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Influence of organic management on As bioavailability: Soil quality and tomato As uptake

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HIGHLIGHTS

- An improvement of tomato and soil health was observed in the organic system.
- Arsenic 56–75 mg kg^{-1} in soil didn't represent a stress for the microbial community.
- The organic system mitigates arsenic accumulation in plant tissues.
- Tomato fruits grown in arsenic rich soil do not represent a risk for human health.

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ABSTRACT

The research studied the effects of organic vs. conventional management of soil quality and tomato yield quality, cultivated in a geogenic arsenic contaminated soil. The chemical and biochemical properties were analyzed to evaluate soil quality, arsenic mobility and its phyto-availability, as well as arsenic accumulation in the tomato plant tissues and if tomatoes cultivated in arsenic rich soil represents a risk for human health. A general improvement of tomato growth and soil quality was observed in the organic management, where soil organic carbon increased from 1.24 to 1.48% and total nitrogen content. The arsenic content of the soil in the organic management increased from 57.0 to 65.3 mg kg^{-1}, probably due to a greater content of organic matter which permitted the soil to retain the arsenic naturally present in irrigation water. An increase of bioavailable arsenic was observed in the conventional management compared to the organic one (7.05 vs 6.18 mg kg^{-1}). The bioavailable form of metalloid may affect soil microbial community structure assessed using El-FAME analysis. The increase of the total arsenic concentration in the organic management did not represent a stress factor for soil microbial biomass carbon (Cmic), which was higher in the organic management than in the conventional one (267 vs. 132 μg Cmic g^{-1}). Even if the organic management caused an increase of total arsenic concentration in the soil due to the enhanced organic matter content, retaining arsenic from irrigation water, this management mitigates the arsenic uptake by tomato plants reducing the mobility of the metalloid.

1. Introduction

Soil is a complex system with a high variability in terms of mineral and organic matter composition. Some elements in agricultural soil, such as heavy metals, can be undesirable as they may represent a risk for crop yield quality and human health. Arsenic (As) in its inorganic form can interact in various ways with the soil's chemical and biological components which can affect its mobility, bioavailability and translocation in plant tissues and food. Arsenic concentration, in uncontaminated soils, rarely exceeds 10 mg kg-1; conversely, depending on the nature of the source (geogenic or

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anthropogenic), in polluted soils As concentration ranges from <1 to 250,000 mg kg^{-1} (Mahimairaja et al., 2005). A deeper knowledge of soil characteristics could allow to foresee As absorption and desorption mechanisms, which would enable a proper use of soils in agricultural cropping systems to minimize the risks of food contamination.

The As bioavailability does not correspond to the phytoavailability; the plants uptake of As varies among species and it depends on the As form and its oxidation state. The management of agroecosystems plays a key role in soil quality, because agricultural practices influence the elements uptake of crops. Therefore, their quantity in plant tissues and in human food or animal feed, can have negative effects on human and animal health so possible links between organic management and soil and food quality have been studied (Reeve et al., 2016). Soil microorganisms and enzyme activities are sensitive indicators of soil functionality when investigating the impacts of metals/metalloids (e.g. As) (He et al., 2005) and/or agricultural management, such as organic or conventional management on environmental quality (Condron et al., 2000). In particular, it is known that the organic management improves soil nutritional and microbiological conditions; with increased levels of available nutrients, microbial biomass content, and its activity (Marinari et al., 2006; Reganold, 1988). Organic management is often considered as an effective agricultural system to improve soil quality (Watson et al., 2002) in order to produce healthy food (Maggio et al., 2013; Reeve et al., 2016). For instance, it has been demonstrated that the organic management improves the quality of tomatoes due to an increase of oxidative stress during fruit development (Oliveira et al., 2013). However, very few studies investigated the effect of organic management on the behavior of heavy metals in naturally contaminated soils. Gousul Azam et al. (2017) have studied the effect of organic vs. conventional management on the As bioavailability only for cereal crops, but no other study has been carried out on different crops. For this reason, the aim of this study was to verify if organic management can mitigate As uptake in tomato plants by soil quality improvement. In particular, the attention has been posed on As bioavailability for tomato crops grown on geogenic contaminated soils (As ranging from 56 to 75 mg kg^{-1}), irrigated with As rich water (35 μg L^{-1} of As). The main questions posed were: (i) Does organic management influence the As mobility in soil of a geogenic As rich area? (ii) Does the organic management mitigate the As plant uptake with respect to the conventional one?

2. Materials and methods

2.1. The study area

The study area is located within the Cimino and Vico volcanic complexes (Fig. 1), formed in the Pleistocene after post-orogenic extensional and local subsidence processes. The region is characterized by substantial CO_2 emissions, which control the genesis of the travertine deposits that outcrop throughout the Viterbo thermal area (Minissale and Duchi, 1988). The natural occurrence of As in soil and water in the study area is related to the presence of geothermal systems (Webster and Nordstrom, 2003; Ballantyne and Moore, 1988) or to water–rock interactions that lead to As mobilization from the aquifer (Charlet and Polya, 2006; Smedley and Kinniburgh, 2002). In the Italian volcanic areas, high As concentrations have been related to the deep-rising fluids of the active geothermal systems (Aiuppa et al., 2003).

2.2. Experimental site

The study was carried out in 2013 as part of a long-term field experiment established in October 2001 at the Experimental Farm of the University of Tuscia (Viterbo, Italy) (Fig. 1). The soil was volcanic and classified in the textural class (0–20 cm depth) as clay loam with 45% sand, 38% clay and 17% silt, and a pH (H_2O) of 6.78.

The experimental field was arranged in a randomized block design with three replications, where conventional (CONV) and organic (ORG) management were compared. In the CONV system, the traditional agricultural practices (mainly the pesticides treatments and the chemical fertilizers were applied when needed and in the agronomic correct times) were adopted, while in the ORG system the operations were carried out according to the Council Regulation N. 834/2007 (EC) concerning organic production and the labeling of organic products. Three-year crop rotation was carried out for both cropping systems (CONV and ORG), including durum wheat (*Triticum durum* Desf.), processing tomatoes (*Licopersicum esculentum* Mill.), and chickpeas (*Cicer arietinum* L.). In the organically managed cropping system, the crop rotation was implemented with common vetch (*Vicia sativa* L.) and oilseed (*Brassica napus* L.) used as green manure, which were plowed under about 10 days before tomato transplanting and pea planting, respectively. The three main crops were grown each year in the experimental field consisting in 18 plots (2 cropping systems x 3 crops x 3 replicates). In both cropping systems (CONV and ORG) the maximum tillage depth was 20 cm. Soil tillage was carried out before tomato transplanting in May and at the same time the soil was fertilized with 80 kg ha^{-1} P_2O_5 (using perphosphate in CONV and rock phosphate in ORG system). The tomato crops were drip irrigated in order to reintegrate the 90% of water lost through evapotranspiration estimated by a class A pan and adjusted by the crop coefficients during the growth cycle. This study focused on the tomato crop inserted in the organically and conventionally managed cropping systems in the long-term field experiment, described above.

2.3. Soil and plant sampling

Soil sampling was carried out in summertime (August 2013) at the end of the vegetative cycle of the tomato crop. After removing the litter layer two soil cores (0–20 cm depth) were taken from each plot and then pooled together, for a total of 18 soil samples. The soil samples were air dried, sieved (<2 mm) and preserved at room temperature. Then, prior to biochemical analyses, the soil moisture content of air dried samples was adjusted to 60% of their water holding capacity and soils were re-conditioned for 5 days. Two plant samples at their physiological maturity were taken from the central area of each plot. The various parts of each plant (fruits, leaves, stems and roots) were separated and transferred to the laboratory for further analyses.

2.4. Soil quality

Soil quality in the ORG and CONV systems was assessed according to chemical and biological properties, such as nutrients content, microbial community structure, its activity and diversity.

2.4.1. Soil nutrient content

Soil organic carbon (SOC) and total nitrogen (TN) were determined by dry combustion using an elemental analyzer (Thermo Soil NC – Flash EA1112, USA), while Carbon and Nitrogen labile pools were extracted using K_2SO_4 0.5 M (1:4 w:v) and determined with the TOC-V CSN and TNM-1 analyzer (Shimadzu, Japan). Moreover, soil available P was determined following the colorimetric method (Bray and Kurtz, 1945).