Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XV, 2026
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

EFFECT OF SOIL TYPE AND MANAGEMENT ON POTENTIALLY TOXIC ELEMENTS (As, Cu, Zn) IN SOILS OF OLIVE GROVES IN DALMATIA, CROATIA

Aleksandra BENSA, Nikolina JURKOVIĆ BALOG, Aleksandra PERČIN

University of Zagreb Faculty of Agriculture, Svetošimunska cesta 25 10000, Zagreb, Croatia

Corresponding author email: abensa@agr.hr

Abstract

The objectives of the study were to (i) establish and compare As, Cu, and Zn concentrations in two contrasting soil types under different management and (ii) assess soil pollution of the study area by the mentioned potentially toxic elements. A 40 composite topsoil samples were collected in Middle Dalmatia, Croatia, out of which 20 were from Terra rossa and 20 from Regosols. On each soil type, 10 samples were taken from intensive olive groves (IOG) and 10 from traditional low-input olive groves (TOG). The total concentrations of As, Cu, and Zn were obtained using the pXRF method. The mean As, Cu, and Zn concentrations in Terra rossa were 21.9, 112.7, and 124.5 mg/kg, respectively. In Regosols, mean As, Cu, and Zn concentrations were 6.3, 55.0, and 63.6 mg/kg, respectively. Significantly higher ($p<0.05$) As, Cu, and Zn concentrations were determined in Terra rossa compared to Regosols. Significantly higher ($p<0.05$) Cu concentrations were found in IOG compared to TOG (124.5 and 43.2 mg/kg, respectively). Terra rossa under IOG was polluted with Cu, while the other soils were not. The studied soils were not polluted with As and Zn.

Key words*: olive groves, potentially toxic elements, Regosol, soil pollution, Terra rossa.*

INTRODUCTION

Potentially toxic elements (PTE) represent a threat to soil fertility, quality, health, and security, as recognized in various studies e.g. Kibblewhite et al. (2007), Hou et al. (2020). The PTE distribution in soils is governed by natural conditions and anthropogenic inputs. Among the natural reasons for PTE variability, soil properties, parent material, climate, and geomorphology stand out (Mottese et al., 2020). The most important areas of olive production in Dalmatia, Croatia, are widespread on soils derived from limestones (Terra rossa and Calcocambisols) and flysch deposits (Regosols). These are two contrasting parent materials on which soils with different properties develop. Soils developed over limestones contain elevated levels of PTE (Kabata-Pendias & Pendias, 2001; Halamić & Miko, 2009). Furthermore, high clay content and abundance of Fe and Al oxides contribute to strong adsorption and retention of PTE in the top-soil horizon of Terra rossa (Miloš & Bensa, 2021). PTE concentrations are typically lower in soils formed on flysch sediments, though this varies depending on the nature and sedimentation processes of the rock-derived material (Lovrenčić Mikelić et al., 2013). Also, since these soils contain lower clay and humus content, they retain less PTE. Anthropogenic inputs of PTE in soils involve different types of emissions from the industrial areas, as well as from agricultural activities (Zhang et al., 2019). Fertilizers and plant production products are the primary agricultural sources of PTE in agricultural soils (Pathak et al., 2002; Wyszkowski & Brodowska, 2020). Since the late 19th century, viticulture in Europe extensively used Cu-based fungicides (Komarek et al., 2010). Furthermore, nitrogen and phosphate fertilizers can be significant sources of As and Zn in cultivated soils (Kabata Pendias & Mukherjee, 2007; Sachdeva et al., 2025). Given its impact on food safety, PTE pollution in agricultural soils is especially concerning (Antoniadis et al., 2017; Edelstein & Ben-Hur, 2018) considering negative consequences for all agroecosystems (Kibblewhite et al., 2007). Elevated Cu concentrations in soil diminish microbial growth and biomass (Díaz Raviña et al., 2007) as well as development of plant roots (Ambrosini et al., 2015).

Increased concentrations of Cu are predominantly reported for soils of permanent crops, particularly vineyards (Komarek et al., 2010) and olive groves (Avramidis et al., 2019). Pollution of agricultural soils by As (Jimenez Balesta et al., 2023) and Zn (Fernández-Calviño et al., 2012) was also stated in earlier literature findings. Excessive concentrations of arsenic can induce aberrant plant growth and disturb ecological equilibrium (Kabata-Pendias & Pendias, 2001). Soil organisms such as earthworms (Lev et al., 2010) and bacterial communities (Pan et al., 2020) are negatively affected by high Zn concentrations. We hypothesized that Terra rossa and Regosols differ in PTE concentrations, and that soil management in olive groves affects PTE concentrations in soil. The objectives of this study were (i) to establish and compare As, Cu, and Zn concentrations in two contrasting soil types under different management and (ii) to assess soil pollution of the study area by the mentioned PTE.

MATERIALS AND METHODS

The study was conducted in Middle Dalmatia, Croatia (Figure 1A), distinguished by a Mediterranean type of climate (Csa), commonly referred to as an "olive climate" (Filipčić, 1998). The western part of the study area is built up of Cretaceous platy and massive limestones with pronounced stratification, while the eastern part consists of Eocene flysch deposits (Figure 1B). The limestones are of Senonian and Turonian age and are characterized by dominant biocalcarenites. Flysch deposits are predominantly classified as calcarenites, breccia-conglomerates, calcirudites, and marls (Marinčić et al., 1967).

This area is characterized by typical karst geomorphology, with the steeper slopes in the northern part and the gentler ones in the southern part. Therefore, the northern part of the area is subject to erosion processes and characterized by shallow soils, while in the southern parts, colluvial processes are present and deeper soils dominate. The dominant soil types on limestones are Terra rossa, while Regosols are developed on Flysch deposits (Figure 1C; Čolak & Martinović, 1974). Terra rossa is a Mediterranean soil distinguished by its red colour, heavy texture and inconstant depth. Regosols on flysch deposits are calcareous silty soils highly susceptible to erosion and characterized by alkaline reaction and low humus content. The correlation analogs of Terra rossa and Regosol are Leptic Chromic Cambisols (Clayic) and Regosols (Calcaric, Siltic/Loamic), respectively (IUSS Working Group of WRB, 2015). This area is under long-term anthropogenic influence, which is evident in the numerous terraces and dry-wall enclosures (Miloš & Bensa, 2021). Olive growing in the study area is characterized by dry farming, encompassing traditional low-input (TOG) and intensified olive growing systems (IOG). The traditional low-input growing system is characterized by periodic soil cultivation, fertilization with low doses of fertilizers, and rare application of pesticides. In a more intensive olive growing system, fertilization and plant protection are more often applied, including larger quantities of fertilizers and pesticides.

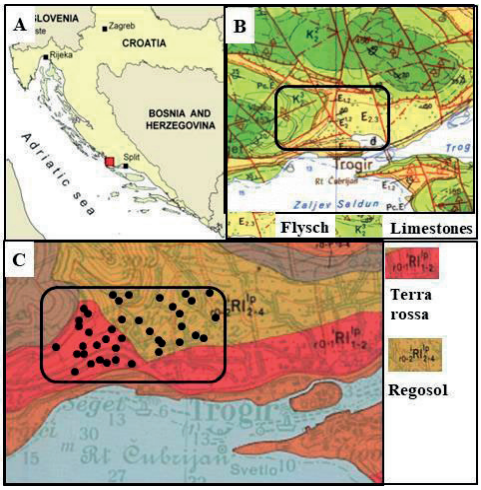


Figure 1. Location of the study area (A), Basic geological map of Croatia at scale 1:100 000 section Split (Marinčić et al., 1967) with indicated study area (B) and Basic soil map of Croatia at scale 1:50 000 section Šibenik 4 (Čolak & Martinović, 1974) with indicated study area and sampling locations (C)

A 40 composite topsoil samples (0-20 cm) were taken in currently productive private olive groves in the study area (Figure 1C). The composite soil samples consisted of 3 sub-samples taken at a distance of 1 m in a cross

arrangement. The 20 samples were taken from Terra rossa and 20 samples from Regosols. On each soil type, 10 samples were taken from traditional low-input olive groves (TOG) and 10 from intensive ones (IOG).

The disturbed soil samples were prepared according to ISO 11464:2006. Soil particle size distribution was analyzed by the pipette method using wet sieving and sedimentation. Soil pH in H_2O and KCl (c=1M) was measured after ISO 10390:2005. A modified volumetric method (ISO 10693:1995) was used for determination of $CaCO_3$ content. Humus content was dteremined using the Tjurin method (JDPZ, 1966) and subsequently converted to soil organic carbon (SOC) by dividing by the Van Bemmelen factor (1.724). The P_2O_5 and K_2O concentrations were determined using lactate-acetate as the extraction solution (Egner et al., 1960).

The total concentrations of As, Cu, and Zn were determined using the Vanta handheld XRF analyser C Series (Olympus, Waltham, MA, USA, 2019) according to the loose powder method (Takahashi, 2015). The certified (SRM 2711) and reference soil samples (ISE 989) were used to control accuracy and precision of the analyses. The results of the analyses were acceptable (accuracy: RPD < 5% and recovery 95%-105%; precision: RSD < 5%).

The Ordinance on the protection of agricultural land from pollution (Official Gazette 71/19) was used to evaluate the pollution of the studied soils. When agricultural land contained more PTE than the maximum permissible concentrations (MPC) (mg/kg), it was considered polluted. The MPC of PTE in agricultural soils is prescribed considering pH_{KCl} values (Table 1).

Table 1. Maximum permissible concentrations (MPC) (mg/kg) of selected PTE in agricultural soils in Croatia (Official Gazette 71/19)

	pH_{KCl}		
Element	< 5	5-6	>6
As	15	25	30
Cu	60	90	120
Zn	60	150	200

Descriptive statistics (minimum, maximum, mean, coefficient of variation, and skewness) were used to process obtained data of basic chemical soil properties and PTE concentrations. A two-way analysis of variance (ANOVA) was carried out for statistical comparison of analysed PTE concentrations. All statistical analysis was performed using MS Excel.

RESULTS AND DISCUSSIONS

Basic soil properties govern adsorption processes in soils. Adsorption and retention of PTE in soils dominantly depend on soil texture, especially clay minerals (Bradl, 2004; Uddin, 2017; Huang et al., 2020), organic matter content (Kabata-Pendias & Pendias, 2001; Wan et al., 2024), and pH values (Elzahabi & Yong, 2001; Romić et al., 2014).

Particle size analysis has shown differences between the studied soil types (Table 2).

Table 2. Descriptive statistic for particle size distribution of Terra rossa and Regosols

Soil type	Min.	Max.	Mean	CV	Skew
	Coarse sand (2.0-0.2 mm)				
Terra rossa	0.1	0.7	0.3	80.7	1.08
Regosol	1.9	12.3	5.7	55.7	1.14
	Fine sand (0.2-0.063 mm)				
Terra rossa	1.9	3.1	2.6	14.3	0.09
Regosol	4.8	15.7	9.2	33.4	0.66
	Coarse silt (0.063-0.02 mm)				
Terra rossa	15.9	22.3	19.6	9.5	-0.43
Regosol	14.3	23.8	19.2	13.89	-0.18
	Fine silt (0.02-0.002 mm)				
Terra rossa	35.6	50.2	43.4	8.1	-0.38
Regosol	31.1	51.1	42.4	13.8	-0.42
	Clay (< 0.002 mm)				
Terra rossa	27.6	46.0	34.2	14.0	1.47
Regosol	18.2	29.1	23.5	14.6	0.04

Min. - minimum; Max. - maximum; CV - coefficient of variation; Skew - skewness

Terra rossa soils are composed predominantly of fine silt (mean value 43.4%), followed by clay particles (mean value 34.2%). Sand particles (coarse and fine) form less than 3% on average. In Regosols, fine silt particles also dominate (mean value 42.4%). However, a lower content of clay particles (mean value 23.5%) was observed in comparison to Terra rossa soils. Furthermore, a higher content of sand was recorded in Regosols in comparison to Terra rossa soils (Table 2).

Terra rossa has mainly a silty clayey loamy texture, while Regosols are mainly silty loams, but silty clayey loams also occur (Figure 2). The

determined texture of the studied soils is consistent with literature findings for Terra rossa (Bellanca et al., 1996; Vingiani et al., 2018; Miloš & Bensa, 2021) and soils on flysch deposits (Bogunović et al., 2009; Miloš & Bensa, 2019; Bensa & Jurković Balog, 2023).

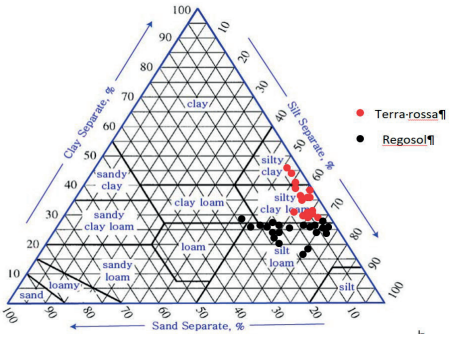


Figure 2. Display of soil samples on texture triangle (FAO/UNESCO, 1990)

Terra rossa soils under both management types have a slightly acidic to neutral reaction and low $CaCO_3$ content (Table 3).

Table 3. Descriptive statistic for basic chemical properties of Terra rossa soils under traditional (TOG) and intensive olive groves (IOG)

Management type	Soil property	Min.	Max.	Mean	CV	Skew
TOG	pH (KCl)	6.07	6.90	6.61	4.33	-1.10
	pH (H2O)	7.11	7.78	7.43	3.22	0.02
	$CaCO_3$	1.50	3.00	1.94	23.1	1.31
	SOC	2.52	4.45	3.44	17.4	0.08
	P_2O_5	0.59	5.85	1.98	78.3	1.73
	K_2O	25.5	57.3	36.4	30.2	0.72
IOG	pH (KCl)	5.62	7.01	6.53	6.46	-1.07
	pH (H2O)	6.51	7.77	7.25	5.18	-0.47
	$CaCO_3$	1.90	4.34	2.88	24.5	0.75
	SOC	3.31	7.20	4.59	23.5	1.38
	P_2O_5	21.8	49.4	34.4	26.1	0.09
	K_2O	71.3	252	111.6	43.0	2.86

Min. - minimum; Max. - maximum; CV - coefficient of variation; Skew - skewness

The SOC content in Terra rossa under TOG was in the range of 2.52-4.45% with symmetric data distribution (skew 0.08), while Terra rossa under IOG had higher SOC content (3.31-7.20%), with asymmetric data distribution (skew 1.38). This suggests various organic fertilizations in Terra rossa soils under IOG, as well as different soil tillage systems. Several authors have noted an increase in SOC content after the application of organic amendments (Perez Lomas et al., 2010; Aranda et al., 2015; Mekki et al., 2017; Mbarek et al., 2020). Conversely, soil tillage promotes mineralization and lowers SOC content (Haddaway et al., 2017; Hashimi et al., 2022). In Terra rossa soils under TOG a lower P_2O_5 concentrations (0.59-5.85 mg/100 g of soil) were established, compared to soils under IOG (21.8-49.4 mg/100 g of soil). The supply of K_2O was rich and very rich in soils under both management types, although Terra rossa soils under IOG contained much higher K_2O concentrations compared to TOG (mean values 111.6 and 36.4 mg/100 g of soil, respectively) (Table 3).

The Regosols under both management types were highly calcareous and had an alkaline soil reaction with minor differences (mean $pH_{(KCl)}$ values of 7.28 and 7.41, respectively) (Table 4).

Table 4. Descriptive statistic for basic chemical properties of Regosol under traditional (TOG) and intensive olive groves (IOG)

Management type	Soil property	Min.	Max.	Mean	CV	Skew
TOG	pH (KCl)	7.19	7.40	7.28	0.90	0.62
	pH (H2O)	7.63	7.98	7.88	1.29	-1.60
	$CaCO_3$	15.0	23.0	18.3	13.9	0.14
	SOC	1.13	1.97	1.46	17.0	0.73
	P_2O_5	0.29	1.96	1.09	47.7	0.30
	K_2O	9.80	23.0	18.3	21.3	-0.87
IOG	pH (KCl)	7.23	7.58	7.41	1.77	-0.07
	pH (H2O)	7.73	8.47	8.26	2.68	-1.71
	$CaCO_3$	14.3	25.0	19.0	16.7	0.19
	SOC	1.39	2.12	1.79	12.8	-0.07
	P_2O_5	4.42	13.0	7.57	38.6	0.57
	K_2O	27.5	66.0	40.4	25.7	1.54

Min. - minimum; Max. - maximum; CV - coefficient of variation; Skew - skewness

The SOC content was lower in Regosols under TOG compared to IOG (mean values 1.46% and 1.79%, respectively). The Regosols under TOG were poorly supplied with P_2O_5, while soils under IOG were moderately supplied (mean values 1.09 and 7.57 mg/100 g of soil, respectively). The K_2O concentrations were also lower in Regosols under TOG than in IOG (mean values 18.3 and 40.4 mg/100 g of soil, respectively) (Table 4).

The obtained results correspond to earlier studies of Terra rossa (Durn, 1999; Vingiani et al., 2018; Miloš & Bensa, 2021) and Regosols on flysch deposits (Bogunović et al., 1999; Miloš & Bensa, 2019). Higher concentrations of P_2O_5, K_2O and SOC in soils under IOG, in both soil types, confirmed application of mineral and

organic fertilizers in much higher doses compared to TOG.

Descriptive statistics for PTE (As, Cu, and Zn) in the studied soils are presented in Table 5. A two-way ANOVA has shown the effect of soil type, soil management, and their interaction on PTE concentrations in the studied soils (Table 6).

Table 5. Descriptive statistic for As, Cu and Zn concentrations in Terra rossa and Regosol under traditional (TOG) and intensive olive groves (IOG)

ST	MT	Element	Min.	Max.	Mean	CV	Skew
Terra rossa	TOG	As	21.7	26.6	23.4	6.6	0.73
		Cu	33.9	85.7	48.9	30.9	1.74
		Zn	114.0	135.5	124.6	5.7	-0.02
	IOG	As	16.1	24.1	20.3	14.0	-0.17
		Cu	68.7	290.8	176.4	45.2	0.11
		Zn	42.5	165.0	124.5	33.6	-1.56
Regosols	TOG	As	4.50	6.52	5.58	10.8	-0.18
		Cu	19.8	63.5	37.4	40.5	0.48
		Zn	32.3	66.7	52.7	24.5	-0.67
	IOG	As	5.38	8.50	7.03	15.3	-0.21
		Cu	43.4	107.1	72.6	31.4	0.15
		Zn	55.7	95.7	74.5	16.5	0.19

ST - soil type; MT - management type; Min. - minimum; Max. - maximum; CV - coefficient of variation; Skew - skewness

Soil type and the interaction effect of soil type and management significantly influenced As concentrations in the studied soils, while soil management had no significant impact (Table 6). Significantly higher As concentrations (p<0.05) were detected in Terra rossa soils in comparison to Regosols (16.1-26.6 and 4.50-8.50 mg/kg, respectively) (Table 5).

The As concentrations in Terra rossa soils and Regosols (16.1-26.6 mg/kg and 4.50-8.50 mg/kg, respectively) are analogous to findings from the Geochemical Atlas of Croatia (Halamić & Miko, 2009) which indicated As level over 25 mg/kg in soils derived from limestones and below 12 mg/kg in soils on flysch deposits. Peh et al. (2003) also reported higher As concentrations in Terra rossa soils than in flysch-derived soils in Istria (mean values 20.31 and 7.83 mg/kg, respectively).

The As concentrations in Terra rossa soils in current study are also in accordance with previous findings for a broader study area in Dalmatia (Miko et al., 2001; Bensa et al., 2025). Although As concentrations in soils under different land management types did not differ significantly (Table 6), Regosols under IOG contained higher As concentrations than Regosols under TOG (mean values 7.03 and 5.58 mg/kg, respectively) (Table 5). The increased level of As in agricultural soils may be attributed to the application of mineral fertilizers as emphasized by Kabata Pendias & Mukherjee (2007).

Table 6. Summary statistics of the two-way ANOVA for PTE concentrations in the studied soils

Source of variation	SS	df	MS	F_{exp}	p value	F_{crit}
As						
Soil type	**2417**	**1**	**2417**	**723.6**	**1.97E-25**	**4.11**
Soil management	6.66	1	6.66	1.99	0.16666	4.11
Interaction	**51.26**	**1**	**51.26**	**15.35**	**0.000383**	**4.11**
Within	120.26	36	3.34			
Total	2595.4	39				
Cu						
Soil type	**33287**	**1**	**33287**	**16.33**	**0.000267**	**4.11**
Soil management	**66183.7**	**1**	**66183.7**	**32.47**	**1.76E-06**	**4.11**
Interaction	**21258.3**	**1**	**21258**	**40.43**	**0.002648**	**4.11**
Within	73376.8	36	2038.2			
Total	194105.9	39				
Zn						
Soil type	**37161**	**1**	**37161**	**63.36**	**1.89E-09**	**4.11**
Soil management	1171.5	1	1171.5	1.997	0.166176	4.11
Interaction	1204.1	1	1204.1	2.053	0.160537	4.11
Within	21115.3	36	586.5			
Total	60652.1	39				

SS - the sum of squares, df - degrees of freedom, MS - mean square

The Cu concentrations in Terra rossa soils and Regosol displayed wide ranges (33.9-290.8 and 19.8-107.1 mg/kg, respectively), (Table 5). Data distributions for Cu concentrations in Regosols under both management types, as well as in Terra rossa soils under IOG were approximately symmetric (skew<0.5). However, Terra rossa soils under TOG revealed positively skewed data distribution (skew 1.74), (Table 5). This can be attributed to the fact that some low-input olive groves were planted on former vineyard soils with accumulated Cu (Miloš & Bensa, 2021), although recent use of Cu-based fungicides is rare or completely absent on these soils. Significantly higher Cu concentrations (p<0.05) were established in Terra rossa soils compared to Regosols, as well as in soils under IOG in comparison to TOG (Tables 5 and 6). Significantly higher Cu concentrations in Terra rossa soils than in Regosol can be linked to higher SOC and clay content (Tables 2 and 3). Soil colloids (organic matter and clay minerals) adsorb copper strongly (Parat et al., 2002). Organically complex Cu is particularly firmly bound, inhibiting its mobilization and leading to

Cu accumulation in topsoil (Cerqueira et al., 2011). Additionally, amorphous and crystalline Fe and Al oxides readily adsorb Cu (Romić et al., 2014), leading to increased Cu concentrations in Terra rossa soils. Significantly higher Cu concentrations in soils under IOG compared to TOG can be ascribed to the increased application of Cu-based fungicides. Nevertheless, the Cu concentrations in the current study are lower compared to those reported by Avramidis et al. (2019) for intensive olive groves in Greece (mean value 286.2 mg/kg).

Soil type significantly influenced Zn concentrations in the studied soils, while soil management and the interaction effect of soil type and management did not have a statistically significant impact (Table 6). Significantly higher Zn concentrations (p<0.05) were determined in Terra rossa soil than in Regosol (42.5-165.0 and 32.3-95.7 mg/kg, respectively), (Table 5). The obtained results are in line with previous findings for the studied soil types. Peh et al. (2003) also stated lower Zn concentrations in flysch derived soils in comparison to soils on limestones (45-130 and 59-186 mg/kg, respectively).

A similar range of Zn concentrations in a broader study area in Dalmatia was reported for the studied soil types. Miloš & Bensa (2019) established a range of 24.1-105.9 mg/kg in anthropogenic terraced soils on flysch deposits in the Kaštela bay coastal area. A study of former vineyard soils on Terra rossa in Middle Dalmatia under natural vegetation and olive groves revealed Zn mean values similar to the current study (118.1 and 138.0 mg/kg, respectively) (Bensa et al., 2025).

Soil pollution by PTE

All studied soils exhibited As concentrations below the maximum permissible concentrations (MPC) of 30 mg/kg (Official Gazette 71/19 (Figure 3). Obtained results are comparable to previous studies of As concentrations in a broader study area in Croatia (Lovrenčić Mikelić et al., 2013; Bensa et al., 2025) which similarly found no evidence of arsenic pollution of agricultural soils. Grattacaso et al. (2025) documented an As concentration range of 5.55-14.6 mg/kg in olive grove soils derived from various parent materials in Italy, which were not contaminated with arsenic.

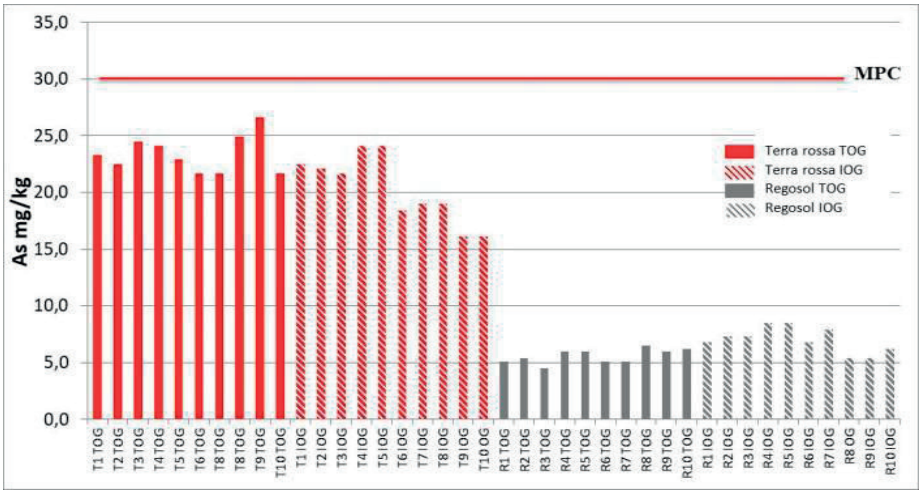


Figure 3. As concentrations in studied soils and MPC (Official Gazette 71/19)

The majority of the studied Terra rossa soils under IOG (70%) exhibited pollution by Cu, but the remaining portion (30%), along with Terra rossa soils under TOG, showed no pollution (Figure 4). The Cu concentrations in Regosols under both management types were below the MPC of 120 mg/kg (Official Gazette 71/19) (Figure 4).

Pollution of olive grove soils by Cu was reported in many studies. Avramidis et al. (2019) reported a range of 58.4 -671.6 mg/kg in various soils of Aetoliko lagoon in Greece developed

over limestones and clastic sediments, out of which 88% of samples were polluted by Cu. Similarly, Bensa et al. (2025) established pollution by Cu in 90% of the samples from Terra rossa soils under olive groves planted on former vineyard soils. However, Miloš & Bensa (2021) reported only 10% of Cu-polluted Terra rossa soils under olive groves in Middle Dalmatia. In olive groves on terraced soils on flysch deposits, Miloš & Bensa (2019) established much lower Cu concentrations (mean value 38.1 mg/kg) far below MPC, that are comparable to the current study.

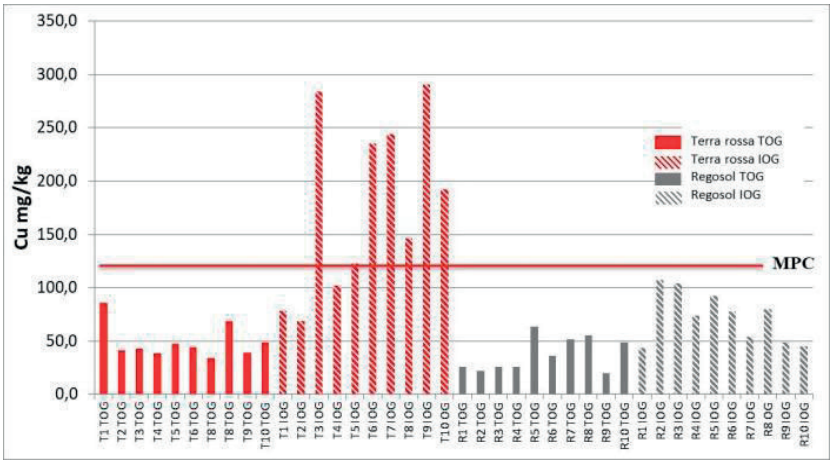


Figure 4. Cu concentrations in studied soils and MPC (Official Gazette 71/19)

The Zn concentrations in Terra rossa soils and Regosol under both management types were below the MPC of 200 mg/kg (Official Gazette 71/19) (Figure 5). Obtained results are in line with previous studies on broader study areas for Terra rosa soils (Miko et al., 2001, Bensa et al., 2025) and Regosols (Miloš & Bensa, 2019). However, previous study of olive grove soils (Doğan & Gülserr, 2020) pointed out higher Zn concentrations, and the authors stated that studied soils can be considered polluted. Additionally, Lovrenčić Mikelić et al. (2013) found elevated Zn concentrations in agricultural soils of the Kaštela Bay coastal area in Dalmatia that may be considered polluted.

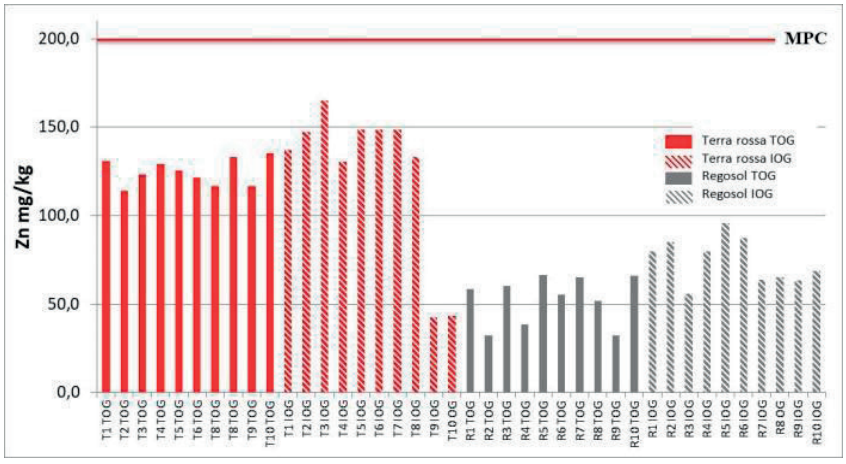


Figure 5. Zn concentrations in studied soils and MPC (Official Gazette 71/19)

CONCLUSIONS

A study of PTE concentrations in Terra rossa soils and Regosols under traditional low-input and intensive olive groves showed significantly higher As, Cu, and Zn concentrations in Terra rossa soils compared to the Regosols. Furthermore, significantly higher Cu concentrations were found in soils under intensive olive groves than in soils under traditional low-input management. The soil management type did not significantly influence As and Zn concentrations. According to Croatian legislation (Official Gazette 71/19), only Terra rossa soils under intensive olive groves were polluted with Cu, while other studied soils were not polluted with Cu. Likewise, the studied soils were not polluted by As and Zn. The obtained results indicate the need for further, more detailed study on copper in olive grove soils in Dalmatia, especially on Terra rossa soils.

REFERENCES

Ambrosini, V.G., Rosa, D.J. Prado, J.P.C., Borghezan, M., Melo, G.W.B., Fonsêca de Sousa Soares, C.R., Comin, J.J., Simao, D.G., & Brunetto, G. (2015). Reduction of copper phytotoxicity by liming: A study of the root anatomy of young vines (*Vitis labrusca* L.). *Plant physiology and biochemistry,* 96. 270-280.

Antoniadis, V., Shaheen, S.M., Boersch, J., Frohne, T., Du Laing, G., & Rinklebe, J. (2017). Bioavailability and risk assessment of potentially toxic elements in garden edible vegetables and soils around a highly contaminated former mining area in Germany. *Journal of Environmental Management*, 186(2). 192-200.

Aranda, V., Macci, C., Peruzzi, E., & Masciandaro, G. (2015). Biochemical activity and chemical-structural properties of soil organic matter after 17 years of amendments with olive-mill pomace co-compost. *Journal of Environmental Management*, 147. 278-285.

Avramidis, P., Barouchas, P., Dünwald, T., Unkel, I., & Panagiotaras, D. (2019). The Influence of Olive Orchards Copper-Based Fungicide Use, in Soils and Sediments - The Case of Aetoliko (Etoliko) Lagoon Western Greece. *Geosciences,* 9(6). e267.

Bellanca, A., Hauser, S., Neri, R., & Palumbo, B. (1996). Mineralogy and geochemistry of Terra Rossa soils, western Sicily: insights into heavy metal fractionation and mobility. *Science of The Total Environment*, 193(1). 57–67.

Bensa, A., & Jurković Balog, N. (2023). Humus quality of anthropogenic soils from flysch deposits. Case study: Kaštela bay, Croatia. In D. Kovačević (Ed.), *Book of proceedings XIV International Scientific Agriculture Symposium "Agrosym 2023"* (pp. 877-883). Jahorina, Bosnia and Herzegovina: Faculty of Agriculture University of East Sarajevo

Bensa, A., Jurković Balog, N., Matan, K., & Perčin, A. (2025). Potentially toxic elements (As, Cu, Pb and Zn) in former vineyard soils under olive groves and natural vegetation. *Journal of Central European Agriculture,* 26(3). 772-784.

Bogunović, M., Bensa, A., Husnjak, S., & Miloš, B. (2009). Suitability of Dalmatian soils for olive tree cultivation. *Agronomski glasnik*, 5-6. 367-404.

Bradl, H.B. (2004) Adsorption of heavy metal ions on soils and soil constituents. *Journal of Colloid and Interface Science*, 277(1). 1-18.

Cerqueira, B., Covelo, E.F., Andrade, L., & Vega F.A. (2011). The influence of soil properties on the individual and competitive sorption and desorption of Cu and Cd. *Geoderma*, 162(1-2). 20-26.

Čolak, A., & Martinović, J. (1974). *Basic soil map of Croatia 1: 50 000 section Šibenik 4*. Croatia, Split: Institute for Adriatic Crops and Karst Reclamation

Díaz-Raviña, M., Calvo de Anta, R., & Bååth, E. (2007). Tolerance (PICT) of the bacterial communities to copper in vineyard soils from Spain. *Journal of Environmental Quality,* 36(6). 1760-1764.

Doğan, B., & Gülser, C. (2020). Soil quality assessment for olive groves areas of Menderes district, Izmir-Turkey. *Eurasian Journal of Soil Science,* 9(4). 298-305.

Durn, G., Ottner, F., & Slovenec, D. (1999). Mineralogical and geochemical indicators of the polygenetic nature of terra rossa in Istria, Croatia. *Geoderma,* 91(1-2). 125-150.

Edelstein, M., & Ben-Hur, M. (2018). Heavy metals and metalloids: Sources, risks and strategies to reduce their accumulation in horticultural crops. *Scientia Horticulturae*, 234. 431-444.

Egner, H., Riehm, H., & Domingo, W.R. (1960). Untersuchungen uber die chemische Bodenanalyse als Grundlage fur die Beurteilung des Nahrstoffzustandes der Boden, II: Chemische Extractionsmetoden zu Phosphorund Kaliumbestimmung. *Kungliga Lantbrukshugskolans Annaler,* 26. 199-215.

FAO/UNESCO (1990). *Guidelines for soil description*. Rome, Italy: FAO/UNESCO

Elzahabi, M., & Yong, R.N. (2001). pH influence on sorption characteristics of heavy metal in the vadose zone. *Engineering Geology,* 60(1-4). 61-68.

Fernández-Calviño, D., Pateiro-Moure, M., Nóvoa-Muñoz, J.C., Garrido-Rodríguez, B., & Arias – Estévez, M. (2012). Zinc distribution and acid-base mobilisation in vineyard soils and sediments. *Science of the Total Environment*, 414. 470-479.

Filipčić, A. (1998). Climatic regionalization of Croatia according to W. Köppen for the standard period 1961–1990 in relation to the period 1931–1960. *Acta Geographica Croatica*, 34. 1–15.

Grattacaso, M., Canali, G., Vannini, A., Protano,G., Nannoni, F., De Lucia, V., Di Lella, L.A., Biagiotti, S., & Loppi, S. (2025). Health and ecological risk from potentially toxic elements in soils and extra virgin oils from Valdichiana Senese, Tuscany (Italy). *Journal of Plant Nutrition and Soil Science*, 188(2). 241-250.

Haddaway, N.R., Hedlund, K., & Jackson, L.E. (2017). How does tillage intensity affect soil organic carbon? A systematic review. *Environmental evidence*, 6. 30.

Halamić, J., & Miko, S. (2009). *Geochemical Atlas of the Republic of Croatia.* Zagreb, Croatia: Croatian Geological Survey

Hashimi, R., Kaneko, N., & Komatsuzaki, M. (2022). Impact of no-tillage on soil quality and crop yield in Asia: a meta-analysis. *Land, Degradation & Development*, 34(4). 1004-1018.

Hou, D., O'Connor, D., Igalavithana, A.D. *et al.* (2020). Metal contamination and bioremediation of agricultural soils for food safety and sustainability. *Nature Reviews Earth & Environment,* 1. 366–381.

Huang, B., Yuan, Z., Li, D., Zheng, M., Nie, X., & Liao, Y., (2020). Effects of soil particle size on the adsorption, distribution, and migration behaviours of heavy metal(loid)s in soil: a review. *Environmental science*: *Processes & Impacts,* 22(8). 1596-1615.

ISO (1995). *Soil quality. Determination of carbonate content. Volumetric method (ISO 10693:1995).* Geneva, Switzerland: International organization for standardization

ISO (2005). *Soil quality. Determination of pH (ISO 10390:2005)*. Geneva Switzerland: International organization for standardization

ISO (2006). *Soil quality, "Pretreatment of samples for Physico-chemical analysis" (ISO 11464:2006)* Geneva Switzerland: International organization for standardization

IUSS Working Group WRB (2015). World Reference Base for Soil Resources 2014, Update 2015. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. World Soil Resources Reports No. 106, Rome: FAO.

JDPZ (1966). *Handbook for soil analysis. Book I. Chemical methods for soil analysis*. Beograd, Yugoslavia. Yugoslav Soil Science Society

Jimenez-Ballesta, R., Bravo, S., Perez-de-los-Reyes, C., Amoros, J.A., & Garcia-Navarro, F.J. (2023). Contents and spatial distribution of arsenic in vineyard soils in Mediterranean environment. *Water, Air, Soil Pollution*, 234. e83.

Kabata Pendias, A., & Mukherjee, A.B. (2007). *Trace elements from soil to human.* Berlin, Germany: Springer Verlag

Kabata-Pendias, A., & Pendias, H. (2001) *Trace Elements in Soils and Plants. 3rd edition*. London, United Kingdom: CRC Press.

Kibblewhite, M.G., Ritz, K., & Swift M.J. (2007). Soil health in agricultural systems. *Philosophical Transactions of the Royal Society B*, 363. 685-701.

Komarek, M., Čadkova, E., Chrastny, V., Bordas, F., & Bollinger, J.C. (2010). Contamination of vineyard soils with fungicides: A review of environmental and toxicological aspects. *Environment International*, 36(1). 138-151.

Lev, S.M., Matthies, N., Snodgrass, J.W., Casey, R.E., & Ownby, D.R. (2010). Effects of zinc exposure on earthworms, *Lumbricus terrestris* in an artificial soil. *Bulletin of Environmental Contamination and Toxicology*, 84. 687-691.

Lovrenčić Mikelić, I., Oreščanin, V., & Barišić, D. (2013). Distribution and origin of major, minor, and trace elements in sediments and sedimentary rocks of the Kaštela Bay (Croatia) coastal area. *Journal of Geochemical Exploration,* 128. 1–13.

Marinčić, S., Magaš, N., & Borović, I. (1967). *Basic geological map SFRJ 1:100000, List Split i Primošten K 33-20 i K 33-21*. Zagreb, Croatia: Geological Survey Zagreb

Mbarek, H.B., Gargouri, K., Mbadra, C., Chaker, R., Souidi, Y., Abbas, O., Baeten, V., & Rigane, H. (2020). Change and spatial variability of soil organic matter humification after long-term tillage and olive mill wastewater application in arid regions. *Soil research*, 58(4). 388-399.

Mekki, A., Aloui, F., & Sayadi, S. (2017). Influence of biowaste compost amendment on soil organic carbon storage under arid climate. *Journal of the Air & Waste Management Association*, 69(7). 867-877.

Miko, S., Halamić, J., Peh, Z., & Galović, L. (2001). Geochemical baseline mapping of soils developed on diverse bedrock from two regions in Croatia. *Geologia Croatica,* 54(1). 53-118.

Miloš, B., & Bensa, A. (2019). Cd, Cu, Pb and Zn on terraced soil on flysch deposits of Kaštela bay coastal area Croatia. *Journal of Central European Agriculture*, 20(3). 974-985.

Miloš, B, & Bensa, A. (2021). The copper content in soil of olive orchards from Dalmatia, Croatia. *Eurasian Soil Science*, 54. 865-874.

Mottese, A.F., Sabatino, G., Di Bella, M. *et al.* (2020). Environmental screening for the assessment of potentially toxic elements content in PGI soils from the Mediterranean region (Italy and Turkey). *Environment Earth Science,* 79. 499.

Official Gazette (2019). *Ordinance on the protection of agricultural land from pollution* (in Croatian). Zagreb, Croatia: Government of Republic of Croatia, Ministry of Agriculture and Forestry

Pan, X., Zhang, S., Zhong, Q., Gong, G., Wang, G., Guo, X., & Xu, X. (2020). Effect of soils chemical properties and fractions of Pb, Cd and Zn on bacterial and fungal communities. *Science of The Total Environment*, 715. e 136904

Parat, C., Chaussod, R., Leveque, J., Dousset, S., & Andreux, F. (2002). The relationship between copper accumulated in vineyard calcareous and soil organic matter and iron. *European Journal of Soil Science*, 53(4). 663-670.

Pathak, V.M., Verma, V.K., Rawat, B.S., Kaur, B., Babu, N., Sharma, A., Dewali, S., Yadav, M., Kumari, R., Singh, S., Mohapatra, A., Pandey, V., Rana, N., & Cunill, J.M. (2022). Current status of pesticide effects on environment, human health and its eco-friendly management as bioremediation: A comprehensive review. *Frontiers in Microbiology*, 13. e 962619

Peh, Z., Miko, S., & Bukovec D. (2003). The geochemical background in Istrian soils. *Natura Croatica*, 12(4). 195-232.

Perez Lomas, A.L., Delgado, D., Parraga, J., Delgado, R., Almendros, G., & Aranda, V. (2010). Evolution of organic matter fractions after application of co-compost of sewage sludge with pruning waste to four

Mediterranean agricultural soils. A soil microcosm experiment. *Waste Management*, 30(10). 1957-1965.

Romić, M., Matijević L., Bakić, H., & Romić, D. (2014). Copper accumulation in vineyard soils: distribution, fractionation, and bioavailability assessment. In: M.C. Hernandez-Soriano (Ed.), *Environmental risk assessment of soil contamination* (pp 845-859). InTech

Sachdeva, S., Varshney, A., Barman, H.C., Powell, M. A., & Sahoo, P.K. (2025). Potentially toxic elements in different inorganic and organic fertilizers: A comprehensive review on global perspective and fertilizer-wise differences. *Applied Soil Ecology,* 209. e 105996.

Takahashi, G. (2015). Sample preparation for X- ray fluorescence analysis. *Rigaku Journal*, 31(1). 26-30.

Uddin, M.K. (2017). A review on the adsorption of heavy metals by clay minerals, with special focus on the past decade. *Chemical Engineering Journal,* 308. 438-462.

Vingiani, S., Di Iorio, E., Colombo C., & Terribile F. (2018). Integrated study of Red Mediterranean soils from Southern Italy. *Catena*, 168. 129-140.

Zhang, Z., Zheng, D., Xue, Z., Wu, H., & Jiang, M., (2019). Identification of anthropogenic contributions to heavy metals in wetland soils of the Karuola Glacier in the Qinghai – Tibetan plateau. *Ecological Indicators,* 98. 678-685.

Wan, Y., Liu, J., Zhuang, Z., Wang, Q., & Li, H. (2024). Heavy metals in agricultural soils: sources, influencing factors, and remediation strategies. *Toxics*, 12(1). 63.

Wyszkowski, M., & Brodowska, M.S. (2020). Content of trace elements in soil fertilized with potassium and nitrogen, *Agriculture,* 10(9). e 398.