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Concentrations of potentially toxic elements and soil environmental quality evaluation of a typical Prosecco vineyard of the Veneto region (NE Italy)

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Abstract

Purpose The aim of this work was to assess the concentrations of potentially toxic elements and to evaluate the soil quality of a typical Prosecco Denomination of Controlled and Guaranteed Origin vineyard of the Veneto region, NE Italy.
Materials and methods Soil samples and leaves of *Taraxacum officinale* and *Vitis vinifera* were collected during spring–summer 2014. Element determination (Al, Cd, Cr, Cu, Fe, Mg, Mn, Ni, P, Pb, V, and Zn) were performed with ICP-OES after microwave digestion of samples. Soil quality was assessed via the biological soil quality (BSQ-ar) index. Lipid peroxidation test was performed to evaluate the vegetation oxidative stress, based on malondialdehyde (MDA) content via spectrophotometer.
Results and discussion High concentrations of Al, Mg, and P were identified in soil, while high contents of Al, Cu, Fe, and Zn were found in *V. vinifera* leaves. The high concentrations in soil are probably due to agricultural activities, whereas those in leaves are probably due to atmospheric deposition and repeated use of foliar sprays in viticulture. The bioconcentration factor showed an effective transport of Cu, P, and Zn, from soil to leaf. The BSQ-ar values registered were similar to those obtained in preserved soils; hence, the biological class (VI) of these soils is high. The MDA content in *T. officinale* and *V. vinifera* leaves was below the reference value for *T. officinale* (2.9 ± 0.2 μM), suggesting that the metal content did not stress the vegetation in the investigated site.
Conclusions The MDA value for *V. vinifera* (1.1 ± 0.7 μM) could be adopted as another control value for soil quality, which in our case is of "good quality." Moreover, our results suggest that high concentrations of elements detected in the analyzed samples do not influence negatively the quality of soil, but a better agronomic management could improve soil quality in the studied area.

Keywords LPO test · Prosecco DOCG area · Soil quality · Toxic elements · Vegetation stress · *Vitis vinifera*

1 Introduction

Italy is among the top leading wine producers in the world. Indeed, Italian wine is the most exported, recording €5 billion in 2013 (Preti et al. 2016). Several factors contributed to the success of this product. The climate significantly contributes to the successful production of a wine with unique characteristics for which Italy is famous. Another key factor is the peculiarities of soil providing nutrients for the plant growth, as well as, water supply.

In an area where the economy is mostly based on viticulture, which influences life and uses of the inhabitants, it is important to evaluate the agronomic management of land and its impact on soil quality. Wine quality derives from the perfect interaction among morphology, climate, soil, and plants, i.e., the *terroir* (Van Leeuwen and Seguin 2006). Knowledge of land characteristics, together with cultivation techniques and management, is essential to understand the soil quality and the typicality of the wine. According to USDA Natural Resources Conservation Service, soil quality is the capacity of a specific kind of soil to function, sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Johnson et al. 1997). A new definition was proposed by the Joint

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Research Centre of the EC: soil quality is an account of the soil ability to provide ecosystem and social services through its capacities to perform its functions and respond to external influences (Tòth et al. 2007). Human activities are the main factors that hinder the soil to perform its services, such as biomass production, biodiversity pool, carbon pool, freshwater purification, food production, source of raw materials, and cultural environment for human and archive of archeological and geological heritage (Vidal Legaz et al. 2016). Human activities with long-term impact, such as agriculture, can easily lead to soil quality degradation (MEA 2005). Up to now, several criteria were applied for soil quality assessment, using a large number of indicators that predict soil functions, such as soil organic matter (Bowman et al. 2000; Brejda et al. 2000), bulk density (Kettler et al. 2000; Gilley et al. 2001; Li and Lindstrom 2001), aggregate stability (Bowman et al. 2000; Six et al. 2000), and biological indicators, such as microbial biomass and earthworm activity (Pankhurst et al. 1997; Liebig and Doran 1999; Gilley et al. 2001). Recently, several authors proposed new methods for soil quality evaluation studying the presence of invertebrate organisms, microorganisms, and plants (Menta et al. 2008; Branzini and Zubillaga 2010; Gong et al. 2001). For example, the biological quality of soil index (BSQ-ar index) is based on the evaluation of microarthropods in soil sample, which have been shown to respond to agricultural practices (Parisi et al. 2005). Land contamination by potentially toxic elements is arising as an important topic, especially for human health (Li et al. 2016; Islam et al. 2018; Carré et al. 2017) because wide utilization of fertilizers and pesticides may cause accumulation of toxic substances in soil and possible translocation to the food chain (Bini 2008; Wahsha et al. 2012). For this reason, metal contamination of soils and plants becomes a main issue in agricultural production. The recognition of the contamination source is also an important issue; it can be natural, arising from trace metals in rocks (Kabata-Pendias and Mukherjee 2007; Bonifacio et al. 2010; Gonnelli and Renella 2013), and/or anthropogenic, as industrial or agriculture activities, i.e., using chemicals, fertilizers and pesticides, sewage sludge, and irrigation with wastewater (Adriano 2001; Bini et al. 2008). In viticulture, treatments with manure and/or fungicides may cause contamination of soils and plants. Recent studies on trace elements in vineyards are focused on (i) contaminations of Cr, Cu, Ni, and As caused by the intensive application of fungicides and pesticides (Huzum et al. 2012); (ii) high concentration of Cd used as phosphate fertilizer was found (Alloway 2004); (iii) accumulation of Cu and Zn applied as fungicides (Tiecher et al. 2016). Furthermore, metal toxicity could induce the production of reactive oxygen species (ROS) resulting in lipid peroxidation, the oxidative degradation of lipid (Kusvuran et al. 2016). During this process, free radicals take electrons from lipid, damaging the cell membrane. The chemical products of this process are known as lipid peroxides and the end product mostly used as a marker for oxidative degradation is malondialdehyde (MDA). This molecule can react with molecules in DNA and may be carcinogenic to animals and human population (Marnett 1999). Several studies suggest that the accumulation of heavy metals induces an increase of oxidative stress in certain plant species (Shah et al. 2001; Malecka et al. 2001), e.g., Pb in rice plant (Shah et al. 2001) and Cd in fava bean (Lin et al. 2007). The oxidative degradation can limit crop production and destroy biomass (Kusvuran et al. 2016) due to several effects, such as salinity, drought, flooding, chilling, metal toxicity, nutrient deficiency, UV exposure, and air pollution, among others (Rehman et al. 2005). It is a useful tool to investigate the level of plant stress. In this view, our attention focused on determination of soil quality of a typical Prosecco DOCG (appellation of controlled and guaranteed origin) vineyard of Veneto region through different approaches: the evaluation of metal content in soils and grape leaves, biological quality, and vegetation stress.

2 Materials and methods

2.1 Study area

This research was accomplished in a vineyard (16 ha) close to Conegliano town, renowned especially for its sparkling wine Prosecco DOCG, which is located about 30 km north of Treviso province, Veneto region, NE Italy (Fig. 1). The farm was founded in 1962 and almost all the vines have the same age (about 40 years).

This wine variety is regulated by the Conegliano Valdobbiadene production Consortium, to protect both consumers and producers. The Conegliano Valdobbiadene Prosecco represents the highest quality of such wine and combines a long-standing tradition with a particular land suitability for viticulture. The geological substrate consists of a Tortonian–Messinian conglomerate formed of calcareous pebbles in a sandy or silty matrix (Bondesan et al. 2013). The annual average atmospheric temperature is 13 °C and an increase of total annual rainfall from 1990 (294 mm) to 2014 (951 mm) has been observed.

2.2 Field survey and sampling

A field survey was conducted during spring–summer 2014: 89 soil observations with hand auger were carried out to ascertain the variability of the soil characteristics. Afterwards, 10 representative soil profiles were opened (Fig. 1) and described according to national guidelines. The distance of soil profile from the vine is about 1.2 m. Soil samples were taken for each horizon. For metal determination, two samples from each profile were collected at different depths: 0–20 cm (topsoil) and 20–40 cm (subsoil). For BSQ-ar test, soil samples were

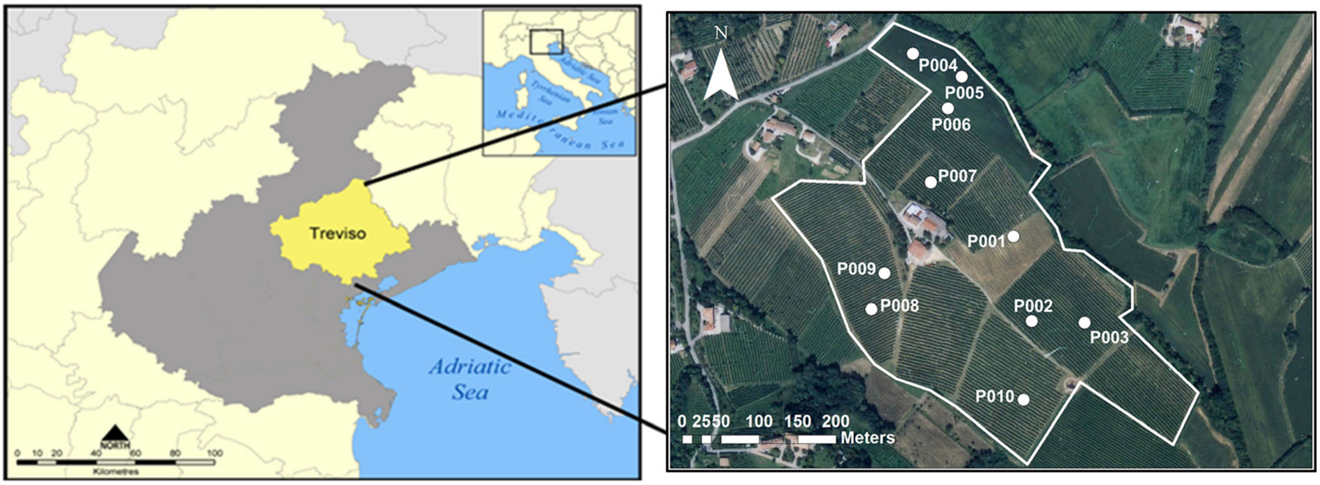


Fig. 1 Studied area (Treviso province, NE Italy) and related sampling sites (white points). The boundary of the studied area is depicted in white line

collected in triplicate at a depth of 0–10 cm (O + A horizons) with size 10 × 10 × 10 cm. Both native (*Taraxacum officinale* Weber) and cultivated (*Vitis vinifera* L.) samples were collected according to Benton Jones (2008) with some minor modifications. *T. officinale* and *V. vinifera* leaves were sampled at maturity vegetative phase and normal morphological appearance. The sampling was conducted randomly close to the collection of the corresponding soil clod, along the same row. About 5–6 leaves were sampled. The samples were rinsed gently with tap and distilled water to remove soil residues; then they were dried in ventilated oven at 50 °C for 48 h, milled with an agate mill, and stored for further elemental content determination according to Benton Jones (2008).

2.3 Chemical and physical analyses

All chemical reagents used in this research were of analytical grade (Sigma-Aldrich Co., USA). The soil samples were oven-dried (at 105 °C for 24 h) and disaggregated to pass through a 2-mm sieve. All soil samples were analyzed for pH in soil water suspension solution (1:2.5) using glass electrode (Violante and Adamo 2000), soil particle size distribution was determined by pipette method (Genevini et al. 1994), organic carbon was determined by Walkley and Black (1934) method, total carbonates was determined following the gas-volumetric method (Boero 2000), and the cation exchange capacity (CEC) was determined by $BaCl_2$ and triethanolamine extraction (at pH 8.2) followed by EDTA titration according to the Gessa and Ciavatta (2000) method. For element characterization (Al, Cd, Cr, Cu, Fe, Mg, Mn, Ni, P, Pb, V, and Zn), soil samples were milled with an agate mill. About 0.2 g of the powder obtained was mineralized with 5 mL of Aqua Regia (3:1 HCl 37% and HNO_3 65%) and 1 mL of HF 48% using a microwave digestion system (model 1600-Ethos, Milestone), according to the method of Fontana et al. (2010). After digestion, 1 mL of cold saturated H_3BO_3 solution was added. The quality of the analytical procedure was checked using a reference material (certified reference material SOIL-5, International Atomic Energy Agency, Wien). Percentage recoveries of SOIL-5 standard reference material ranged between 75% (Al) and 133% (Cr). Cr values were considered as semi-quantitative, due to high recovery in QC/QA. For plant samples, according to the method suggested by Unterbrunner et al. (2007) and Fontana et al. (2010), 0.5 g of milled sample was digested in an acid mixture of 5 mL 65% HNO_3 and 3 mL 30% H_2O_2. For soil and plant samples, the content of elements was determined by inductively coupled plasma optical emission spectrometry (ICP-OES), according to the method reported by Margesin and Schinner (2005).

2.4 Biological quality of soil index

Samples ($n = 30$) were analyzed for soil quality control. The extraction of microarthropods was conducted according to the method reported by Parisi et al. (2005). Organisms were evaluated according to their adaptation to soil edaphic environment (e.g., miniaturization, elongated body, flattened body, reduced, appendages depigmentation of skin, loss of integument thickened, development of chemoreceptors and hygroreceptors, etc.) using the eco-morphological index (EMI) proposed by Parisi et al. (2005). This index ranges from 1 to 20: eu-edaphic organism gets an EMI equal to 20, hemi-edaphic gets an index proportional to its degree of specialization, epi-edaphic organism gets an EMI equal to 1. A good degree of microarthropod adaptation to soil indicates their less ability to leave the land in unfavorable conditions. Thus, the presence or absence of the more suited soil organisms becomes a good indicator of the level of soil disturbance. The sum of EMIs gives the value of the class quality, from 0 to 7 (highest class).

2.5 Lipid peroxidation test

Lipid peroxidation (LPO) in leaves was performed by the TBARS assay (thiobarbituric acid reactive substances assay), according to Heath and Packer (1968), Taulavuori et al. (2001), Verma and Dubey (2003), and Lin et al. (2007). It was expressed as MDA content and it was calculated using Lambert–Beer law with an extinction coefficient of 155 mM^{-1} cm^{-1}. For quality control, 10 samples were collected from not contaminated site, in the Ca′ Foscari University garden (Wahsha et al. 2012).

2.6 Statistical analysis

Linear correlation coefficient was used to determine the strength and direction of relationships between couples of variables. Statistical significance was declared for p value ≤ 0.05 and < 0.01. Analysis was performed with R software.

3 Results and discussions

3.1 Soil characteristics

The results of physical and chemical analyses of soil samples are shown in Table S1 (Electronic Supplementary Material). pH varied in a narrow range from 7.7 to 8.7 (slight to moderate alkaline), consistent with the values suggested by Costantini et al. (2006) for Prosecco grape variety (alkaline); some results were higher than the upper limit (e.g., P001 and P005 in Bw horizon), but this does not produce a decrease on availability of analyzed elements. Moreover, results show a slight increase with depth due to calcareous parent material, which is derived from alluvial deposits of the Piave River.

The average and the respective standard deviation values of organic carbon content are 1.9 ± 0.9 g kg^{-1} (ranges from 0.5 to 3.9 g kg^{-1}), showing a decrease along the soil profile. In this case, the agricultural practices (application of chemical fertilizer and herbicide, use of tractors, etc.) caused the loss of organic matter with depth. It is worth to highlight that soils were sampled at the end of the growing season of vineyard and, thus, low values could probably be induced by wheel traffic or by a more intense mineralization of soil organic matter (Ayuke et al. 2011; Zhang et al. 2016). Total carbonate showed a wide range (7.9–181.5 g kg^{-1}), in connection to the parent material. Its presence is positive for the nutritional role of Ca which influences the decomposition rate of organic matter. Indeed, a great amount of carbonate reduces the organic compounds' decomposition and transformation in soil (Kaiser et al. 2016). The sampled soils also had noteworthy variability in particle size distribution (28–70% sand, 3–48% clay, 1–61% silt), depending on the nature of the substrate. Therefore, a wide range of soil texture, including loam, silt loam, silty clay loam, clay loam, and sandy loam, was observed in the study area. Due to the variability of particle size, the CEC has a wide range (6 to 38 cmol kg^{-1}). This parameter depends both on organic matter and on percentage of clay in the soil (Havlin et al. 2009), because of the large specific surface area and the important electrostatic surface charges. In general, the studied soils are shallow and not well developed, with little presence of diagnostic horizons. Based on field and laboratory results, the soil profiles were identified following the Soil Taxonomy classification (USDA 2014), as shown in Table 1. Soils investigated are suitable for viticulture except the Oxyaquic and Aquic subgroups, which could present water stagnation features, while the fine–clayey texture could be hard to plow creating some limitations to agricultural land use.

3.2 Metal content in soil

The metal concentrations (Al, Cd, Cr, Cu, Fe, Mg, Mn, Ni, P, Pb, V, and Zn) of soil samples and the respective reference values are shown in Fig. S1 (Electronic Supplementary Material): the adopted reference levels are (i) Italian averages according to Angelone and Bini (1992) and Costacurta et al. (2004), (ii) Italian legislation (D.L. 152/2006), and (iii) International averages reported by Kabata-Pendias (2011). Results show that (i) the concentrations of Cr, Cu, Mg, and P decreased with depth, while other metal contents were variable along the investigated profiles (P005, P007, and P010); (ii) Al, Fe, and V were more abundant in subsoil than in topsoil, suggesting a contribution from parent material; (iii) Cr, Cu, Mn, Ni, and V were below the reference values of D.L. 152/2006; (iv) Cd, Pb, and Zn were below the limit of detection; and (v) Al, Mg, and P were higher than the values shown in Fig. S1 (Electronic Supplementary Material). Concerning Fe, its content was within the Italian average level in soils reported by Angelone and Bini (1992). Only the elements, whose concentrations were above the reference values shown in Fig. S1 (Electronic Supplementary Material), are discussed in this paragraph. In the study area, high Al content was probably related to clay percentage (i.e., to the effect of parent material) and to specific treatments (3.5 kg ha^{-1} of fosetyl–aluminum) that prevent and control oomycetes fungi (e.g., *Phytophthora* spp.) applied to foliage and soil (Herbguide 2017). Phosphorous is mostly used as agricultural fertilizer. Fertilization is likely to increase P concentration in soil and/or in plants. In the study area, the high concentrations of P were probably due to this agricultural practice (applied as P_2O_5: 5–10 kg ha^{-1}). Nevertheless, its high concentration could be dangerous for microorganism in soil and could cause iron chlorosis (Bavaresco et al. 2006), although it had no negative effects on the normal grapevine growth. Since there is no limit of P in the Italian legislation, the average concentration for Italy was used (Costacurta et al. 2004) for comparison. P

Table 1 Taxonomy of the soil profiles studied

Profile	Order	Suborder	Great group	Subgroup	Family
P001 P003 P007	Inceptisol	Udept	Eutrudept	Typic	Coarse–loamy, mixed, calcareous, mesic, superactive
P002 P010	Inceptisol	Udept	Eutrudept	Oxyaquic	Fine–clayey, mixed, calcareous, mesic, superactive
P005	Inceptisol	Udept	Eutrudept	Typic	Coarse–loamy over fine loamy, mixed, calcareous, mesic, superactive
P008	Inceptisol	Udept	Eutrudept	Oxyaquic	Coarse–loamy, mixed, calcareous, mesic, superactive
P009	Inceptisol	Udept	Eutrudept	Aquic	Coarse–loamy, mixed, calcareous, mesic, superactive
P004	Entisol	Orthent	Udorthent	Typic	Coarse–loamy over fine loamy, mixed, calcareous, mesic, superactive
P006	Entisol	Orthent	Udorthent	Typic	Fine–loamy, mixed, calcareous, mesic, superactive

concentration of all soil samples (both topsoil and subsoil) was above the considered average (20 $\mu g\ g^{-1}$), with concentration in topsoil higher than in subsoil, as expected in consequence of fertilization. Magnesium concentration in the examined soils was largely above the international average suggested by Costacurta et al. (2004); it is likely that parent material and fertilization practices adopted in the study area could have contributed to the high Mg concentrations.

3.3 Metal content in plant

Figure S2 (Electronic Supplementary Material) shows the concentrations of elements in samples of *Vitis vinifera* and the metal reference levels in leaves adopted by Angelova et al. (1999), Fregoni and Corallo (2001), Ko et al. (2007), Kabata-Pendias (2011), and Karakaseva et al. (2012). Concerning Mg and P, to the best of our knowledge, there are no reference values for leaves in literature. The contents of Cd, Cr, Ni, and Pb were below the limit of detection (LOD). The concentrations of Mn and V were lower than the values reported by Karakaseva et al. (2012) and Kabata-Pendias (2011), respectively. In some sites, Cu and Zn were above the reference values reported by Fregoni and Corallo (2001) and by Karakaseva et al. (2012), respectively. Al and Fe contents were above the reference values suggested by Karakaseva et al. (2012), except for Fe in P003, P004, P007, and P010. Aluminum is a common constituent of plants and it is evident that it has a positive effect on plant growth (Kabata-Pendias and Pendias 2001). The major problem for grapes is associated with Al toxicity, which limits the root growth and subsequent decrease in the uptake capacity of nutrients and water (Matsumoto et al. 2001). In the examined plants, no toxicity signs were visible. Higher values of Al in leaves can be attributed to its concentration in the soil matrix and to foliar treatments against *Phytophthora* spp. The recorded high concentration, nevertheless, seems to have no negative effects on plant growth and on productivity of vineyard. Copper is a constituent of several enzymes and also plays important functions in physiological processes, such as photosynthesis, respiration, reproduction, and water permeability (Kabata-Pendias 2011). The most important practical implications are related to deficiency and toxicity of Cu: the deficiency affects physiological process and plant production, while Cu toxicity induces some inhibitory action of chemical compound in roots, iron chlorosis, and root malformation (Maksymiec and Krupa 2007). In the study area, the high concentration of Cu is likely to be due to fungicide application. Iron is a micronutrient essential for synthesis and other life processes of the cell, such as chlorophyll formation, photosynthesis electron transfer, reduction of nitrites and sulfates, and metabolism of nucleic acids (Kabata-Pendias 2011). High concentration of Fe is associated with soil texture (loamy soil), salinity, and a low phosphorous content and can produce toxic effects in plants (Kabata-Pendias 2011). In the study area, the high content of Fe recorded was probably due to soil texture. Necrotic spots in leaves that indicate an accumulation of Fe in plant were not visible during sampling. Zinc has a very important role in several enzymatic reactions. It participates in the

Table 2 Bioconcentration factor from soil to leaf in sampling sites

	Metals (a.u.*)							
Samples	Al	Cu	Mn	Mg	Fe	P	V	Zn
P001	0.01	14.89	0.06	0.23	0.01	3.10	0.05	2.66
P002	0.01	10.46	0.07	0.19	0.01	4.12	0.03	1.14
P003	0.01	11.91	0.07	0.19	< 1	4.62	0.04	0.98
P004	0.02	26.61	0.16	0.17	0.01	4.72	0.04	1.33
P005	0.01	33.88	0.13	0.20	0.01	3.81	0.04	1.90
P006	0.01	12.02	0.08	0.14	0.01	3.27	0.03	1.21
P007	0.01	6.18	0.08	0.18	0.01	4.70	0.03	0.85
P008	0.04	21.56	0.20	0.19	0.02	6.90	0.07	1.94
P009	0.01	6.01	0.13	0.18	0.01	3.09	0.04	2.44
P010	0.01	8.81	0.18	0.25	< 1	3.54	0.04	0.33
Average	0.01	15.23	0.12	0.19	0.01	4.19	0.04	1.48

*Arbitrary unit

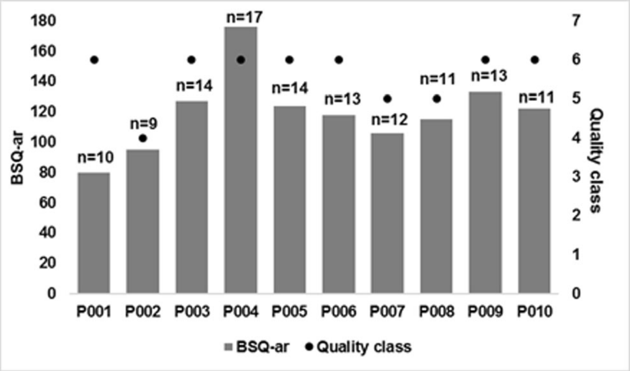


Fig. 2 Summary of the biological quality of soil (BSQ-ar) index and quality classes (black points) in sampling sites; *n* = number of biological forms

synthesis and degradation of carbohydrates, lipids, proteins, and nucleic acids and has shown to play an essential role in the processes of genetic expression (Kabata-Pendias and Mukherjee 2007). Kabata-Pendias and Mukherjee (2007) reported that sensitive plants die when soil Zn concentration exceeds 100 mg kg^{-1} and photosynthesis is inhibited with a concentration more than 178 mg kg^{-1}. Zn deficiency in plants is generally observed when the plant contains less than 20 mg kg^{-1} and occurs firstly in younger leaves (Bini and Whasha 2014). High concentration of Zn in the study could be caused by prolonged use of Zn fertilizers. The concentrations of Cd, Cr, Ni, and Pb were lower than the LOD of our experimental setup.

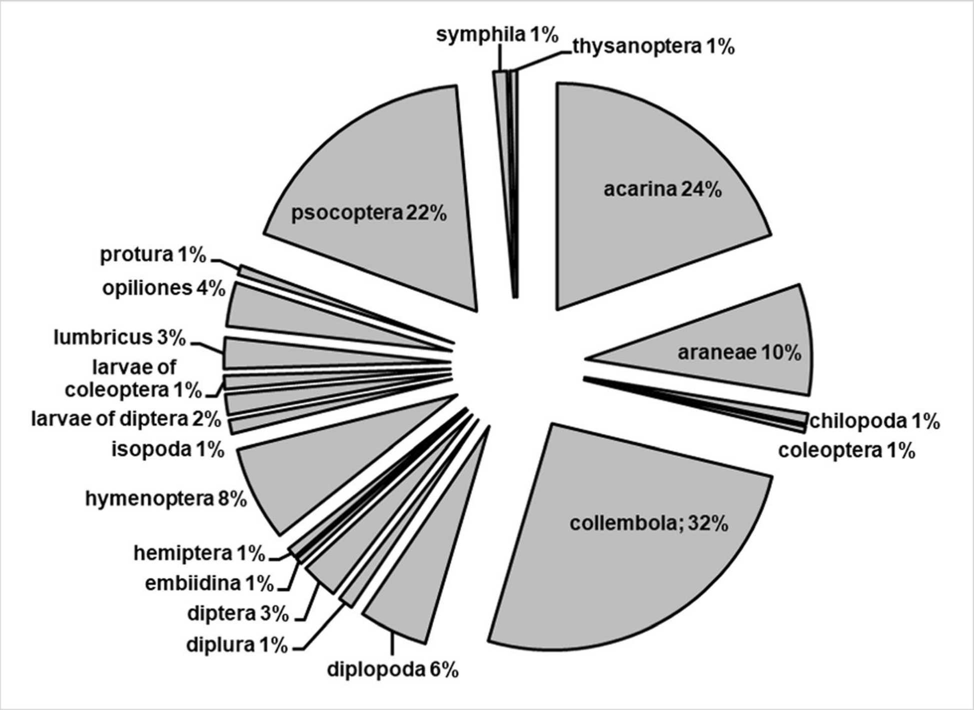
The bioconcentration factor (BCF) was calculated to find out the accumulation of metals from soil to plant (Table 2). Our results showed a BCF > 1 for Cu, P, and Zn (average equal to 4.19, 15.23, and 1.48 respectively) suggesting that these elements could be effectively translocated from the soil to the plant. The less concentrated elements were Al and Fe (BCF average is 0.01 for both metals), even though the high concentration of Al in leaves was likely related to the high content in soil.

3.4 Biological quality of soil index

The BSQ-ar values fall within a wide range, between 80 and 176 (Fig. 2). According to Parisi et al. (2005), BSQ-ar values between 100 and 200 identify a stable ecosystem with good quality. Sites from P003 to P010 have a good biological soil quality, while site P002 presents a medium soil biological quality, due to the absence of Coleoptera and Protura in addition to the low BSQ-ar value.

It was possible to assign different classes of soil biological quality (range from 4 to 6): the lower value indicated a state of suffering of the soil, probably due to the agronomic practices such as herbicide application, chemical fertilization, and plowing (Gagnarli et al. 2015). The abundance of organisms at investigated sites is reported in Table S2 (Electronic Supplementary Material). It should be noted that site P001 is associated with a high-quality class even if it has a BSQ-ar value of less than 100; this is due to the presence of particular microarthropod, the coleoptera. The

Fig. 3 Average percentage of microarthropods in sampling sites



number of biological forms is an index of organisms well adapted to the environmental condition of the study area (Fig. 3). Acarina and Collembola, the eu-edaphic groups, were found in each site in abundance range from 9 to 50% and from 10 to 61%, respectively. Among insects, the highest average percentages are registered for Collembola (32%) followed by Acarina (24%), Psocoptera (22%), Araneae (10%), Hymenoptera (8%), Diplopoda (6%), and Opiliones (4%).

Finally, among the holometabolous larvae, we could find the presence of both Diptera (2%), Coleoptera (1%), and Lumbricus (3%). Acarina and Collembola seemed to be only weakly affected by agricultural land use, as suggested by Parisi et al. 2005; indeed, they were present in every sample, together with Diptera and larvae of Diptera. The less abundant species (1%), Diplura, Symphyla, Hemiptera, Chilopoda, Isopoda, Protura, Embiidina, Thysanoptera, and Coleoptera, were probably strongly affected by land use type.

3.5 Lipid peroxidation quantification

The results obtained from the LPO test are presented in Fig. 4. LPO level in *Taraxacum officinale* and grape (*Vitis vinifera*) leaves varied with the level of heavy metals in soils of the corresponding site. The content of MDA in *Taraxacum officinale* leaves ranged from 1.1 μM (site P008) to 2.4 μM (site P007) and in grape leaves ranges from 0.3 μM (site P001) to 2.6 μM (site P010). The average values (± σ) were 1.9 (± 0.4) μM and 1.1 (± 0.7) μM, respectively in *Taraxacum officinale* and in *Vitis vinifera* samples. No reference values of *Vitis vinifera* are reported in literature; thus, we compared the leaf samples to the reference value of *Taraxacum officinale*, reported by Wahsha et al. (2012) (2.9 ± 0.2 μM), since we collected both samples in the same area. The average value of grape leaf samples was below the reference value *of T. officinale*, suggesting that the elevated concentration of some metals did not affect the soil quality in the investigated site. Thus, the MDA value for *V. vinifera* could be adopted as another reference value indicating a good quality soil.

3.6 Statistical analysis

Table S3 (Electronic Supplementary Material) shows the correlation values between soil variables. Significant correlation (p value < 0.05) can be observed between some elements: strong correlation ($r > 0.70$; in bold) between Al and V ($r = 0.86$), Fe and V ($r = 0.75$), Fe and Zn ($r = 0.74$), Zn and V ($r = 0.73$), Zn and Cr ($r = 0.70$), and P and Cu ($r = 0.72$) and appreciable correlation ($0.70 < r < 0.50$; in italic) between Al and Fe ($r = 0.57$), Al and Zn ($r = 0.60$), Al and Cr ($r = 0.56$), Mn and Cr ($r = 0.60$), Zn and Cu ($r = 0.58$), V and Cr ($r = 0.56$), V and %clay ($r = 0.64$), Cu and Cr ($r = 0.56$), and Cr and CEC ($r = 0.62$). Slight and moderate ($r < 0.50$) correlations are also recorded between other elements, except for Mg which is not correlated with any other element. There is an inverse correlation between pH (slight to moderate alkaline) and metals (e.g., pH–Al = − 0.19 and pH–Mn = −0.43). Several studies have found a negative correlation between pH and metal mobility; elements are more mobile in acid conditions (Wang et al. 2006; Fanrong et al. 2011; Thouin et al. 2016) and their increasing absorption in plants and humans threatens their health (Saiful Islam et al. 2015; Gu et al. 2016). Organic carbon does not show any strong or appreciable correlation with the considered variables. Clay content shows an appreciable correlation with V, due to its tendency to be concentrated in argillaceous sediments. V is also correlated with Al, Cr, Fe, and Zn; indeed, it forms different minerals associated with Al (roscolite, $KV_2(OH)_2(AlSi_3O_{10})$) and Zn (mottramite, $Pb(Cu,Zn)(VO_4)(OH)$) and seems to be associated with Fe oxyhydroxides (Kabata-Pendias 2011). Concerning other correlations, they are due to the different metal behavior in soil: Zn in soil is associated with Fe, and Cr seems to be directly related to Mn contents (Chung and Sa 2001).

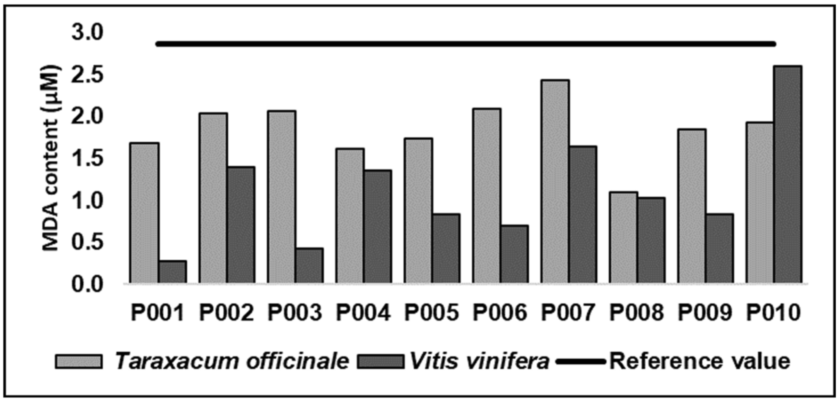


Fig. 4 Malondialdehyde content (μM) in *Taraxacum officinale* and *Vitis vinifera* leaves. Reference value for *T. officinale* (black line) suggested by Washa et al. (2011)

4 Conclusions

The main goal of this research was to assess the concentrations of potentially toxic elements and the soil quality of a typical Prosecco DOCG vineyard of Veneto region (NE Italy) via several approaches: metal analyses, soil biological quality, and vegetation stress. The high contents of the metals are due to anthropogenic pressure; indeed, human influence related to agricultural activities, such as fertilization, fungicides application, and foliar treatment, has produced the accumulation of several elements (Al, Mg, and P in soil and Al, Fe, Cu, and Zn in plant). The study area has a good biological soil quality, even if only one site presents a medium quality due to the agronomic practices, such as plowing, herbicide/fungicide application, and chemical fertilization. Average content of MDA in leaves (*T. officinale* and *V. vinifera*) was below the reference value for *T. officinale*, suggesting that the high metal content do not stress the vegetation. Thus, the MDA value for *V. vinifera* could be adopted as another reference value indicating a good-quality soil, since the samples were collected from the same area where both *T. officinale* and *V. vinifera* grow. Finally, our findings suggest that a better agronomic management, focusing on the minor use of fertilizers and fungicides, may decrease the high levels of the elements detected in the analyzed samples, improving plant yield and the soil quality.

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