



Soil leaching as affected by the amendment with biochar and compost



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ABSTRACT

Nutrient leaching in intensively cultivated soils has deleterious agronomical and environmental impacts. We assessed volumes and chemical properties of the solution percolated through soils unamended or amended with biochar, compost or their mixture. We performed an 18-month experiment in lysimeters filled with 503 kg of a sandy soil in which single 1-year old nectarine trees were grown. In a randomized experimental design with 4 replicates the following soil-applied strategies were compared with an unamended control: (a) hardwood-derived biochar (20 g kg⁻¹), (b) compost (77 g kg⁻¹) and (c) biocompost (mixture of the previous two treatments). Soil leachate was daily collected and monthly cumulated for the first 12 months from the trial establishment. Thereafter, leachate was also collected (for one month) after 18 months amendment incorporation. Monthly, leachate subsamples were analyzed for chemical concentration and data were used to estimate losses through leaching referred to the soil volume of 1 ha.

The amendment with compost contributed to increase soil water retention capacity while mixing compost with biochar resulted even more effective, suggesting a positive interaction. Biochar significantly decreased the leaching volume in 4 (out of 12) months compared with the unamended soil. The cumulative amounts of dissolved organic carbon (DOC), total dissolved nitrogen (TDN), mineral N (mainly under Nitrate-N (NO₃⁻-N)) and elements leached out were overall increased in compost-treated soils (either with or without biochar) as a consequence of easily soluble organic compounds supplied with the composted biomasses. We observed a synergism between the two amendments which in turn promoted the leaching of DOC and cumulative amount of TDN, although the source of these extra rates remains uncertain. Ag, Be, Cd, Sb, Ti and Tl were never detected in the leachate while Al, As, Co, Hg, Pb, Sn and V were detected in traces. However, the concentration remained below the limits for drinking water. Independently of the amendment, the most abundant elements leached during the first year of experiment were in average Calcium (614 kg ha⁻¹), Sulphur (359 kg ha⁻¹) and Sodium (224 kg ha⁻¹) which coincided with the elements most supplied with irrigation and rain water. This should be taken into account in the fertilization recommendations.

Despite compost promoted the loss of minerals through leaching, our results indicate that biochar and compost of high quality and even their mixture, could be adopted as a sustainable agronomical strategy, since they did not represent potential source of heavy metals for groundwater.

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1. Introduction

Nutrient leaching in soil occurs when ions dissolved in the solution move outside the rooting zone (Major et al., 2009). This affects nutrient cycling in agriculture (Brady and Weil, 2008), depletes soil fertility (Laird et al., 2010) and poses potential environmental hazards for groundwater pollution and eutrophication. Soil hydraulic conductivity, soil water retention capacity

and crop transpiration rate mainly govern water percolation through the soil profile. Furthermore, atmospheric precipitations, irrigation, rate and chemical forms of external fertilizers affect leaching patterns in cultivated lands (van Es et al., 2002; Cahn et al., 1993), contributing to modulate interactions of the elements dissolved in solution with other soil particles (Brady and Weil, 2008).

Biochar is the carbon(C)-rich residue of biomass pyrolysis intentionally applied to crop lands with the purpose to permanently sequester photosynthetically fixed C (Glaser et al., 2002), thus potentially mitigate climate changes (Woof et al., 2010). Meanwhile, interacting with the plant-soil-microbial components

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(Spokas et al., 2012; Downie et al., 2009), biochar has been advocated to ameliorate soil properties and plant growth (Spokas et al., 2012; Verheijen et al., 2010). Mechanisms that have been proposed to elucidate benefits of biochar in soils include: (i) direct nutrients supply; (ii) alteration of the nutrient dynamics; (iii) increase of chemically active surfaces (cation exchange capacity (CEC)); (iv) shift of physical parameters such as porosity, and (v) increase of water retention capacity and plant available water (Baronti et al., 2014; Ippolito et al., 2012; Spokas et al., 2012; Sohi et al., 2010; Verheijen et al., 2010; Downie et al., 2009 and literature therein). Among these mechanisms, the application of charred biomasses seems effective in reducing the impact of soil leaching on both surface and groundwater quality (Ding et al., 2010; Laird et al., 2010; Lehmann et al., 2003). In fact, acting as a sponge, biochar in soil may retain water, nutrients and organic matter (OM) (Glaser et al., 2002). Previous experiences demonstrated the effectiveness of biochar in increasing soil water holding capacity (WHC) (Baronti et al., 2014) and reducing losses through leaching (Sorrenti et al., 2016; Ventura et al., 2013; Laird et al., 2010; Lehmann et al., 2003; Glaser et al., 2002). Recently, through a modeling approach, it was suggested that depending of the biochar:soil ratio, environmental conditions, biochar and soil characteristics, nutrient migration through the soil profile may be reduced by biochar, thereby nutrient availability for plant uptake may be extended (Sun et al., 2015). However, the behavior of biochars in different soils and its potential utilization as a nutrient retaining additive is only beginning to be explored.

Compost is the stabilized soil amendment resulting from the aerobic biodegradation of a wide range of organic substrates (by-products). Compost enhances and restores soil OM and represents a source of plant available nutrients (i.e. N, phosphorus (P), potassium (K), Ca, Mg, sulphur (S) and essential trace elements; Caballero et al., 2009; Smith and Collins, 2007; Haug, 1993), thereby its adoption as a soil conditioner is progressively gaining interest (Diacono and Montemurro, 2010). Furthermore, the use of compost in agriculture permits to recycle municipal organic solid and agri-food industry-related wastes, offering environmental advantages and reduction of social costs. Though agronomical benefits have been confirmed (Sorrenti et al., 2012; Hargreaves et al., 2008), concerns about the use of compost in agriculture have been raised due to its high availability of $\text{NO}_3\text{-N}$ that can be easily leached out the soil profile. Besides, compost may represent a potential source of heavy metals such as lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn) and organic compounds (Giusquiani et al., 1995), thereby potentially increasing soil and, through leaching, groundwater pollution. The fate of minerals in compost-amended soils has been previously studied (Johnson et al., 2004). Nevertheless, given that compost includes a high variety of organic materials, further knowledge in this field is required.

To date, most of the studies on this topic were focused on the effect of either soil-applied compost or biochar mainly on the leaching of PO_4^{3-} , $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$ ions (Ding et al., 2010) and heavy metals (Wang et al., 2008), while much less is known on a wider range of elements. Likewise, the fate of dissolved organic C (DOC) and total dissolved N (TDN) in biochar and compost-amended soils are of crucial importance since they have the potential to impact adjacent terrestrial or aquatic ecosystems (Jacinthe et al., 2004). However, scientific evidences were often obtained from short-term experiments (<6 months), frequently carried out adopting the soil-column or the suction cup approach, under unnaturally leaching conditions and in tropical soils which effects are expected to differ from temperate regions. Even less is known about soil leaching properties when biochar is mixed with organic amendments, such as compost.

This study was undertaken to assess the effect of soil-applied biochar, compost and their combination on the volume and

chemical properties of the soil leachate drained from lysimeters during the first 12 months and then after 18 months from amendments incorporation.

2. Materials and methods

2.1. Experimental conditions and treatments

We performed a 18-month experiment (2012–2013) outdoors at the experimental station of the University of Bologna (44°54' N, 11°41' E, 36 m a.s.l.) adopting 0.496 m³ lysimeters (L 1.12 m × W 1.03 m × D 0.43 m), arranged in a single N-S oriented row and filled with 503 kg of a sandy soil (Table S1 of the Supplementary material). Single trees (1-year old nectarine trees (*Prunus persica* L. Batsch) of the cv. Big Top grafted on Adesoto (Puebla de Soto 101 – *Prunus insititia* (L.), Bullace) were transplanted in the lysimeters at the end of March 2012. Trees were trained as slender spindle and watered (May through September) with microirrigation (4 drippers per plant of 2 L h⁻¹) to return the evapotranspiration (ET_o) rate as estimated by a class A evaporation Pan and the specific crop coefficient (K_c) for nectarine trees, whereas weeds were manually removed. Irrigation volumes, precipitations, air temperature and relative humidity (UR) were recorded throughout the experiment. Climate data were acquired by an automated weather station available at the experimental farm.

In a randomized block design with 4 replicates (experimental unit = single lysimeter), the following soil-applied amendment strategies were compared: (a) biochar (at a rate of 20 g fw kg⁻¹) equal to 87.4 Mg fw ha⁻¹ (assuming a soil incorporation up to 0.35 m depth and a soil bulk density of 1.248 Mg m⁻³); (b) compost (at a rate of 76.8 g fw kg⁻¹); (c) biochar + compost (named biocompost from now on) at the same rates of the previous two treatments, and (d) unamended control. Amendments were carefully homogenised to the soil before filling the lysimeters.

The biochar was produced in a commercial slow-pyrolysis unit using a vertical charcoal kiln of 8.14 m³. We used non-contaminated chipped hardwood (peach and grapevine pruning wood) slowly pyrolyzed at ~550 °C with a 30 min peak temperature hold time. Compost was obtained by 3-month aerobic biological decomposition of organic municipal wastes (85%) mixed with pruning material of urban ornamental trees and garden management (6.5%) and agro-industrial organic residues (8.5%). Main physical and chemical characteristics of the biochar and compost are summarized in Tables S2 and S3 (Supplementary material), respectively.

Unamended and biochar-amended soils received 41.7, 9.3 and 6.9 g lysimeter⁻¹ of N, P and K, respectively in the first season and 62.4, 12.0 and 22.9 g lysimeter⁻¹ of N, P and K, respectively in the second season in order to fulfil plant nutrient requirements. Urea, ammonium-nitrate (NH_4NO_3) and complex NPK (14-25-5 + SO_3 + microelements) commercial fertilizers were used as a source of nutrients supplied by fertigation from growth resumption until late summer, at about 2 weeks intervals. Compost-based amended soils (with or without biochar) received an equal volume of tap water in coincidence of the fertigation events.

2.2. Soil leachate recovering

We daily collected (when present) the leachate percolated through the soil profile from April 2012 through March 2013. The solution was monthly cumulated and stored at 4 °C. At the end of each month, about 500 mL solution were sampled from the cumulated volume then stored at -20 °C to await analysis.

We adopted the same procedure for the leachate percolated in September 2013, 18 months after the trial establishment.

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