Long-term compost amendment of a Mediterranean agricultural soil. Part II: Assessment of heavy metals and nitrates contamination risk for soil, groundwater and crops

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Abstract

Long-term soil amendments with municipal solid waste (MSW) compost have been tested in open field to evaluate the heavy metals and nitrates contamination risk for soil, groundwater and crops in a Mediterranean agricultural soil, in southern Italy. Even if recurrent applications of compost caused an increase in soil metal bioavailability, this organic amendant may be used in agriculture as a soil fertilizer, without any risk of metal accumulation in the edible parts of the studied tomato and onion crops. In the meantime, MSW compost does not seem to carry risks of excessive release of NO_3-N in soil and groundwater.

Introduction

Amendment of agricultural soils with municipal solid waste (MSW) compost allows to deal, accordingly to sustainability criteria, with two environmental issues of great topicality: the decay of natural fertility of agricultural soils and the urgent need to give an ecologically consistent disposal to organic wastes [1]. As a consequence, composting of kitchen and yard wastes has been adopted by many municipalities [2].

Notwithstanding the positive effects on numerous biological, physical and chemical soil properties related to compost use in agriculture [3, 4, 5], the main concern is loading the soil with metals that can result in increased metal content in the crops [4]. So, even using high quality compost, it is important to investigate the potential impacts of compost amendments in medium and long-term on both soil and crops. Recurrent applications may determine metal accumulations; moreover, the addition of organic matter to the soil may modify the exchange complexes that, in turn, may determine the mobilization of metals present in the soil in poorly soluble or strongly complexed chemical forms, increasing the risk of uptake by crops [6]. Finally, variability in responses of different species or even cultivars has to be considered [4].

Another concern of compost application, at the rates commonly used in farming, regards putting in soil big amounts of organic nitrogen, that mineralizes gradually over periods hard to tell. Although MSW compost increases soil N concentration, compost is often reported to be less effective in supplying bioavailable N in the first year of application to the soil-plant system than inorganic mineral fertilizers [3, 4]. As mineralization of organic N supplied with compost depends on many factors including C/N ratio, composting conditions, compost maturity, time of application, compost quality [4] and soil properties, monitoring of NO_3-N in soil along time is advisable to verify a possible excessive release and the associated risk of leaching in groundwater.

The aim of this research is to assess the heavy metals and nitrates contamination risk for soil, groundwater and crops at the fifth year of repeated compost amendments of a Mediterranean agricultural soil, in an open-field trial, in southern Italy.

Material and Methods

The trial was carried out at the Scafati (Campania Region) experimental station of CRA (Consiglio per la Ricerca e la Sperimentazione in Agricoltura). Four treatments, performed according to a randomized-block design, with four replications, were applied to the soil for five consecutive years: unfertilised control (UF), mineral NPK fertilization (MF), amendment with compost at the dose 30 t ha^{-1} of dry matter per year for the first three years and 15 t ha^{-1} for other two years (CF), amendment with compost at the dose 15 t ha^{-1} per year for five years plus mineral nitrogen at half dose of that supplied in mineral fertilization (CM). The compost, obtained from municipal food wastes, was applied once a year in spring; its composition matched with the Italian limits for agricultural use (D.L. 75/2010).

Cd, Cu, Fe, Mn, Pb and Zn concentrations were measured in fruits of tomato (*Lycopersicon esculentum* Miller) and in bulbs and roots of onion (*Allium cepa* L.) grown under the different soil treatments. Heavy metals were also measured in soil (0-30 cm layer, 2 mm sieved) collected at the end of each crop cycle, as total and bioavailable (DTPA-extractable) concentrations. In order to measure the total concentrations, plant and soil samples were oven-dried (75 °C), ground-powdered and digested with HF (50%) and HNO_3 (65%) at ratio of 1:2 in a micro-wave oven (Ethos, Milestone). The soil bioavailable fractions were extracted according to Lindsay and Norvell method [7]. Metal concentrations were measured by ICP-OES (Optima 7000DV, PerkinElmer). Standard reference materials (NIST 1575a Pine Needles and NCS DC73321 Soil) were also analyzed. To evaluate the relative accumulation degree in the two hypogeal organs of onion plants, metal bulb/root concentration ratios were calculated.

Soil (0-30 cm layer) NO_3-N concentrations were monthly measured during one year. Three soil cores per plot were sampled along the irrigation pipelines in the rhizosphere. Soil samples were stored at 4 °C, then they were extracted in water (1:5) and filtered; the determination of nitrates was made by a Bran+Luebbe AutoAnalyzer.

The significance of the differences in metal concentrations in tomato fruits, as well as in soil total and bioavailable metal concentrations, from different soil treatments, was evaluated by One-Way ANOVA. The significance of the differences in metal concentrations in onion bulbs and roots from different soil treatments was evaluated by Two-Way ANOVA, with the soil treatment and the organ as fixed factors. The significance of the differences in NO_3-N concentrations among the treatments and along time were evaluated by Two-Way ANOVA, with fertilization treatment and sampling time as fixed factors. All the ANOVA tests were followed by the Tukey post hoc test (α=0.05). The analyses were carried out on normalized (logarithmic transformed) data (normality was assessed by Kolmogorov-Smirnov test, α=0.05), using the SigmaPlot 11.0 (Systat Software, Inc) or the Statistica 7 (StatSoft) software packages.

Results and Discussion

Five years of compost amendments determined a significant increase in soil bioavailable Cd, Mn and Zn and in total Pb concentrations at the end of tomato crop (Figure 1b), as well as a significant increase in bioavailable Fe, Mn and Zn concentrations at the end of onion crop (Figure 1d). Despite these evidences, no significant increases in all heavy metal concentrations were found in both tomato fruits (Figure 1a) and onion bulbs (Figure 1c) due to compost amendment. Already in a previous study [6], carried out on other soils in Campania Region, we demonstrated that repeated MSW compost amendments affected the bioavailability of heavy metals in soil more than the total concentrations. These findings, also supported by Fagnano et al. [8] and by numerous studies reported in Hargreaves et al. [4], are linked to the effects of compost organic matter addition, that mainly modifies the soil exchange complexes, resulting in different metal dynamics. Moreover, other studies report that tomato uptake and accumulation of numerous heavy metals in fruits did not occur in plants grown on soil amended with MSW compost, despite increases in soil bioavailable metal concentrations [9]. The observed differences, above all in soil total and available Cd concentrations measured at the end of tomato and onion crops, are independent from soil fertilization treatments (Figures 1b and 1d). Other researches report temporal variations in soil metal concentrations apart from experimental factors that are mainly attributed to climatic effects [6, 10].

Mineral fertilized soils did not show differences in heavy metal concentrations, compared to unfertilised soils, with the exception of total Cu and Pb at the end of tomato crop, which were higher in mineral fertilized soils (Figure 1b). Total metal concentrations in agricultural soils often increase after the application of mineral fertilizers [6, 11], which contain metals as common impurities. Also in this case, however, no significant differences in heavy metal concentrations attributable to mineral fertilization were found in crops (Figures 1a and 1c).

Onion plants from all the fertilization treatments showed on average metal concentrations in bulbs always lower than those measured in roots (Figure 1c): the bulb/root ratios were below 1 for Pb, Cd and Zn (0.57, 0.32 and 0.21, respectively), and one order of magnitude lower for Mn, Fe and Cu (0.049, 0.013 and 0.011, respectively). These findings are in agreement with those of Soudek et al. [12], who demonstrated that the highest heavy metal concentrations in onion plants grown in hydroponics were found in roots, and the transport to bulbs was rather low.

The mean soil NO_3-N concentrations (CM = 14.3, CF = 11.3, MF = 8.7 and UF = 4.4 mg kg^{-1} d.w.) significantly differed among the treatments and along time (Figure 2). The monthly trend of NO_3-N concentrations highlighted that all treatments reached peaks in spring-summer and in autumn; after January till to April 2012 NO_3-N concentration lowered beneath 10 mg kg^{-1} d.w. In Figure 2 is reported the interaction between the two factors. At a glance, it has to underline that in the whole monitored period the NO_3-N content was always under the threshold of 20-25 mg kg^{-1} d.w. (= 80-100 kg ha^{-1}) indicated by Hartz (2006) [13] as the optimal concentration for good crop yields. In particular, NO_3-N content in July was higher in CM than in UF (15.6 vs 5.6 mg kg^{-1} d.w.), in October it was higher in CM (19.7 mg kg^{-1} d.w.) than MF and UF (7.4 and 6.1 mg kg^{-1} d.w., respectively) and in November it was significantly higher in the three fertilized treatments than UF. Nitrate concentrations measured in 30-60 and 60-90 cm soil layers were comparable to those above reported (data not shown).

Conclusion and Perspectives

The results of this study show that recurrent applications of compost do not represent a heavy metal contamination risk for crops and do not seem to carry risks of excessive release of NO_3-N in groundwater in agreement with Jaber et al. [14]. MSW composts, containing relatively low amounts of metals, such as that of this case study, even though can cause an increase in metal bioavailability, may be used in agriculture as a soil fertilizer without any risk of metal accumulation in the edible parts of the studied crops.

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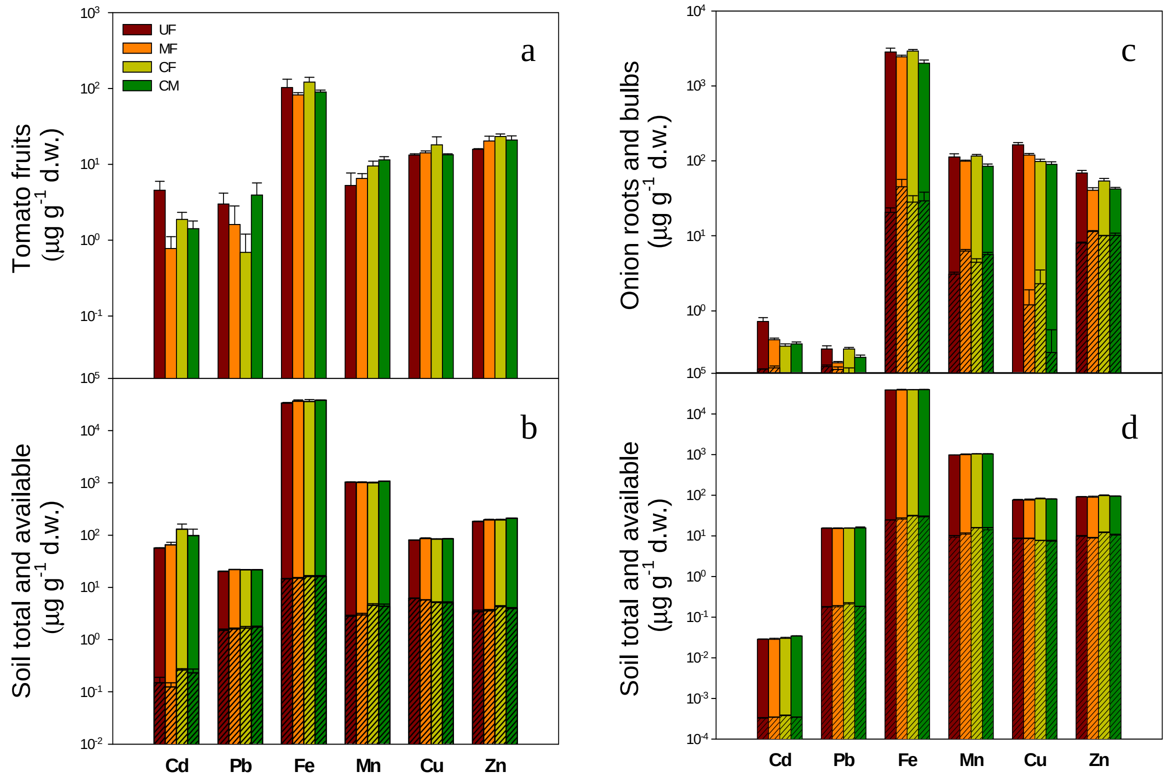

Figure 1. Mean heavy metal concentrations in tomato fruits (empty bars) [a], in onion roots (empty bars) and bulbs (filled bars) [c] and mean total (empty bars) and bioavailable (filled bars) concentrations in soil, at the end of tomato crop [b] and at the end of onion crop [d]. Standard errors are also reported.

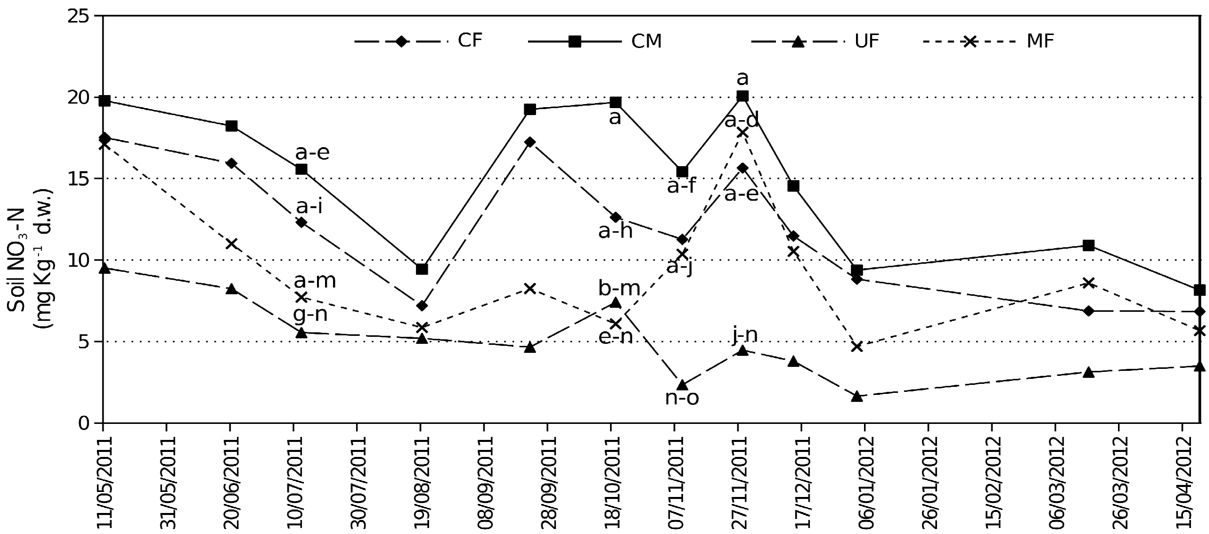

Figure 2. Soil NO_3-N content in the layer 0-30 cm along time. Different letters indicate significant differences among the levels of the interactions between the treatment and time variables, according to Tukey HSD test (α = 0.05).