3. Tomatoes production and quality

Data on the quantity and quality of tomato fruits and their content of heavy metals are presented in Table 4. The yield increased significantly ($P \leq 0.001$) in amended plots, especially in the case of FWC at the highest dose, while the size of the fruits and their dry matter did not show significant variations among all treatments. Therefore, plants grown in amended soils produced higher number of fruits per plant with respect to control. The pH values and the °Brix of tomato juice did not change significantly among control and amended plots. The contents of Cd, Zn and Cr appeared significantly ($P \leq 0.05$) greater in fruits obtained from soils amended with the highest dose of composts, as well as Ni but with a higher significance ($P \leq 0.01$). In terms of fresh weight, tomatoes from SSC 4.5 and FWC 4.5 treatments showed a Cd concentration of 0.0234 and 0.0248 mg kg^{-1}, respectively, and complied with the European legal limit of 0.050 mg kg^{-1} fresh weight (Commission Regulation No 488/, 2014). Copper and Pb content did not show any significant variation among treatments and their concentration must comply with the legal threshold of 5 mg kg^{-1} (Regulation No 396/, 2005) and 0.2 mg kg^{-1} fresh weight (Commission Regulation No, 1881/, 2006Commission Regulation No /, 2006Commission Regulation No, 1881/, 2006), respectively. The Cu content ranged from 0.9 to 1.13 mg kg^{-1} fresh weight, while Pb concentration varied from 0.05 to 0.074 mg kg^{-1} fresh weight, therefore both metals complied with the corresponding legal limits.

The results obtained are in accordance to several studies conducted in short and long period of investigation. Ozores-Hampton et al. (1997) and Zheljazkov and Warman (2004) found that the concentration of Pb in Swiss chard, tomato, squash fruit, and basil tissues was not affected by municipal solid wastes-compost. Sukkariyah et al. (2005) showed no excessive amounts of plant metal uptake after 17–19 years biosolid application, despite the high application rate containing concentrations of Cu and Zn that exceeded the pollutant concentration limits. Rajaie and Tavakoly (2016) did not evidence any deleterious effect on tomato growth applying a municipal waste compost with high Pb, Cu and Zn concentration. Giannakis et al. (2014) found no increase of heavy metals concentration in fruit of tomato grown in soils amended with 50 and 100 tons ha^{-1} of a municipal solid wastes based compost.

4. Conclusions

The combined application of amendments and inorganic fertilizer results in an increase of the yield of tomatoes in comparison to a complete inorganic fertilization, when almost the same amount of N is applied. The slower release of the organic N and the synergistic effects of the inorganic fertilizer and compost could be the reasons for the results obtained. In addition, the organoleptic quality of the production is apparently not affected by the fertilization.

The application of the highest dose of composts results in a significant higher availability of all studied heavy metals in soil that influences the content of certain potentially toxic elements in the fruits, even if their tomato concentrations respect the legal thresholds. As a precaution, fresh composts like the ones applied in the present trial should be used at the lower dose studied to avoid possible contamination of fruits with repeated applications. Another possibility could be to alternate the application of compost with other slow release organic matter sources, such as manures, horn and hoof meal based fertilizers, etc. Results show that the combination of amendment and inorganic fertilizer, applied only at the beginning of the crop cycle, is apparently more sustainable with respect to the sole inorganic fertilization in which the N application is split, also as fertigation, during the crop cycle.

Finally, between the two composts studied, FWC shows better results in terms of yield while, regardless the doses applied, no phenomena of plant toxicity or soil pollution have been recorded.

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