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Keywords: arsenic uptake; arsenic mobility; organic farming; microbial community; human risk.

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Abstract: The research studied the effects of organic vs. conventional management on soil health and tomato yield and quality cultivated in a geogenic arsenic contaminated soil. It was analyzed chemical and biochemical properties to evaluate soil health, arsenic mobility and its phyto-availability, as well arsenic accumulation in the tomato plant tissues and if tomato cultivated in arsenic rich soil represents a risk for human health. A general improvement of tomato growth and soil health was observed in the organic system, where soil organic carbon increased from 1.24 to 1.48% and total nitrogen content from 0.11 to 0.22%. Arsenic content in the organic system increased from 57.0 to 65.3 mg kg-1, probably due to a greater content of organic matter that allow the soil to retain the arsenic naturally present in irrigation water. The increase of the total arsenic concentration in the organic system did not represent a stress factor for soil microbial biomass carbon (Cmic), which was higher in the organic system than in the conventional one (267 vs. 132 µg Cmic g-1). A shift of microbial population from bacteria to fungi and protozoa was observed in the organic system; probably due to soil chemical properties changes such as the lower C/N ratio, the slight increase of pH (6.78 vs. 6.63) and the lower concentration of bioavailable arsenic. In the organic soil arsenic uptake resulted toned down compared to the conventional one. In both managements the concentration of arsenic in tomato fruits did not reach the threshold for human health risk.

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Prof. Roberto Mancinelli, PhD

Viterbo, April 11th, 2018

Prot. _ _ _ _ _ _ _ _ _ _

**To the Editors in Chief**
**GEODERMA Journal**

Dear Editors,

Please, find here enclosed the Manuscript titled “Soil health, tomato yield and quality under organic vs. conventional management in a geogenic arsenic rich area’’ to be considered for publication in Geoderma journal.

This study was aimed to assess the impact of agricultural management, organic vs. conventional, on soil and tomato health in an As rich area irrigated with contaminated water. In particular, the attention has been posed on the tomato crops grown in a geogenic contaminated soil (As ranging from 56 to 75 mg kg$^{-1}$), irrigated with As rich water (35 µg L$^{-1}$ of As).

The very interesting aspect is that the concentration of As in the tomato fruits, which resulted not significantly different between the two systems, was not affected by the concentration of the As in soil. In addition, in both management systems, the tomato fruits analysed in this study have not exceeded the thresholds for As provided by the limits suggested by the European Food Safety Authority (EFSA).

To date there aren’t scientific work aimed to compare these two managements for As behavior in soil-plant system, for this reason we think that this manuscript is of interest for Geoderma readers.

Best regards,

Roberto Mancinelli, on behalf of all the authors

# Soil health, tomato yield and quality under organic vs. conventional management in a geogenic arsenic rich area

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The authors of this article declared they have no conflicts of interest

## Highlights

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

# Soil health, tomato yield and quality under organic vs. conventional management in a geogenic arsenic rich area

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## Abstract

The research studied the effects of organic vs. conventional management on soil health and tomato yield and quality cultivated in a geogenic arsenic contaminated soil. It was analyzed chemical and biochemical properties to evaluate soil health, arsenic mobility and its phyto-availability, as well arsenic accumulation in the tomato plant tissues and if tomato cultivated in arsenic rich soil represents a risk for human health. A general improvement of tomato growth and soil health was observed in the organic system, where soil organic carbon increased from 1.24 to 1.48% and total nitrogen content from 0.11 to 0.22%. Arsenic content in the organic system increased from 57.0 to 65.3 mg kg$^{-1}$, probably due to a greater content of organic matter that allow the soil to retain the arsenic naturally present in irrigation water. The increase of the total arsenic concentration in the organic system did not represent a stress factor for soil microbial biomass carbon (Cmic), which was higher in the organic system than in the conventional one (267 vs. 132 µg Cmic g$^{-1}$). A shift of microbial population from bacteria to fungi and protozoa was observed in the organic system; probably due to soil chemical properties changes such as the lower C/N ratio, the slight increase of pH (6.78 vs. 6.63) and the lower concentration of bioavailable arsenic. In the organic soil arsenic uptake resulted toned down compared to the conventional one. In both managements the concentration of arsenic in tomato fruits did not reach the threshold for human health risk.

**Keywords:** arsenic uptake; arsenic mobility; organic farming; microbial community; human risk.

## 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 an undesirable presence to ensure the quality of crop yield since those elements may represent risks for human health. Arsenic (As) in its inorganic form can interact in various ways with the soil's chemical and biological components that can affect its mobility, bioavailability and translocation in plants tissues and finally to food chains. Arsenic concentration, in uncontaminated soils, rarely exceeds 10 mg $kg^{-1}$; conversely, depending on the nature of the source (geogenic or anthropogenic), in polluted soils As concentration ranges from <1 to 250,000 mg $kg^{-1}$.

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 system to minimize the risks of the food chain contamination.

The As bioavailability does not correspond to the phyto-availability; the plants uptake of As vary among species and it depends on As form and oxidation state. The management of agroecosystems plays a key role on soil health, since the agricultural practices influence the elements uptake by crops. Therefore their concentration in plant tissues, such as food or feed, produces potential effects on human and animal health. 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 systems on environmental quality (Marinari et al., 2006). 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 producing healthy food (Reeve et al, 2016). However, very few studies investigated the effect of agricultural management system, such as the organic farming, on the behavior of heavy metals in naturally contaminated soils. Gousul Azam et al. (2017) have studied the effect of organic vs. conventional farming on the As bioavailability only for cereal crops, but no other study has been carried out on different crops. For this reason, this study focused on the effect of agricultural management (organic vs. conventional) on soil health and tomato yield quality in an As naturally contaminated area. In particular, the attention has been posed on the 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 agricultural management influence the As mobility and soil health in a geogenic As rich area? (ii) Does the agricultural management system (ORG or CONV) affect As accumulation in plant tissues? In particular, does the ORG system mitigate the As plant uptake with respect to the CONV one? (iii) Does the tomato grown in As rich soil represent a risk for human health?

## 2. Materials and Methods

### 2.1 The study area

The study area is located within the Cimino and Vico volcanic complexes (Figure 1), which 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 arsenic 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 arsenic mobilization from the aquifer (Charlet and Polya, 2006; Smedley and Kinniburgh, 2002). In the Italian volcanic areas, high arsenic 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) (Figure 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 6.79.

The experimental field was arranged in a randomized block design with three replications, where conventional (CONV) and organic (ORG) cropping systems were compared. In the CONV system, the traditional agricultural practices (e.g. pesticides, chemical fertilizers, etc.) were adopted, while in the ORG system the operations were carried out according to the Council Regulation N. 834/2007 (EC, 2007) concerning organic production and the labeling of organic products. A three-year crop rotation was carried out for both cropping systems (CONV and ORG), including durum wheat (*Triticum durum* Desf.), processing tomato (*Licopersicum esculentum* Mill.), and chickpea (*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.) cover crops, which were green manured 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 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 performed 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 12 soil samples. The soil samples were air dried, sieved (<2 mm) prior to analyses. 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 in laboratory for further analyses.

## 2.4 Soil health

Soil health 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 total organic carbon (TOC) 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).

### *2.4.2 Microbial biomass, community profiles and its activity*

The total amount of microbial biomass C (MBC) and N (MBN) were analyzed using the fumigation extraction (FE) method (Vance et al., 1987). Microbial biomass C was calculated as follows: Cmic = EC:$k_{EC}$, where EC is the difference between organic C extracted from fumigated soils and organic C extracted from non-fumigated soils and $k_{EC}$ = 2.64. Microbial biomass in terms of N was calculated as: Nmic= EN:$k_{EN}$, where EN is the difference between organic N extracted from fumigated soils and organic N extracted from non-fumigated soils and $k_{EN}$ = 2.22.

The Ester linked-Fatty Acid Methyl Ester (El-FAME) microbial community profiles were determined (Stazi et al., 2017), quantified and converted to $\mu mol \cdot g^{-1}$ using peak areas from internal standard (methylnonadecanoate, C19:0), used at known concentrations. Three analytical replicates of each sample were extracted.

The sum of the El-FAMEs considered to be predominantly of bacterial origin (i14:0, 14:0, i15:0, a15:0, 15:0, i16:0, 16:0 16:1ω9; 16:1ω7t, i17:0, a17:0, 17:0, cy17:0, 18:0 and cy19:0) was used as an index of the bacterial biomass (B), and the quantity of the FAs 18:2ω6,9 and 18:1ω9c were used as an index of the fungal biomass (F) (de Dato et al., 2017). The fungal bacterial ratio (F/B ratio) was calculated as an index of soil microbial community change.

The sum of El-FAMEs characteristic of general bacteria, G+ bacteria, G− bacteria, actinomycetes, fungi, were used as broad taxonomic microbial groupings (Table 1**).** Lastly, the ratio of monounsaturated (MONO) and saturated (SAT) El-FAMEs were used as indicators of physiological or nutritional stress in bacterial communities (Bossio and Scow 1998). Finally, the El-FAME obtained were identified and organized in biomarker groups (de Dato et al., 2017).

Soil microbial activity was measured in terms of both respiration and enzyme activities. For measuring microbial respiration 20 g of soil (oven-dry basis) at 60 % of water holding capacity (WHC) were placed in 1L hermetically sealed glass jars. The $CO_2$ released was trapped, after 1, 3, 7, 10, 14, 21, 28 35, 42 days of incubation, in 2 ml 1N NaOH and determined by titrating the excess NaOH with 0.1N HCl as reported in Marabottini et al. (2013). Ecophysiological indices such as microbial quotient (qmic, the percentage of microbial carbon to total organic carbon) and metabolic quotient ($qCO_2$, the basal respiration of microbial biomass unit) were both calculated according to Moscatelli et al. (2005). The soils were analyzed for eight enzyme activities involved in the major nutrient cycles (C, N, P, S-(Marinari et al., 2013).

The enzyme activities were determined with the microplate assay using fluorogenic methylumbelliferyl (MUF)-substrates (Marx et al., 2001). The Synthetic Enzymatic Index (SEI) was calculated as the sum of all enzyme activities which release the same reaction product (MUF) (Moscatelli et al. 2018). Substrate induced respiration (SIR) was determined using the Microresp© soil respiration system with 15 carbon substrates (Lagomarsino et al., 2007)**.** Finally, the microbial structural and functional diversity were assessed by the Shannon’s Weiner Index calculated using data of PLFA and microbial activity [enzyme activities (H’Enz) and substrate induced respiration (H’SIR)], respectively (Zak et al., 1994).

### 2.5 Arsenic in soil, plant tissues and irrigation water

The total amount of As in soil ($As_{tot}$) and in the tomato plant components (roots, steam, leafs, berries) was determined after mineralization of the samples with concentrated hydrochloric acid (36% HCl), nitric acid (69% $HNO_3$) and hydrogen peroxide (30% $H_2O_2$) (Merck, Darmstadt, Germany) with a microwave assisted digestion, using a commercial laboratory microwave oven (Mars plus CEM, Italy). The procedure was reported in Stazi et al 2016 (a). For the As quantification in soil and plant, was used an ICP-OES (8000 DV, PerkinElmer, Shelton, CT, USA) equipped with: an ultrasonic nebulizer for plant samples, and a Scott nebulizer for soil samples. The accuracy of the measurements was assessed using standard reference materials trace metals: Loamy Sand 3 (CRM034-Fluka) and tomato leaves (SRM 1573a). The quantity of inorganic As in irrigation water was determined with hydride generation method (HG-ICP-OES).

The mobility of As in soil was determined by sequential extraction procedure according to Marabottini et al. (2013) with minor modifications. Briefly, three soil fractions were studied: Water Soluble (WS), not Specifically Sorbed (NSS) and Specifically Sorbed (SS). The As of the three fractions is considered chemically labile and available for plants. The sum of As measured in the three fractions is named as $As_{bio}$. $As_{tot}$ and $As_{bio}$ together with soil available phosphorous were used to assess the influence of the agricultural management systems on the mobility of the toxic element in soil.

The plant/soil bioaccumulation factor of As (BAF) was calculated as the ratio between the concentration of As in root and the $As_{bio}$ in soil. Arsenic translocation, from roots to the aboveground part of the plant, was calculated as the ratio of the amount of As in shoots or berries and the that in roots (Translocation Factor-TF) (Stazi et al., 2016b).

## 2.6 Statistical analysis

All data were subjected to analysis of variance (ANOVA) using JMP statistical software package 4.0 (JMP, 2000). To homogenize the variance, after the Bartlett test, if necessary, the data were subjected to angular transformation before the variance analysis. A randomized block experimental design was adopted in the field located in the geogenic As rich area. Treatment mean values were compared with Fisher's protected least significant difference (LSD) test at the 0.05 probability level.

## 3. Results

### 3.1 Soil health and arsenic availability

In this work, soil health in ORG and CONV agricultural systems was assessed in terms of soil chemical and biochemical properties. The organically managed soil showed a slight but significant increase of pH (6.78 vs. 6.63), of total organic carbon (+19%) and a major increase of total nitrogen (+100%). Similar trends were observed for the extractable fractions of C and N. Conversely, even if the difference was not statistically significant, available P tended to be higher in CONV with respect to ORG soil (+5%) (Table 1). The ORG system showed a general soil health improvement, also by the increase of microbial activity (SEI and SIR) (Table 1). Moreover, the Shannon-Weiner indices showed different patterns of microbial functional diversity between the two systems, in ORG the index was lower in terms of enzymatic hydrolytic activities (H'Enz) but higher in terms of catabolic functions (H'SIR) than in CONV system (Table 1). Similarly, the soil microbial community composition measured by El-FAME analysis differed between the two systems. In particular, the ORG system, microbial biomass and its diversity showed a shift of population from bacteria to fungi and protozoa (Figure 2).

As for the concentration of arsenic in the ORG soil, the total As resulted significantly higher than in the CONV one (65.3 vs. 57.5 mg $kg^{-1}$) ($P= 0.002$). Conversely, according to the chemical fractionation, the bioavailable $As_{bio}$ was significantly higher in CONV than in ORG soils (7.05 vs 6.18 mg $kg^{-1}$) ($P = 0.009$). Moreover, negative correlations between $As_{bio}$ and TOC, $As_{SS}$ and TOC ($P<0.0001$) were found in CONV soil, while between the same soil properties the correlation coefficients were positive in the ORG soils (Table 2).

The concentration of 18:1ω9c was well correlated to 18:2ω6,9 and both FAs increased in ORG soils, attesting an proliferation of fungal biomass. EL-FAMEs markers of Gram (-) bacteria were lower in ORG soil than in CONV ones. The ORG system showed the lowest amount of saturated EL-FAMEs typical markers of Gram (+) bacteria, while specific protozoa and actinomycetes El-FAMEs, increased in the ORG system. Moreover, the sum of methyl-branched FAs representing actinomycetes was slightly lower in CONV than in ORC system. In addition, the G+/G- ratio was lower in ORG than in CONV, suggesting a relative dominance of G+, compared with G-. An opposite response was obtained by the ratio of monounsaturated and saturated El-FAMEs: the value for the ratio of Mono/Sat fatty acids was 0.8 in ORG and 0.7 in CONV which is consistent with the lower C and higher $As_{bio}$ contents in CONV. In Table 1 is also reported the F/B ratio which was significantly higher in ORG than in CONV.

### 3.2 Arsenic uptake and partitioning in plant organs

In Table 3 is reported the partitioning of As in plant organs (concentration of As is referred to the dry matter). The results show a higher quantity of phytoavailable As in roots grown in the CONV than those grown in ORG system displayed by the significantly difference of BAF (0.66 vs. 0.46). The bioavailable toxic element is easily accessible for the tomato plant uptake by the root system. Tomato plants grown in As rich soil are able to take up As and accumulate it in all the plant organs in both management systems. The As partitioning followed the trend $As_{root} > As_{leaf} > As_{stem} > As_{fruit}$. The concentration of As accumulated in roots grown in CONV is about two fold higher than As measured in roots from ORG. Even in the aerial parts, the concentration of As in CONV was significantly higher than those in ORG, except the As in berries where difference between the plants from the two managements was not statistically significant. In both management systems, the plants were able to accumulate the toxic element in the roots and only a little As was translocated in apogee. The ability of a plant to translocate an element was measured by TF, this was higher in plants grown in ORG system (0.035) with respect to those grown in the CONV system (0.019). This was an expected result: the plant moves the toxic element through non-specific transporters (thanks to structural affinity). The plant response to an increase in As concentration was in limiting the toxic element’s movement by rising transporters specificity and reducing its translocation from hypogeum to the epigeous plant components.

### 3.3 Tomato yield

Thirteen years after the experimental field establishment, the organic cropping system management significantly affected the tomato productions in a positive way (Table 3). Fruits, leaves, stems and roots of tomato crop showed a significant increase of both fresh and dry weight of biomass in the ORG management compared with the CONV one. In particular, the aboveground biomass (fruits, leaves and stems) resulted higher in the organic management than in the conventional one (+58%, +56% and +40% of dry weight fruits, leaves and stems, respectively), while the roots biomass increased only by 27% of dry weight in the organic management. Considering the whole biomass production of the tomato crop, the organic management determined an increase of dry weight (+53%).

## 4. Discussion

Previous study conducted in a Mediterranean environment (Marinari et al., 2006;, Mancinelli et al., 2010) attested a general improvement of soil quality under organic management with respect to the conventional one. In this study, conducted in a geogenic As rich area, although an active metabolic response of microorganisms was observed under both managements, the ORG system showed a general improvement of soil health, in terms of microbial activity (SEI and SIR) and microbial diversity, with respect to CONV system. In fact, in the ORG system, the increase of soil organic matter with lower C/N ratio, may enhance microbial biomass and its diversity showing a shift of population from bacteria to fungi and protozoa, as resulted by

El-FAME analysis. Moreover, the increase of readily available nutrients, such as extractable C and N, may have originated from a more intense rhizodeposition or turnover of roots in the agricultural system, where cover crops are included in the crop rotation (Kong & Six, 2012).

By means of an ecological point of view, As labile form represents the bioavailable and phytoavailable forms of the toxic element (Marabottini et al., 2013). Therefore, the CONV managed soils could display an increased risk for soil health and tomato quality, because the percentage of bioavailable As was 14% higher than in the ORG system. The management seems to induce change of As and P concentration in soil; in fact the available P in CONV system slightly increased (+5%). Therefore, as documented in previous works, the increased available P may promote As mobility in soil through competition for the anionic sorption sites, very affine to available P (Pigna et al., 2015; Caporale et al., 2018).

The highest concentration of $As_{bio}$ in CONV could be one of the soil environmental factor affecting microbial groups relative abundance. Therefore, the higher content of organic matter and a lower concentration of $As_{bio}$ in the ORG system, may affect soil microbial community composition showing a more abundant fungal biomass with a reduction of bacteria (G+ and G-). In this study, Protozoa represents the most sensible microbial group to the $As_{bio}$ concentrations in soil; this negative effect of heavy metals on Protozoa was previously reported by Ekelund et al. (2003). Moreover, the sum of methyl-branched FAs representing actinomycetes was slightly lower in the CONV. This result turns out to be in agreement with those reported by other authors, as actinomycetes FAs are usually found in the soil where low quantities of metal are detected (Kelly et al., 2003; He et al., 2005). The elevated concentrations of the metalloid in organic matter enriched soil may contribute to a selection or a shift of the microbial communities towards more metal-tolerant or metal-resistant species (Moreno et al., 2012).

The ratio Mono/Sat used to evaluate the soil microbial communities status under various environmental conditions, should approximately be less than 1 for soils receiving low organic inputs (Zelles et al., 1995). In this study, the ORG management promoted an increase of the Mono/Sat ratio, even if it was still lower than 1. This ratio, also used as an indicator of microbial nutritional status, suggested the maintenance of nutrient bioavailability in the contaminated soils, especially in the ORG system (Ellis et al., 2001). Moreover, since the relative proportion of F/B biomass provides an indication of soil microbial community stability, ecosystem self-regulation (Zeller et al., 2001) and soil quality change in contaminated area (Mummey et al., 2002), the results obtained in this study proved that the ORG management enhanced soil health. The ORG management, compared to the CONV one, revealed a higher soil organic carbon content due to the higher plant residues soil input (Mancinelli et al., 2013). At the same time, the soil $As_{tot}$ resulted higher in the ORG than in the CONV system probably because the increase of soil organic matter promoted the adsorption of As added by irrigation water as a common scenario occurring in As-affected Italian areas  (Baiocchi et al. 2013). Conversely the bioavailable As form resulted higher in the CONV system probably because the mineral fertilization, adopted in this system, enhanced the mobility of As in soil (Caporale et al., 2018). Therefore, the As form in soil may depend on applied agronomic practices since the crop residues management , addressed to increase the soil organic matter in the ORG system, could contribute to link As, justifying the highest total concentration  and the lower mobility of this element in soil.

## 5. Conclusions

A general improvement of tomato growth and soil health was obtained by the organic management system in a geogenic As rich area in Mediterranean environment. The concentration of As in the tomato fruits was not significantly affected by the management systems. In addition, in both CONV and ORG management, the tomato fruits have not exceeded the thresholds for As provided by the limits suggested by the European Food Safety Authority (EFSA, 2009).

According to the main questions posed, it can be concluded that: (1) the soil As concentration ranging from 56-75 mg $kg^{-1}$ does not represent a stress factor for soil microbial community; (2) the ORG management caused an increase of total As concentration in soil  through the enhanced organic matter content, retaining As from irrigation water; (3) the mobility of As increases under CONV system, where more phosphorus is available. Moreover, the ORG management mitigate the As uptake by tomato plant. Finally, even if the agricultural management affects As translocation in plant tissues, (4) the tomato produced under both ORG and CONV management in As rich soil does not represent a risk for human health.

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**Table 1** Soil quality in organic (ORG) and conventional (CONV) agricultural systems: chemical - biochemical properties and microbial diversity. Values belonging to the same parameter with different letters are statistically different according to LSD (0.05). In brackets the standard errors are reported (n=6).

| | ORG | CONV |
|---|---|---|
| *Soil chemical properties* | | |
| pH ($H_2O$) | 6.78 a | 6.63 b |
| TOC (%) | 1.48 a | 1.24 b |
| TN (%) | 0.22 a | 0.11 b |
| C/N | 6.58 b | 10.98 a |
| Available P (µg P $g^{-1}$) | 13.75 a | 14.44 a |
| Extractable C (µg C $g^{-1}$) | 47.29 a | 42.25 b |
| Extractable N (µg N $g^{-1}$) | 9.99 a | 8.81 b |
| *Microbial biomass and diversity* | | |
| Microbial Biomass (µg C-mic $g^{-1}$) | 267 a | 132 b |
| H' Enz | 1.21 b | 1.38 a |
| H' SIR | 2.62 a | 2.54 b |
| H' El-FAME | 2.71 a | 2.56 b |
| *Microbial activity* | | |
| SEI (nmol MUF $g^{-1}$ $h^{-1}$) | 1293 a | 945 b |
| SIR (mg $CO_2$ $g^{-1}$) | 26.64 a | 25.01 b |
| *El-FAME* | | |
| Total Bacteria (µmol $g^{-1}$) | 6.56 b | 7.76 a |
| G(+) (µmol $g^{-1}$) | 2.31 a | 2.85 a |
| G(-) (µmol $g^{-1}$) | 1.27 a | 1.36 a |
| Actynomicetes (µmol $g^{-1}$) | 0.70 a | 0.66 a |
| Fungi (µmol $g^{-1}$) | 1.75 a | 1.48 b |
| Protozoa (µmol $g^{-1}$) | 0.08 a | 0.04 b |
| *Microbial indicators of stress* | | |
| G(+)/G(-) | 1.82 a | 2.10 a |
| Mono/Sat | 0.80 a | 0.72 b |
| F/B | 0.29 a | 0.18 b |

TOC: total organic carbon, TN: total nitrogen, H’Enz: Shannon-Weaver Index on enzyme activities base, H’SIR: Shannon’s Index on substrate induced respiration base, SEI: Synthetic Enzyme Activity. H’ El-FAME : Shannon-Weaver Index from El-FAMEs data.

**Table 2** Pearson-correlation analysis results between studied parameter TOC-organic carbon content, TN-total nitrogen content; C/N ratio; $As_{total}$ total As; WS-water soluble As; SS-No Specifically Sorbed; As; SS-Specifically Sorbed As; As $_{bioav}$ -bioavailable As**.** n.s. = not significant; *, **, ** indicate the significance level at P≤0.05, P≤0.01, P≤0.001, respectively.

| **BIO**<br>**CONV** | **TOC** | **TN** | **C/N** | **As $_{total}$** | **WS** | **NSS** | **SS** | **As $_{bioav}$** |
|---|---|---|---|---|---|---|---|---|
| **TOC** | | *0.82 ** | | *0.79 ** | | | *0.90*** | *0.74 ** |
| **TN** | **1.00 ***** | | | *0.99 **** | | | *0.98 **** | *0.99 **** |
| **C/N** | **1.00 ***** | **1.00***** | | | *-0.96 **** | -0.82 * | | |
| **As $_{total}$** | **-0.75 *** | **-0.75 *** | **-0.76 *** | | | | *0.97 **** | *0.99 **** |
| **WS** | **0.71 *** | **0.71 *** | | | | 0.94 *** | | |
| **NSS** | | | | **0.85 **** | | | | |
| **SS** | **-1.00 ***** | **-1.00 ***** | **-1.00 ***** | **0.75 *** | **-0.71 *** | | | *0.95 **** |
| **As $_{bioav}$** | **-0.99 ***** | **-0.99 ***** | **-0.99***** | **0.79 *** | | | **0.99 ***** | |

**Table 3** Arsenic partitioning , fresh and dry of biomass fractions and yield of the tomato production in organic (ORG) and conventional (CONV) management system. Values between systems for plant components with different letters are statistically different according to LSD (0.05).

| **Plant components** | **System** | **As** mg $kg^{-1}$ D.W. | **Fresh weight** (t $ha^{-1}$) | **Dry weight** (t $ha^{-1}$) |
|---|---|---|---|---|
| **fruit** | ORG | 0.09 a | 50.60 a | 4.05 a |
| | CONV | 0.08 a | 32.10 b | 2.57 b |
| **leaf** | ORG | 1.24 b | 4.73 a | 0.89 a |
| | CONV | 1.30 a | 2.98 b | 0.57 b |
| **steam** | ORG | 0.60 b | 7.37 a | 1.12 a |
| | CONV | 0.69 a | 5.07 b | 0.80 b |
| **root** | ORG | 2.85 b | 0.88 a | 0.19 a |
| | CONV | 4.64 a | 0.59 a | 0.15 a |
| **whole plant** | | | 63.58 a | 6.25 a |
| | | | 40.74 b | 4.09 b |

## Figure captions

Figure 1 - Experimental sites in the thermal area of Bullicame (Baiocchi et al. 2013, modified)

Figure 2 - Microbial population based on EL-FAME profiles under the two different managements. G+= positive bacteria; G- = negative bacteria; Bacterial General = non-specific bacteria; Fungi; Act = Actinomycetes; Protozoa. Microbial groups are assigned to ester linked fatty acids as reported in de Dato et al. (2017). Values belonging to the same parameter between systems with different letters are statistically different according to LSD (0.05).

Figure 1

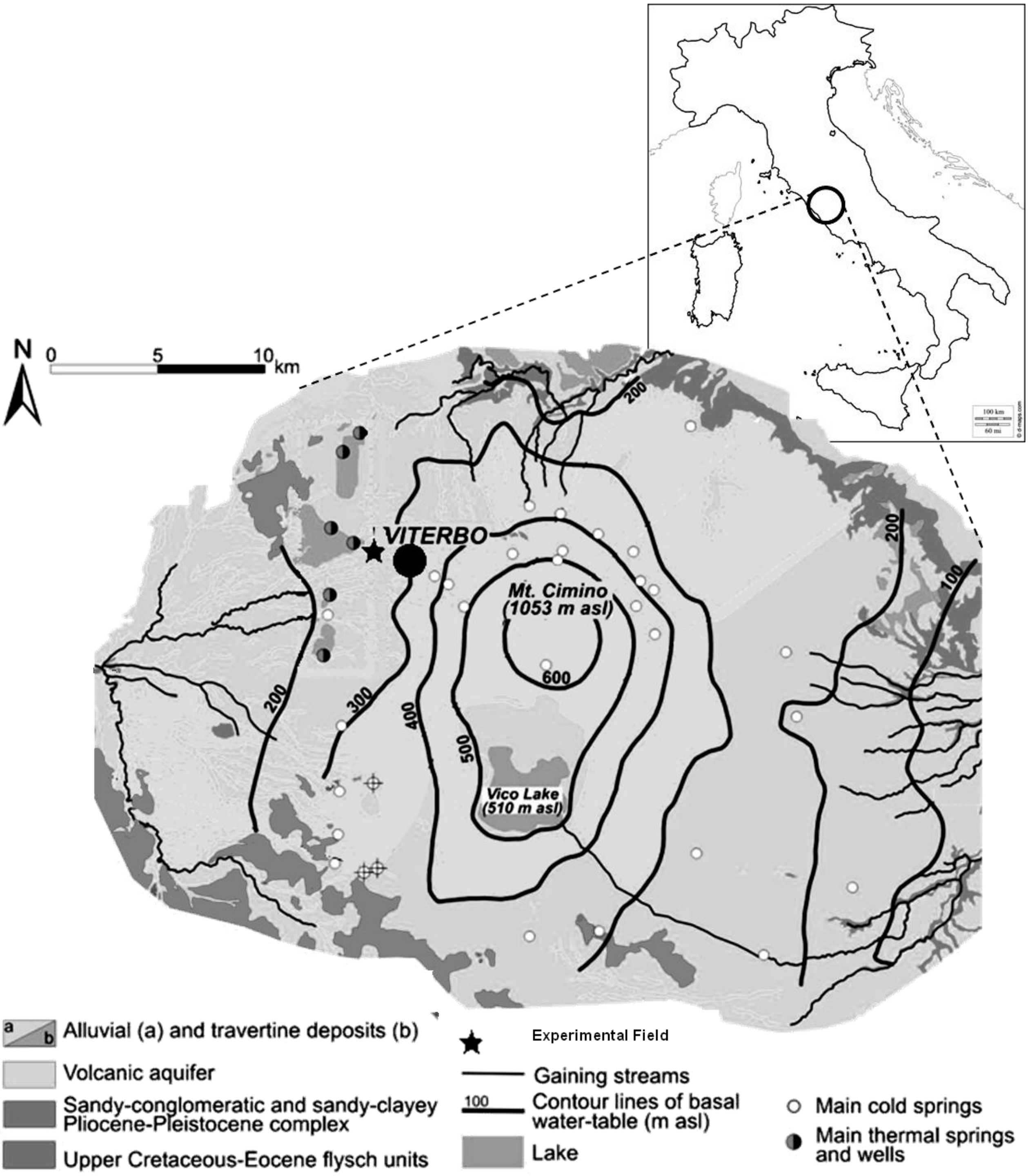
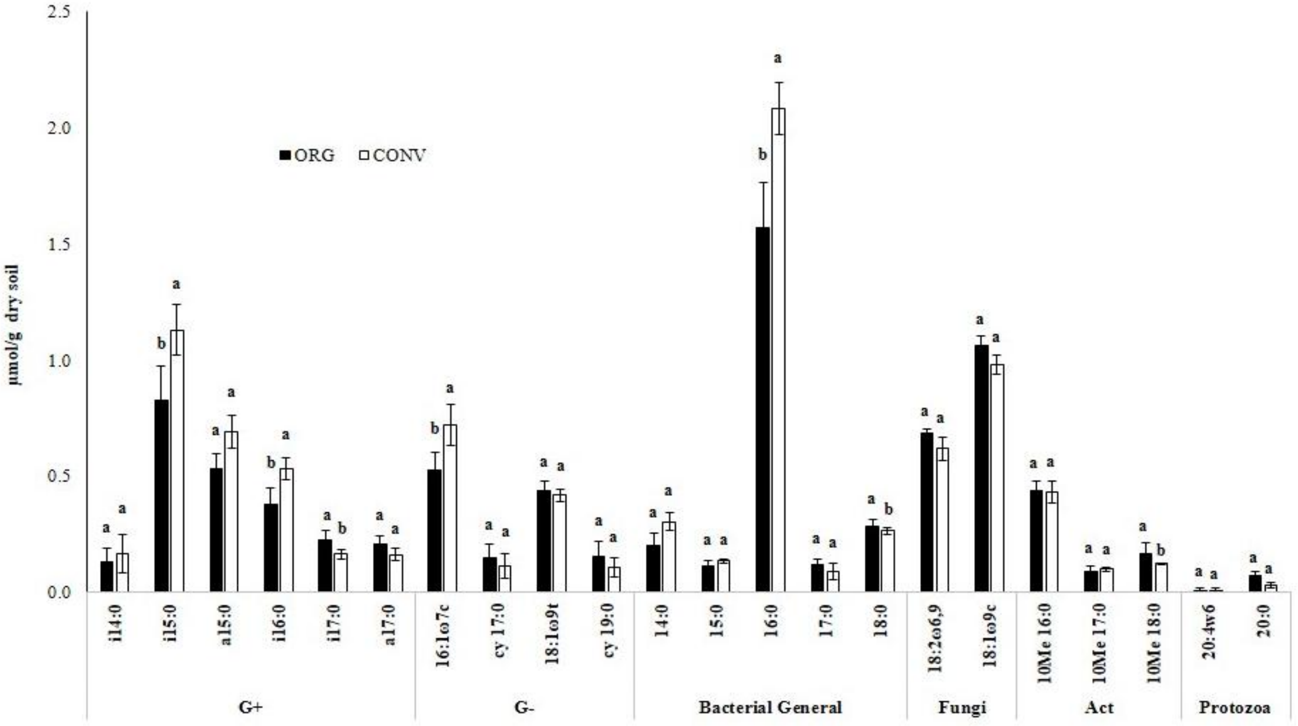

N
0
5
10
km
200
200
100
200
300
400
500
600
VITERBO
Mt. Cimino
(1053 m asl)
Vico Lake
(510 m asl)
100 km
60 mi
© d-maps.com
a
b
Alluvial (a) and travertine deposits (b)
Volcanic aquifer
Sandy-conglomeratic and sandy-clayey Pliocene-Pleistocene complex
Upper Cretaceous-Eocene flysch units
★ Experimental Field
Gaining streams
100
Contour lines of basal water-table (m asl)
Lake
○ Main cold springs
◐ Main thermal springs and wells

**Figure 2**


2.5
2.0
1.5
1.0
0.5
0.0
µmol/g dry soil
■ORG □CONV
a a
b a
a a
b a
a b
a a
b a
a a
a a
a a
a a
a a
b a
a a
a b
a a
a a
a a
a a
a b
a a
a a
i14:0
i15:0
a15:0
i16:0
i17:0
a17:0
16:1ω7c
cy 17:0
18:1ω9t
cy 19:0
14:0
15:0
16:0
17:0
18:0
18:2ω6,9
18:1ω9c
10Me 16:0
10Me 17:0
10Me 18:0
20:4w6
20:0
G+
G-
Bacterial General
Fungi
Act
Protozoa