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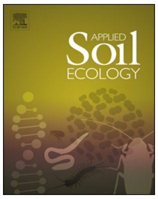

Plant cover and management practices as drivers of soil quality

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ABSTRACT

Human activities intensively modify soil properties and quality according to land-use and management practices. In Mediterranean areas, pollution and fires may directly alter some soil abiotic properties as well as the steady-state condition of soil microbiota. The aim of this study was to evaluate if the chemical and biological characteristics of two kinds of soil, Arenosols and Andosols, of a natural reserve and an urban park respectively, were affected by the same or different plant covers (trees and grasses). At each site, five sub-samples of surface soils (0–10 cm) were collected under maquis (trees) and gap of grasses. The soils were analyzed for physico-chemical parameters (organic matter and water contents, pH, C, N, Cr, Cu, Ni and Pb concentrations) and biological parameters (microbial and fungal biomass, respiration, metabolic quotient and coefficient of endogenous mineralization). The soil quality was evaluated through an integrated index, calculated taken into account all the investigated parameters. The results highlighted that soils under trees inside the urban park, with the highest amount of organic matter, showed higher microbial biomass and activity as compared to soils under grasses. The high concentration of Cu and Pb in these latter soils inhibited the microbial biomass and activity that were not exclusively affected by litter quality. Soil quality would seem to be strongly affected by the pedogenetic derivation and the management practices more than plant covers.

1. Introduction

Human activities introduce pollutants, such as heavy metals, to soils through mining, smelting, industry, agriculture and burning fossil fuels, leading to alterations of several processes that could weaken the whole ecosystem (Pouyat et al., 2009), especially in urban and adjacent areas. Also some disturbances, such as fire, erosion, drought and salinization, have been identified as important threats to soil (Andrews and Carroll, 2001; Commission of the European Communities, 2002) because they may directly alter some soil chemical and physical properties as well as the steady-state condition of soil microbiota, important determinant of carbon turnover (De Marco et al., 2005).

The Mediterranean-type ecosystems, where a lot of areas have been affected by anthropic pressure for thousands of years, are, nowadays, one of the most significantly altered hotspots in the world (Falcucci et al., 2007). In fact, in these ecosystems, pollution and fires are widely recognized as the main drivers of human impact. In particular, fire is by far the most frequent and widespread cause of disturbance to vegetation, altering the structure of land cover and functioning of Mediterranean ecosystems (Dale et al., 2001). However, Mediterranean maquis is highly adapted to frequent fires, shrub fuels are known for their flammability and tendency to sustain high intensity fire (Malkisnon et al., 2011). In heavily degraded Mediterranean region, patches of high and low maquis with small clearings in the shrub cover dominated by herbaceous species occur (Ruth et al., 2009). This mosaic of vegetation contributes to the wide spatial variability of soil physical and chemical properties. Plant species, according to their morphologies, differently intercept air pollutants deriving by dry or wet deposition, affecting their soil accumulation (Maisto et al., 2004). Thus, in turns, determines consequences on soil biological diversity and processes (Trabaud, 2002) modifying soil fertility and quality (Caravaca et al., 2002). In fact, thus can cause changes in growth of the different components (fungi and bacteria) of soil microflora (Vásquez et al., 1993; Bååth et al., 1995; Díaz-Raviña et al., 2006) with consequences on efficiency in carbon assimilation and mineralization due to microbial community (Rutigliano et al., 2007). In addition, soil characteristics also depend on its proximity to lagoons and rivers that suffer both natural and man-induced pollution. In particular, the lagoons are often the recipient of domestic, agricultural and industrial discharges that eventually result in soil heavy metal accumulation (Arienzo et al., 2014).

Soil quality is often assigned to specific soil attributes (*i.e.*, pH, soil structure stability, organic matter content and nutrient supply), also if it is a complex functional concept and cannot be measured directly in the field or laboratory but can be indirectly inferred by soil indicators (Cherubin et al., 2016). Soil indicators are measurable properties and

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describe processes that have the greatest sensitivity to changes in soil functions and its ecosystem services (Andrews et al., 2004; Innangi et al., 2015; Zornoza et al., 2015; Memoli et al., 2018). To assess soil quality is essential to elaborate indices integrating the parameters that are affected by different types of disturbance and that vary in frequency and intensity in relation to human demography and management (Barbero and Quèzel, 1989).

The aim of this study was to evaluate if, in Mediterranean region, the chemical and biological characteristics of two kinds of soil, Arenosols and Andosols, found in a natural reserve and an urban park, respectively, were affected by the same or different plant covers (trees and grasses). The quality of the soils was estimated through an integrated index, taking into account all the investigated parameters. In this concern, the hypotheses were: soils under trees received a major input of litter as compared to those under grasses (H1); pollutant deposition was higher on soils under grasses (H2); microbial biomasses and activities were enhanced by more degradable litter (H3); soil quality of natural reserve was higher than that of urban park (H4). The findings of the research can provide information both at local and global scales, as they can be as useful tool in management plans and can increase the current dataset of soils of Mediterranean area.

2. Materials and methods

2.1. Study area and sampling

The research was carried out in the Mediterranean Region in the South of Italy characterized by dry summers and rainy autumns and winters (mean annual temperature: 18 °C; annual precipitation: 800 mm). In particular, it interested two sites: an urban park (UP) and a natural reserve (NR).

The urban park with an extension of approximately 10 ha, established in 1953 and abandoned until 1997, is located on a flat coastal area of Campi Flegrei, Naples near the Fusaro Lagoon (40°49′N, 14°03′E). The urban park plant cover is similar to that of the reserve including patches of high and low maquis with dominance of holm oak specimens and low shrubs and herbaceous species in the gaps. Soils of Phlegren volcanic region are *Molli-Vitric Andosols* with clay loam texture (di Gennaro, 2002 according to FAO classification, 1998). The Fusaro Lagoon is a saltwater lagoon of relevant hydrological interest. It has often been the object of attention for high levels of degradation and the general state of neglect that, over the years, have caused serious eutrophication phenomena (Carrada, 1973; Arienzo et al., 2014).

The natural reserve, established in 1977 and with an extension of approximately 268 ha, is located at Castel Volturno (40°57′N, 13°33′E) on a flat coastal area of Naples and is covered by a typical Mediterranean maquis, consisting of densely sclerophyllous shrubs and trees, including specimens of *Quercus ilex* L., *Myrtus communis* L., *Arbutus unedo* L., *Pistacea lentiscus* L., *Phillyrea latifolia* L. Locally, small clearings (gaps), representing the 20% of the maquis area, in the woody canopy were covered by grasses and bryophytes (De Marco et al., 2008). The natural reserve has often been interested by prescribed frequent fires that were used as useful tool in the management practices (D'Ascoli et al., 2005).

Soil at the nature reserve is a *Calcaric Arenosol* with sandy loam texture (di Gennaro, 2002 according to FAO classification, 1998).

At each site, five sub-sample of surface soils (0–10 cm) were collected under maquis (trees) and gap of grasses.

2.2. Soil physico-chemical analyses

The soil samples were sieved (< 2 mm) and divided in aliquots to measure: water content (WC), pH, organic matter (OM) content, and C, N, Cr, Cu, Ni and Pb concentrations. Soil water content was assayed drying 5 g of each soil sample at 105 °C until to reach a constant weight. According to USDA-NRCS (2017), pH was measured on soil: distilled water (1:2.5 = v:v) suspension by potentiometric method. In order to calculate OM content, the organic carbon (C_{org}) was determined by gas-chromatography (Thermo Finnigan, CNS Analyzer) on soil samples previously treated with HCl (10%) to exclude carbonates. Successively, the OM content was obtained multiplying the C_{org} for 1.724 (Pribyl, 2010). Total C and N concentrations were evaluated on oven-dried (105 °C, until constant weight) and grounded (Fritsch Analysette Spartan 3 Pulverisette 0) soil samples by gas-chromatography (Thermo Finnigan, CNS Analyzer). Successively, C/N ratios were calculated. Total concentrations of Cr, Cu, Ni and Pb were measured, via graphite furnace, by atomic absorption spectrometry (SpectrAA 20 – Varian) on oven-dried (105 °C until constant weight) and grounded (Fritsch Analysette Spartan 3 Pulverisette 0) soil samples dissolved by an acid mixture (HF 50% and HNO_3 65% at 1:2 = v: v) in a micro-wave oven (Milestone mls 1200 – Microwave Laboratory Systems).

Table 1
pH and water content – Mean values (± s.e.) of pH and water content (WC, expressed as % d.w.) in soils collected at the urban park and the natural reserve under different vegetation covers (maquis and gap of grasses). In bold the maximum and minimum values are reported. Different letters indicate the statistically significant differences (one way ANOVA, $P < 0.05$).

Site typology	Vegetation cover	pH	WC
Urban Park	Maquis	7.22 ± 0.04^A	**60.34 ± 1.73^A**
	Gap	**6.67 ± 0.04^B**	38.44 ± 0.75^B
Natural Reserve	Maquis	7.51 ± 0.03^A	16.19 ± 0.22^A
	Gap	**7.47 ± 0.02^A**	**15.11 ± 0.23^A**

All the described analyses were performed in triplicates.

2.3. Soil biological analyses

Microbial and fungal biomass as well as microbial respiration were measured on fresh soils stored at 4 °C until time of measurements (within a week after sampling). Microbial biomass carbon (C_{mic}) was evaluated by the method of substrate-induced respiration (SIR) according to Degens et al. (2001), while microbial potential respiration (Resp) according to Froment (1972). The CO_2 evolution from the samples at 55% of water holding capacity was measured by NaOH absorption followed by two-phase titration with HCl (Froment, 1972), after incubation at 25 °C in tight containers for 5 and 10 days, respectively, to evaluate C_{mic} and Resp. Total fungal biomass (FB) was assayed by membrane filter technique (Sundman and Sivela, 1978), after staining with aniline blue, determining hypha length by intersection method (Olson, 1950) with an optical microscope (Optika, B-252). In order to make comparable the soil samples collected at different sites, all data were expressed per unit of soil dry weight. The results obtained by the biological analyses were used to calculate two indices: the metabolic quotient (qCO_2), *i.e.* the degree of microbial biomass activity, and the coefficient of endogenous mineralization (CEM), *i.e.* the rate of organic carbon mineralization (Anderson and Domsch, 1993). The qCO_2 was calculated as ratio between Resp and C_{mic}, whereas the CEM was calculated as ratio between Resp and C_{org}.

2.4. Soil quality index (SQI)

In order to evaluate the soil quality, an integrated index was calculated taken into account all the investigated parameters that were ranked by linear scoring technique according to Liebig et al. (2001). The scores, ranging from 0 to 1, were assigned applying the *more is better* or *less is better* functions. The *more is better* function was applied to WC, OM, C and N contents, C_{mic}, FB, Resp and CEM; whereas, the *less is better* function was applied to qCO_2 and metal concentrations (Marzaioli et al., 2010). The maximum score for pH was attributed to 7 (Liebig et al., 2001). The SQI was calculated by summing the parameter scores and dividing for the number of parameters according to Andrews et al.,

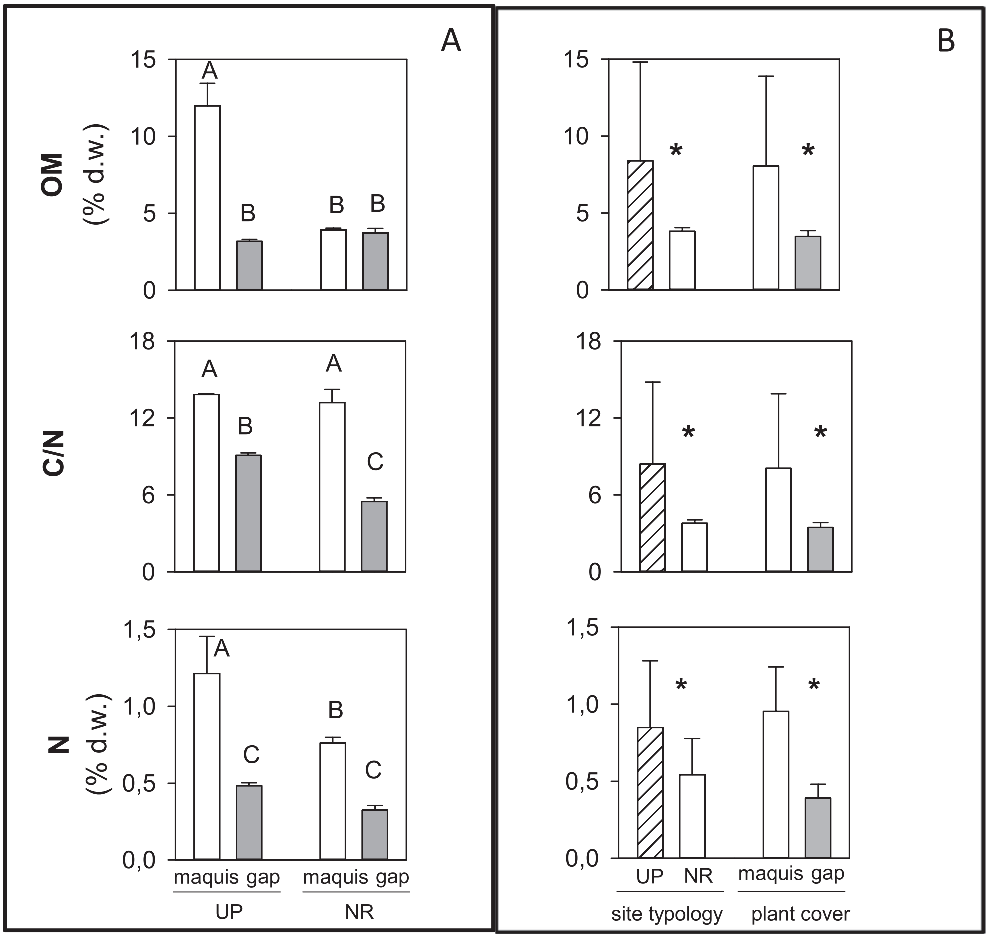

Fig. 1. Chemical characteristics of investigated soils – Mean values (± s. d.) of organic matter (OM), N contents and C/N ratios in soils of: A) different plant covers inside each site typologies and B) different site typologies and plant covers. Different letters indicate the statistically (One-way ANOVA) significant differences among four soils (MUP, GUP, MNR, GUP). The asterisks indicate the statistically significant differences between site typologies and between plant covers (Paired *t*-test).

2003. Among the different indices useful for soil quality assessment (Masto et al., 2008; Gonzàlez-Quiñones et al., 2007) that proposed by Andrews et al. (2003) is commonly used in literature (Marzaioli et al., 2010; Askari and Holden, 2015) as it is easy to calculate, takes into account chemical, physical and biological parameters and provides information about the effects of management practices on soil functions (Andrews et al., 2004).

$$SQI = \sum_{i=1}^{n} \frac{Si}{n}$$

where *SQI* is soil quality index, *S* is the score assigned to each studied parameter and *n* is the number of the studied parameters.

2.5. Statistical analyses

The normality of the data distribution was assessed by the Shapiro-Wilk test.

Spearman's correlation test was performed to evaluate the relationships between physical-chemical and biological characteristics either at two sites sampled either under different vegetation cover (*i.e.* trees and grasses).

The one-way analysis of variance (ANOVA), followed by the Holm-Sidak post hoc test, was performed in order to highlight differences among the four soils (factors for ANOVA were soil typologies and plant covers). The paired *t*-test was performed to evaluate the significance of differences between soil typologies and between plant covers.

All parameters were used in the standardized principal component analysis, PCA, in order to find the main factors affecting the soil quality.

The univariate statistical tests, performed by Systat_SigmaPlot_12.2 software (Jandel Scientific, USA), were considered statistically significant for $P < 0.05$. The PCA was performed by package Syn-tax 2000 (Podani, 1993).

3. Results

3.1. Soil characteristics and soil quality index (SQI)

3.1.1. Comparison among the soils

The soil pH varied between neutral to slightly alkaline with values statistically lower for the soil of the gaps of grasses and higher for the soil under maquis of the natural reserve (Table 1). Soil water (WC) and organic matter (OM) contents were statistically higher in the soil under maquis of the urban park, whereas they were statistically lower in the soils under both the plant covers of the natural reserve (Table 1; Fig. 1A). The OM content in the soil under gap of grasses of the urban park did not statistically differ from the soils under the two plant covers of the natural reserve (Fig. 1A). C/N ratio showed high variability among the soils; instead N content was statistically higher in the soil under maquis of the urban park, and lower in the soils under gaps of grasses of both the sites typologies (Fig. 1A).

Also the heavy metal (Cr, Cu, Ni and Pb) concentrations highlighted wide variability among the soils (Fig. 2A). The highest Cr concentrations were observed in both the soils of the natural reserve (Fig. 2A). Cu and Pb showed the similar spatial trends with the highest concentrations in soil of gap of grasses inside the urban park, whereas the lowest

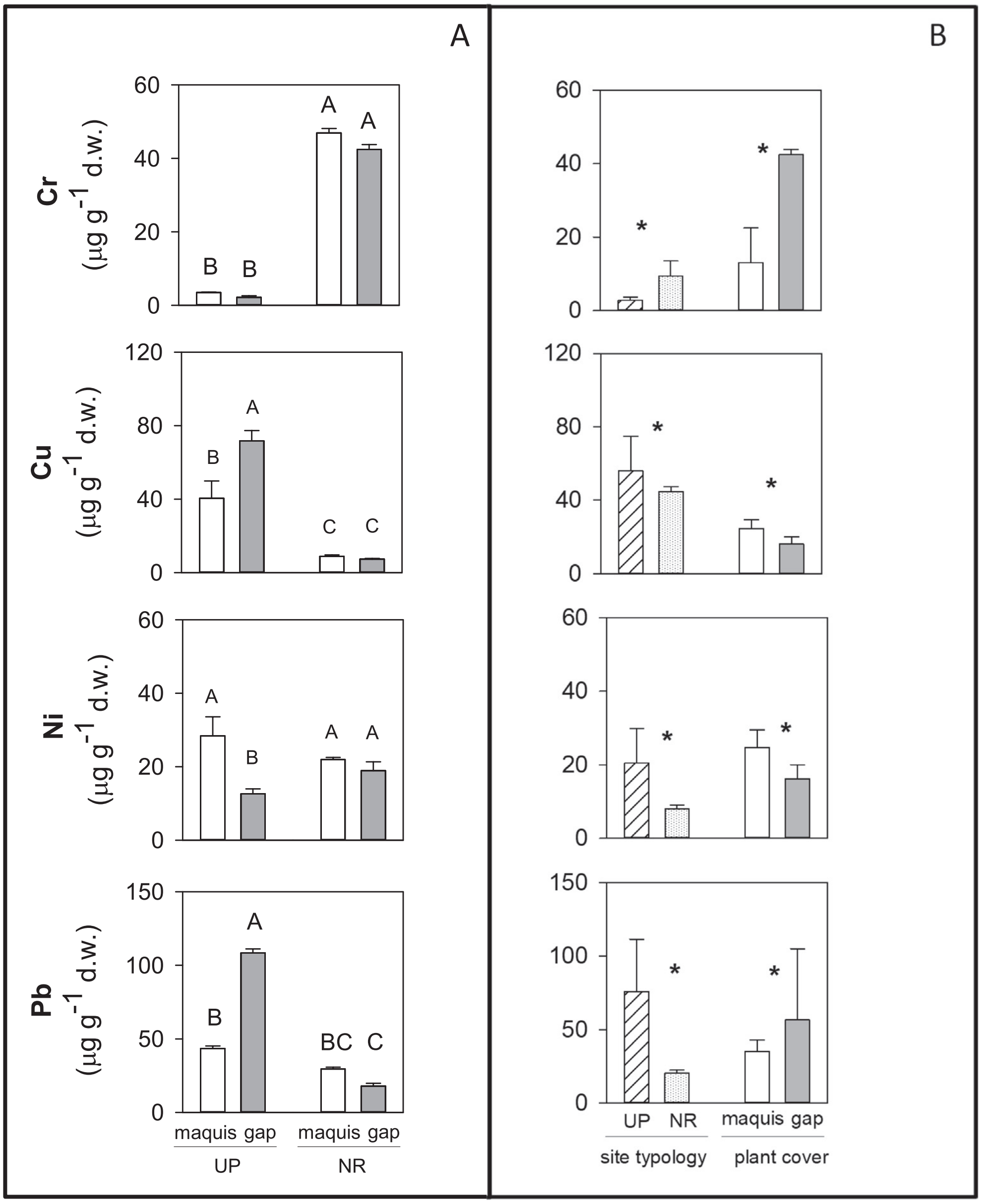

Fig. 2. Heavy metal content measured in investigated soils – Mean values (± s. d.) of Cr, Cu, Ni, Pb, in soils of: A) different plant covers inside each site typologies and B) different site typologies and plant covers. Different letters indicate the statistically (One-way ANOVA) significant differences among four soils (MUP, GUP, MNR, GUP). The asterisks indicate the statistically significant differences between site typologies and between plant covers (Paired *t*-test).

concentrations were measured in soil under both the plant covers inside the natural reserve (Fig. 2A).

The investigated biological parameters highlighted that the highest fungal biomass (FB) were in both the soils inside the natural reserve (Fig. 3A), the highest microbial C (Cmic) in soils under maquis of the urban park (Fig. 3A), the biological activities (Resp, qCO_2, CEM) were statistically higher in soils under gap of grasses of the natural reserve (Fig. 4A). In addition, the biological activities showed similar spatial trends among the soils (Fig. 4A).

The SQIs slightly differed among the soils with not statistically significant differences (Fig. 5A).

3.1.2. Differences between Andosols and Arenosols (urban park and natural reserve)

The comparison between Andosols and Arenosols highlighted statistically higher mean values of OM content, C/N ratio and N concentration in the former (Fig. 1B). Also the heavy metal (Cr, Cu, Ni and Pb) concentrations differed between the soil types (Fig. 2B) with the statistically higher values of Cr in the Arenosols, UP, whereas opposite trends were observed for Cu, Ni and Pb that were statistically higher in the Andosols, NR (Fig. 2B). Differently by Cmic, FB and the microbial activity, measured by Resp, qCO_2 and CEM, were statistically higher in the Arenosols (Figs. 3B and 4B). The SQIs, with values ranging from 0.51 to 0.71 (Fig. 5B), was statistically higher in Andosols (UP) than in the Arenosols (NR).

3.1.3. Differences between plant covers (maquis and gap of grasses)

An overall evaluation highlighted that all the soil physico-chemical characteristics statistically differ between the two plant covers (maquis and gap of grasses), with higher values of pH, WC, OM, N and C/N in soils under maquis (Table 1, Fig. 1B).

The concentrations of all heavy metals highlighted statistically differences between plant covers with higher values of Cr and Pb in soils under gap of grasses and higher values of Cu and Ni in soils under maquis (Fig. 2B).

In addition, all the investigated biological parameters as well as

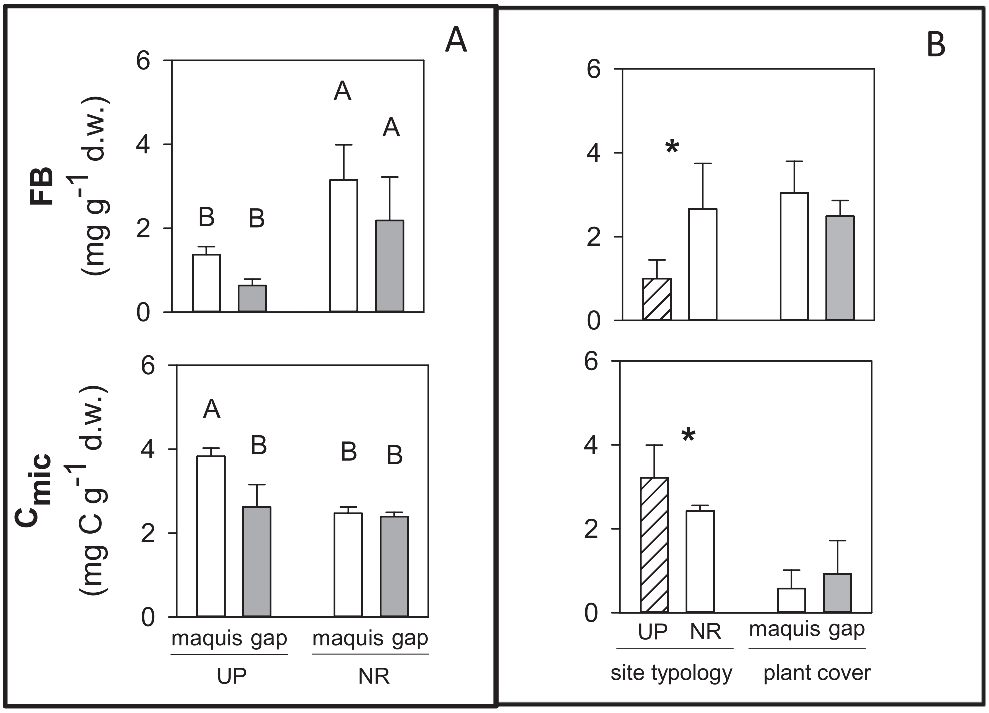

Fig. 3. Microbial and fungal biomass of investigated soils – Mean values (± s. d.) of microbial C (Cmic), fungal biomass (FB) in soils of: A) different plant covers inside each site typologies and B) different site typologies and plant covers. Different letters indicate the statistically (One-way ANOVA) significant differences among four soils (MUP, GUP, MNR, GUP). The asterisks indicate the statistically significant differences between site typologies and between plant covers (Paired *t*-test).

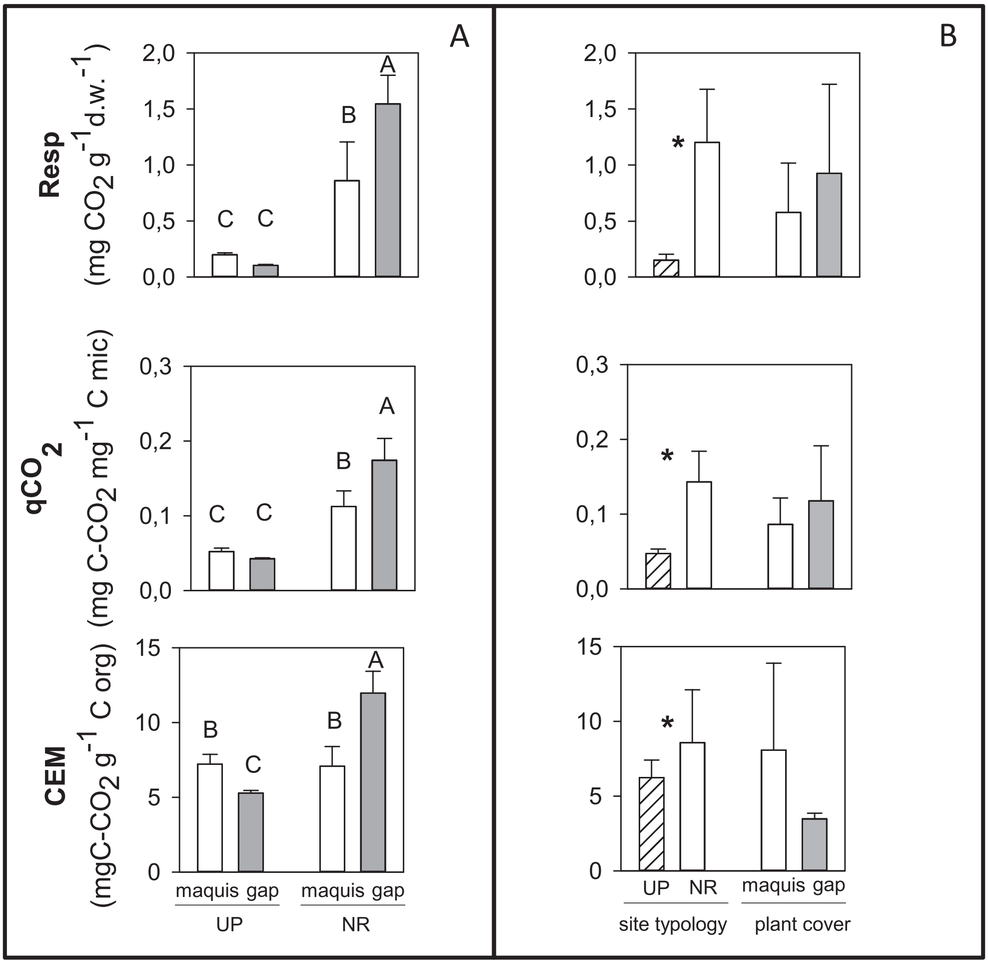

Fig. 4. Microbial activity of investigated soils – Mean values (± s. d.) of microbial respiration, metabolic quotient (qCO_2) and coefficient of endogenous mineralization (CEM) in soils of: A) different plant covers inside each site typologies and B) different site typologies and plant covers. Different letters indicate the statistically (One-way ANOVA) significant differences among four soils (MUP, GUP, MNR, GUP). The asterisks indicate the statistically significant differences between site typologies and between plant covers (Paired *t*-test).)

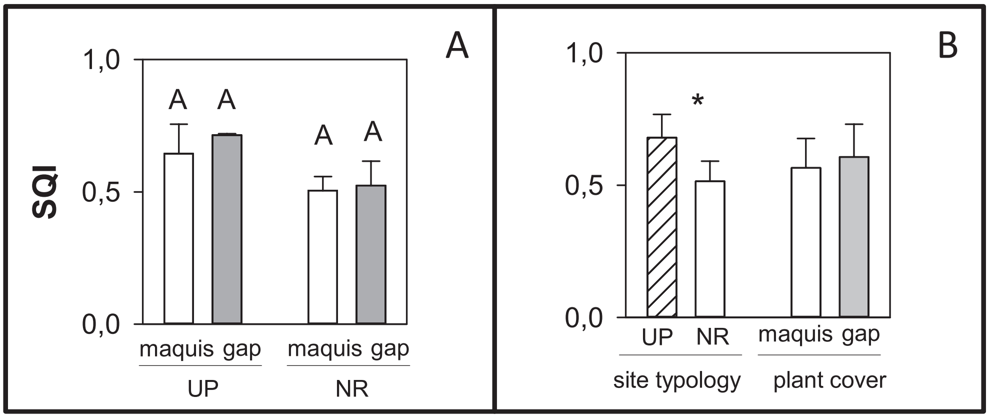

Fig. 5. Soil quality index of investigated soils – Mean values (± s. d.) of the soil quality index (SQI) calculated taking into account all the 15 soil parameters in soils of: A) different plant covers inside each site typologies and B) different site typologies and plant covers. Different letters indicate the statistically (One-way ANOVA) significant differences among four soils (MUP, GUP, MNR, GUP). The asterisks indicate the statistically significant differences between site typologies and between plant covers (Paired *t*-test).

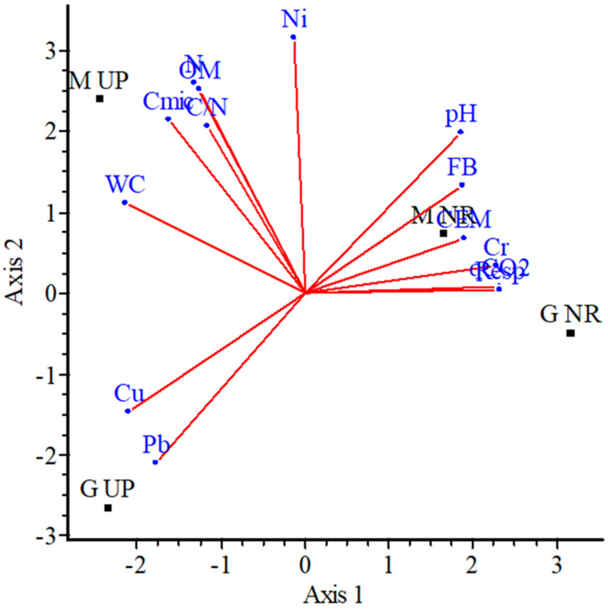

Fig. 6. Results of Principal Component Analysis – Biplot of the all investigated parameters :water content (WC), pH, organic matter (OM), N, C/N, Cr, Cu, Ni, Pb, microbial C (Cmic), fungal biomass (FB), microbial respiration (Resp), metabolic quotient (qCO_2), coefficient of endogenous mineralization (CEM) in the soils collected at the urban park (UP) and the natural reserve (NR) under different vegetation cover (maquis, M and gap, G).

SQIs did not show statistically differences between maquis and gap soil (Figs. 3B, 4B and 5B).

3.2. Relationships among soil chemical and biological characteristics

3.2.1. Principal component analysis

The first two axes of the principal component analysis accounted for more than 99% of the total variance. The biplot showed a clear separation of the soils in the PC space related to plant cover and site typology (Fig. 6). In fact, the axis 1 discriminated for site typology with urban park soils situated in the third and fourth quadrants and the natural reserve soils in the first and second ones (Fig. 6). Instead, the axis 2 discriminated for plant cover with gap soils situated in the second and third quadrants and the maquis soils in the first and fourth ones (Fig. 6).

Also the investigated soil characteristics clearly separated in the quadrants (Fig. 6). In fact, pH, fungal biomass, biological activities and Cr concentrations situated in the first quadrant, soil Cu and Pb concentrations in the third quadrant and all the others in the fourth one (Fig. 6).

3.2.2. Correlations inside each site typology (urban park and natural reserve)

In urban park, all the biological parameters were positively correlated to soil pH and N content (Table 2). In addition, the microbial biomass was also positively correlated to soil organic matter content (Table 2).

In natural reserve, soil respiration, qCO_2 and CEM were negatively correlated to Cu and Ni concentrations and water content (Table 2). In addition, qCO_2 was also negatively correlated to N and Cr contents, and C/N as well as respiration and CEM were negatively correlated to organic matter content (Table 2).

3.2.3. Correlations inside each plant cover (maquis and gap)

In soils under maquis, all the biological parameters were positively correlated to soil pH with the exception of C_{mic} and CEM that were negatively correlated to it (Table 2). Soil respiration and qCO_2 were negatively correlated to water content (Table 2), and, as the fungal biomass, they were also negatively correlated to OM content (Table 2). In addition, the fungal biomass and qCO_2 were negatively correlated to N content (Table 2). Numerous statistically significant correlations were found between microbial biomass and respiration to soil metal concentrations (Table 2).

In gap soils, respiration, qCO_2 and CEM were negatively correlated to water content and Cu concentrations (Table 2) and positively to organic matter; soil respiration was also positively correlated to Cr concentrations (Table 2); in addition fungal biomass was negatively correlated to N content (Table 2).

4. Discussion

The wide ranges of values observed for the investigated parameters suggest high heterogeneity of the soils that integrate both the pedogenetic weathering and the different plant covers. Anyway, the management practices would seem to play an important role in regulating soil characteristics inside the same soil typology, especially at the urban park. In fact, the PCA separated the soils under maquis and gap of grasses for the urban park but not for the natural reserve. The separation of the soils in three groups could depend on the fact that each one is mainly affected by certain soil characteristics. In fact, the gap soils inside the urban site would seem to be strongly affected by high Cu and Pb concentrations. These metals are widely recognized as markers of vehicular traffic emissions (De Silva et al., 2016) that are typical of the urban environment. Their statistically higher values in gap soils at the urban park could be due to the direct air dry or wet depositions that reach these soils (Maisto et al., 2004). In fact, soils covered by plants receive a minor amount of air particulate that is mainly intercepted by canopies (Petroff et al., 2008). The mean value of Pb (110 $\mu g\, g^{-1}$ d.w) in soils collected in gaps of the urban park, exceeding the threshold value reported by the Italian Law for urban soils (D. Lgs 152/2006),

Table 2

Spearman's correlation – Coefficient of Spearman's correlation performed between physico-chemical and biological parameters of soils collected at the urban park and the natural reserve under different vegetation covers (maquis and gap). The values that indicate statistically significant correlations are reported in bold.

	pH	WC	OM	N	C/N	Cr	Cu	Ni	Pb
Urban Park									
FB	**0.878**	0.771	0.600	**0.829**	0.600	0.657	−0.714	0.600	−0.657
C_{mic}	**0.878**	0.657	**0.886**	**0.943**	0.714	0.771	−0.771	0.829	−0.771
Resp	**0.878**	0.543	0.829	**0.943**	0.829	0.771	−0.600	0.714	−0.771
qCO_2	**0.891**	0.667	0.725	**0.986**	0.725	0.638	−0.754	0.754	−0.638
CEM	**0.891**	0.667	0.725	**0.986**	0.725	0.638	−0.754	0.754	−0.638
Natural Reserve									
FB	0.439	0.667	−0.0952	0.0476	0.405	0.429	**0.667**	0.143	0.333
C_{mic}	−0.171	0.476	0.405	0.500	0.452	0.452	0.0476	**0.643**	0.357
Resp	−0.415	−**0.905**	−**0.714**	−**0.667**	−0.595	**0.762**	−**0.905**	−**0.714**	−0.571
qCO_2	−0.195	−**0.786**	−0.643	−**0.762**	−**0.762**	−**0.786**	−**0.786**	−**0.881**	−0.643
CEM	−0.415	−**0.905**	−**0.714**	−0.667	−0.595	−**0.762**	−**0.905**	−**0.714**	−0.571
Maquis									
FB	**0.927**	−0.679	−**0.786**	−**0.857**	−0.536	**0.857**	−0.536	−**0.786**	−0.714
C_{mic}	−**0.852**	0.643	0.714	**0.821**	0.500	−0.643	0.714	**0.821**	**0.786**
Resp	**0.741**	−**0.964**	−**0.929**	−0.607	−0.393	**0.750**	−**0.821**	−**0.821**	−0.571
qCO_2	**0.927**	−**0.786**	−**0.821**	−**0.750**	−**0.750**	0.714	−0.643	−**0.964**	−0.679
CEM	−**0.259**	−0.107	−0.107	0.429	0.000	−0.143	0.107	0.143	0.607
Gap									
FB	0.599	−0.429	0.429	−**0.750**	0.607	0.357	−0.607	0.393	−0.571
C_{mic}	0.0187	−0.286	0.286	0.393	0.035	0.107	−0.286	0.250	0.143
Resp	0.617	−**0.893**	**0.893**	−0.643	−0.500	**0.750**	−**0.786**	0.643	−0.643
qCO_2	0.623	−**0.829**	**0.829**	−0.631	−0.577	0.667	−**0.883**	0.667	−0.559
CEM	0.623	−**0.829**	**0.829**	−0.631	−0.577	0.667	−**0.883**	0.667	−0.559

supports the hypothesis that this element polluted those soils. Anyway, it cannot be excluded input of Cu and Pb in gap soils of the urban park deriving by the Fusaro Lagoon. These inputs cannot reach the soils covered by maquis that instead are located at the opposite size. The Lagoon has been the recipient of domestic, agricultural and industrial discharges, that have metal polluted, over the time (from 1960 to 1990), the Lagoon and, in turn, the soils (Gimeno-García et al., 1996). In particular, a monitoring campaign carried out in 2000 highlighted that Pb content in the water of the Lagoon exceeded the threshold value fixed by the law (De Pippo et al., 2004). The higher mean values of Cu and Pb content in soils at the urban park would not seem to negatively affect the amount of microbial biomass, likely due to the high amount of organic matter that, limiting metal bioavailability by adsorption or formation of stable complexes with humic substances, can mitigate the contamination degree (Liu et al., 2009). Besides, likely the scarce Cu and Pb availability can also be due to the alkaline pH values of these soils (Salvagio Manta et al., 2002). Finally, Cu and Pb could be present in insoluble forms not dangerous for microbial community (Wuana and Okieimen, 2011; Morselli et al., 2003) or tolerance mechanisms can have been developed by the microbial community (Giller et al., 1998). On the whole, the microbial biomass of soils covered by maquis in the urban park would seem to be enhanced by high organic matter and water contents, as widely reported (Liu et al., 2016; González-Quiñones et al., 2009; Carter, 2002). Instead, the soils of the natural reserve were characterized by high amount of Cr that was also higher in the soils covered by maquis than in gaps. In these soils, the fungal biomass was abundant, likely favoured by pH conditions and by the presence of complex organic matter. Previous studies performed on soils of the investigated natural reserve report high spontaneous or prescribed fire frequency at different intensities (De Marco et al., 2005; D'Ascoli et al., 2005; Fierro et al., 2007; Rutigliano et al., 2007) that could cause a decrease of abundance of soil microorganisms. On the other hand, the increase in qCO_2 and CEM could indicate a reduced microbial efficiency in the C resource utilisation (Wardle and Ghani 1995; Bauhus et al., 1998). This result also explains the numerous found negative correlations between microbial activity and metal contents, in the soils of the natural reserve. Other effect of fires was the statistically lower organic matter and N contents in soils of the natural reserve than the urban park to prevent the accumulation of large amount of litter on the surface soil (Gregorich et al., 1998).

Anyway, beyond the management practices also the pedogenetic derivation played an important role in affecting the soil biological characteristics. In fact, on the whole, in the Arenosols of the natural reserve higher fungal biomass and microbial activity, measured by respiration, qCO_2 and CEM (stress indicators), but lower microbial biomass were observed as compared to the Andosols of the urban park. The Arenosols had a sandy loam texture causing a scarce water availability that negatively affected the bacterial biomass and microbial activities. This hypothesis can be corroborated by the higher fungal biomass that are recognized as more stress tolerant (Rutigliano et al., 2007).

In the investigated sites, the quantity and quality of soil organic matter appear to play an important role on microbial biomass and activity. The results agree with De Marco et al. (2008) who report that grasses are more decomposable than shrub leaves as the organic matter of gap soils, exhibiting higher mineralization coefficients, would seem to be less stable than maquis soil. A comparative study about the stability of organic carbon pools in several Mediterranean soils highlighted higher values for gap soils (Rutigliano et al., 2004). Also, the lower values of C/N in gap soils, likely due to the presence of herbaceous species, support the previous hypothesis; in fact, short-lived annual plant have rapidly degradable species, whereas the organic matter content in the holm oak ecotypes are less labile and have lower quality and then slow mineralization (Romanyá et al., 2001; Rodríguez et al., 2017).

The synthetic approach deriving from the use of the SQI pointed out that the pedogenetic derivation together with the management practices were the main drivers to define the soil quality.

5. Conclusions

The higher amount of organic matter observed on soils under maquis inside the urban park enhanced the microbial biomass and activities as compared to those observed under gap. These differences did not occur inside the natural reserve.

The metal accumulation on soil under gap was conspicuous only for the urban park, where the high concentration of Cu and Pb inhibited the microbial biomass and activity that were not exclusively affected by litter quality. Finally, soil quality would seem strongly to be affected by the pedogenetic derivation together with the management practices more than plant covers.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.apsoil.2018.05.001.

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