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AGROCHEMICAL CHARACTERIZATION OF SOILS FROM THE OVCHE POLE VINE DISTRICT: A CASE STUDY FROM TRI CHESHMI AND DOLNO TROGERCI

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Abstract

This study provides a physicochemical, and agrochemical characterization of vineyard soils in the Ovche Pole Vine District, located within the Povardarie Wine Region of North Macedonia. Two representative vineyard locations, Tri Cheshmi and Dolno Trogerci, were selected for comparative assessment based on their contrasting geological conditions. The analysis focused on key soil parameters, including pH, electrical conductivity (EC), organic matter (OM), organic carbon (OC), calcium carbonate ($CaCO_3$) content, texture, as well as available nitrogen (N), phosphorus (P) and potassium (K). The soils in Tri Cheshmi, developed over Neogene lacustrine sediments rich in marl and calcareous clay, showed alkaline pH, moderate carbonate levels and elevated EC, reflecting a strong pedogenic influence from the carbonate-rich parent material. In contrast, the soils in Dolno Trogerci, formed by colluvial-alluvial deposits with contributions from volcanic and metamorphic rocks from the Vardar zone, showed greater textural variability and higher levels of $CaCO_3$ content. The semi-arid climate of the region, characterized by hot, dry summers and moderately cold winters, further shapes soil development and fertility. This study provides a basic understanding of the physicochemical and nutrient-related soil properties in the Ovche Pole Vine District and supports the development of site-specific sustainable vineyard management practices.

Key words: *Ovche Pole Vine District, Povardarie Wine region, vineyard soils, physico-chemical properties.*

INTRODUCTION

Soil is a critical component of vineyard ecosystems, influencing vine development, grape quality and the sustainability of viticultural production. The success of vineyard management is largely dependent on understanding the physical, chemical and nutrient-related properties of soils, which affect water availability, nutrient uptake, root development and microbial activity. Parameters such as pH., electrical conductivity (EC), organic matter (OM), organic carbon (OC), calcium carbonate ($CaCO_3$), texture and essential nutrients like nitrogen (N), phosphorus (P) and potassium (K) are fundamental indicators of soil health and fertility.

The study area is located in the east-central part of North Macedonia and forms part of the Povardarie Wine region (Official Gazette of the Republic of Macedonia, No. 12, 1980; Official Gazette of the Republic of Macedonia, No. 74, 2024) This area is characterized by a semi-arid climate with hot summers and moderately cold winters, making it favorable for viticulture. A general geographical overview of the Ovche Pole Vine District and the vineyard sampling locations, Tri Cheshmi and Dolno Trogerci is presented in (Fig. 1).

Figure 1. Geographical location of the Ovche Pole Vine District within North Macedonia, including the vineyards sites Tri Chesmi and Dolno Trogerci in the Shtip Municipality.

Geologically, the Ovche Pole Vine District is part of the Vardar Zone, a major geotectonic unit in the region. Geological map of the Ovche Pole Wine District particularly around the city of Shtip, shows that this area belongs to the Vardar Zone (VZ) (Markoski & Mitkova, 2011), one of the main tectonic units in the Republic of North Macedonia, (Fig. 2).

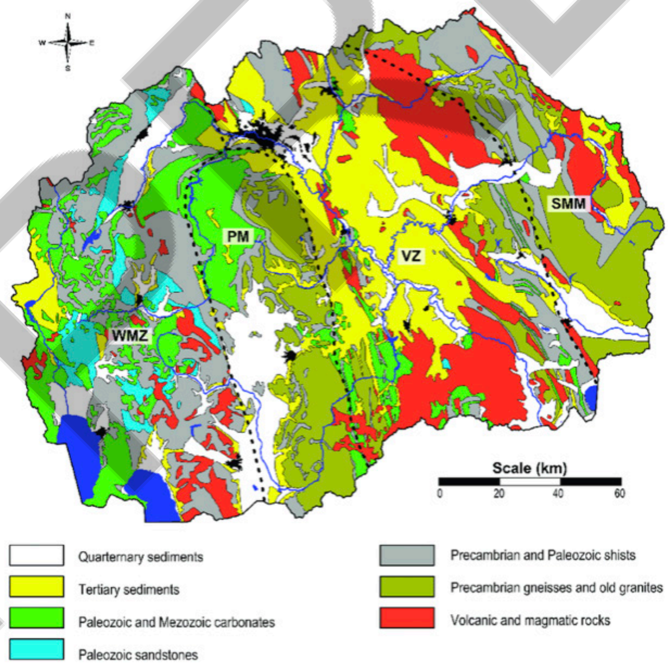

Figure 2. Lithological map of Macedonia, SMM - Serbo-Macedonian massif, VZ - Vardar zone, PM - Pelagonian massif, WMZ - West-Macedonian zone (Barandovski et al., 2012).

This zone is characterized by the presence of Tertiary volcanic rocks such as andesites and tuffs, as well as Neogene and Quaternary sedimentary formations, including marls and sandstones (Dumurdzanov et al., 2004; Dumurdzanov et al., 2005). These lithogenic formations have a significant impact on the soil composition in the region, which is crucial for agricultural activities, including viticulture. The geological structure of this area is dominated by a combination of volcanic (andesitic and pyroclastic) materials, as well as sedimentary (marl, sandstone and conglomerates) and metamorphic rocks. The influence of these diverse geological formations contributes to the complex structure and composition of the soil. Volcanic materials enrich the soils with beneficial macroelements such as calcium, magnesium and iron. Sedimentary rocks affect the soil pH and nutrient retention capacity. The interaction between these base materials and pedogenic processes creates a heterogeneous soil profile that significantly affects soil fertility, and vine growth and productivity. The soil structure in the Ovche Pole Vine District is a product of the geological history, climate, and pedogenic processes that have shaped the area over time. The variety of volcanic, sedimentary, and metamorphic rocks present in this zone results in soils with distinct characteristics. This characteristics Influence viticulture, while also presenting certain challenges that require careful soil management.

Volcanic rocks, such as andesite, tuffs and pyroclastic, dominate the soil formation in parts of the Ovche Pole Vine District. These volcanic materials are rich in essential macroelements such as magnesium (Mg), calcium (Ca) and iron (Fe). When weathered, they contribute to clayey soils with high fertility, favorable for grapevine growth. These soils are usually characterized by good drainage, which is essential in regions with hot and dry summers. Well-drained soils encourage deep root penetration, promoting healthy vines and reducing the risk of root rot (Abad et al., 2021). The mineral content of volcanic soils also supports the health of the vine by providing a stable supply of nutrients that are essential for grape quality. In addition to macronutrients, volcanic soils often contain trace minerals and micronutrients such as zinc (Zn), copper (Cu), and boron (B), which are crucial for plant metabolic processes and disease resistance. These elements, although required in small quantities, can significantly affect vine growth, grape ripening, and the overall flavor of the wine (Pereira et al., 2021). In contrast, soils formed from sedimentary rocks, such as marls, sandstones, and conglomerates, are found in other parts of the Ovche Pole Vine District, particularly around Dolno Trogerci. These materials are more prone to weathering into finer-textured soils that tend to retain moisture and nutrients more effectively than volcanic soils. Soils rich in marl can lead to slightly alkaline conditions, which affect the availability of certain nutrients. The pH of the soil in Gorno Trogerci is typically higher, which can limit the availability of iron (Fe) and other micronutrients, creating a need for careful fertilization practices to ensure vine health (Markoski & Mitkova 2011). Sedimentary soils also tend to have a lower permeability compared to volcanic soils, meaning that water can be retained for longer periods, though excessive moisture can lead to reduced root aeration (Huggett, 2005) irrigation management in this region must take into account the retention of water in the soil, especially during the growing season, to avoid vine stress caused by over-saturation. However, the slightly higher fertility of these soils due to the nutrient retention properties supports grapevine growth, even if nutrient balance must be carefully monitored (Markoski et al., 2020).

The interaction between soil type and climatic conditions also plays a significant role in the Ovche Pole Vine District. The semi-arid climate, characterized by hot summers and cool winters, accelerates soil moisture evaporation in volcanic soils, leading to a requirement for irrigation during the growing season (Costa et al., 2023). However, the clay and silty characteristics of the soils at Gorno Trogerci retain moisture more efficiently, reducing irrigation needs but potentially increasing the risk of soil compaction if not properly manage (Mitkova et al., 2010). Thus, understanding both the soil characteristics and the geological makeup of the Ovche Pole Vine District is essential for optimizing vineyard management and ensuring high grape quality. The soil's texture, fertility, pH, and mineral composition are inextricably linked to the region's geological foundation, creating a complex yet fertile environment for grapevine cultivation that must be managed with precision to enhance vineyard productivity and grape quality.

Two representative vineyard locations within the Ovche Pole Vine District, Tri Cheshmi and Dolno Trogerci were selected for this study due to their contrasting lithological characteristic and landscape positions.

Tri Cheshmi is underlain by Neogene lacustrine sediments rich in marl and calcareous clays, which typically support the development of alkaline soils with moderately high calcium carbonate and elevated electrical conductivity. In contrast, Dolno Trogerci lies on colluvial-alluvial substrates with significant input from volcanic and metamorphic rocks originating from the Vardar Zone. Soils at this location are characterized by higher $CaCO_3$ content, likely influenced by the accumulation and redistribution of carbonate material through slope processes and parent rock contributions.

While previous studies in the region have addressed broader geochemical frameworks and viticultural potential (Markoski et al., 2020), relatively few have focused on the fundamental physicochemical, pedological and agrochemical characteristics that are critical for evaluating the suitability of soils for grapevine cultivation (Mitkova & Mitrikeski, 2005). This study therefore aims to assess the key physical, chemical and nutrient related properties of vineyard soils from Tri Cheshmi and Dolno Trogerci. By establishing a detailed understanding of soil pH, EC, OM, OC, $CaCO_3$, texture and macronutrient levels (N, P, K), the study provides a valuable baseline for site-specific soil management of sustainable viticulture in the Ovche Pole Vine District.

MATERIAL AND METHODS

Soil sampling

A total of 18 representative soil samples were collected from three locations within the Ovche Pole Vine District. Sampling was performed in accordance with standardized procedures for soil collection in vineyard areas, as defined by ISO 18400-101:2017 and ISO 18400-104:2018. All samples were taken from a depth of 0–30 cm using a soil auger. The first two locations (L1 and L2) are situated near Tri Cheshmi, where samples were collected from two vineyard plots locally known as Ridot and Vucevi Livadi (Fig. 3a, b). The third location (L3) is in the vicinity of Dolno Trogerci, where sampling was conducted at three vineyard plots named Orman, Locva, and Bulin Dol (Fig. 3c). This sampling strategy was designed to capture the heterogeneity of vineyard soils influenced by variations in topography, vegetation cover, and geological conditions.

Figure 3. Location of soil sampling sites within the study area: a-Tri Cheshmi location, sampling site Ridot, b-Tri Cheshmi location, sampling site Vucevi Livadi, c-Dolno Trogerci location, sampling site Orman, Bulin Dol and Locva.

In vineyards block larger than 10 ha, the area was subdivided into smaller plots of approximately 1 ha. From each 1 ha plot, 15-20 individual soil cores were collected in a zig-zag pattern. This provides representative coverage of the field. These subsamples were thoroughly homogenized in the field. The quartering method was applied to reduce the volume of the composite sample. This resulted in representative samples with a mass of weighing between 1-1.5 kg. The exact locations of the sampling points were determined using GPS technology to ensure spatial accuracy and reproducibility. The coordinates and description of the sampling points are provided in (Tab. 1).

Sample preparation for analysis

The collected soil samples were dried in a laboratory oven at 40 °C for 48 hours. After drying, the samples were manually ground with a mortar and pestle. The samples were then sieved through a 2 mm mesh to remove coarse fragments and organic residues. For the analysis of organic matter (humus), the samples were sieved through a sieve with a mesh size of 0.25 mm. The prepared soil samples were stored in labeled paper bags and kept in a dry place until further laboratory analysis.

Used chemicals and reagents

All chemicals used for performing the chemical analyses of the soil samples were of analytical grade purity (p.a.). Sulfuric acid (H_2SO_4), lactic acid ($C_2H_4OHCOOH$), hydrochloric acid (HCl), nitric acid (HNO_3), oxalic acid (HCOOH), and orthophosphoric acid (H_3PO_4) were purchased from Sigma-Aldrich, Germany. Potassium permanganate ($KMnO_4$), potassium chloride (KCl), potassium sulfate (K_2SO_4), sodium hydroxide (NaOH), copper (II) sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$), potassium hydrogen phosphate ($KHPO_4$), potassium dichromate ($K_2Cr_2O_7$), iron (II) sulfate heptahydrate ($FeSO_4 \cdot 7H_2O$), ammonium heptamolybdate tetrahydrate [$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$], tin (II) chloride dihydrate ($SnCl_2 \cdot 2H_2O$), antimony potassium tartrate hemihydrate [$K(SbO)C_4H_4O_6 \cdot ½H_2O$], and ammonium acetate (CH_3COONH_4) were purchased from Merck (Darmstadt, Germany). The indicators phenolphthalein, diphenylamine, mixed indicator, as well as buffer solutions with pH 4, pH 7, and pH 10 were obtained from Alkaloid-Skopje. A standard soil sample with known content of the analyzed parameters (BIPEA Soil Terre 203-0115-0074) was also used during the chemical analyses of the soil samples.

Table 1. Labels, locations and coordinates of the unified soil samples.

Sample	Sample Label	Location	Place	Coordinates
1	L1S1	Tri Cheshmi	Ridot	41°46'29"N 22°07'23"E
2	L1S2	Tri Cheshmi	Ridot	41°46'33"N 22°07'39"E
3	L1S3	Tri Cheshmi	Ridot	41°46'18"N 22°07'32"E
4	L1S4	Tri Cheshmi	Ridot	41°46'23"N 22°07'47"E
5	L1S5	Tri Cheshmi	Ridot	41°46'10"N 22°07'40"E
6	L1S6	Tri Cheshmi	Ridot	41°46'13"N 22°07'54"E
7	L1S7	Tri Cheshmi	Ridot	41°46'03"N 22°07'46"E
8	L1S8	Tri Cheshmi	Ridot	41°46'04"N 22°08'00"E
9	L1S9	Tri Cheshmi	Ridot	41°45'54"N 22°07'49"E
10	L1S10	Tri Cheshmi	Ridot	41°45'56"N 22°08'04"E
11	L2S1	Tri Cheshmi	Vucevi Livadi	41°46'52"N 22°07'51"E
12	L2S2	Tri Cheshmi	Vucevi Livadi	41°46'52"N 22°07'46"E
13	L2S3	Tri Cheshmi	Vucevi Livadi	41°46'58"N 22°07'51"E
14	L2S4	Tri Cheshmi	Vucevi Livadi	41°46'57"N 22°07'31"E
15	L3S1	Dolno Trogerci	Locva	41°49'47"N 22°09'38"E
16	L3S2	Dolno Trogerci	Locva	41°49'35"N 22°09'34"E
17	L3S3	Dolno Trogerci	Orman	41°49'15"N 22°09'37"E
18	L3S4	Dolno Trogerci	Bulin Dol	41°49'19"N 22°10'23"E

Physico-chemical analysis of soil samples

Certified standard method were used to determine the physico-chemical and mechanical properties of the soil samples. These analyses included parameters such as pH, electrical conductivity, organic matter, organic carbon, available phosphorus, potassium and nitrogen, calcium carbonate content and soil texture classification. The following methods were applied:

- ISO 10390:2021 - soil quality, determination of pH in H_2O and KCl.
- ISO 11265:2024 - soil quality, determination of electrical conductivity (soil conductivity).
- ISO 10694:1995 - soil quality, determination of organic matter (humus).
- ISO 10693:1995 - soil quality, determination of carbonates, volumetric method.
- ISO 11261:1995 - soil quality, determination of total nitrogen by modified Kjeldahl method.
- ISO 11263:1994 - soil quality, determination of available phosphorus, spectrophotometric method with ammonium molybdate.
- ISO 11465:1993 - soil quality, determination of hygroscopic moisture and hygroscopic coefficient.
- ISO 11277:2020 - soil quality, determination of mechanical composition, pipette B method.
- ISO 11508:2017 - soil quality, determination of soil bulk density.

RESULTS AND DISCUSSION

Soil texture (mechanical composition)

The mechanical composition of the soil samples was determinate based on the relative proportions of sand, silt and clay. Soil texture classes were determined according to FAO/WRB classification system and USDA soil texture triangle (IUSS Working Group WRB, 2015; USDA, (1999). The results are presented in (Tab. 2).

The samples from the first location (L1) Tri Cheshmi, place Ridot, predominantly consist of sandy soils. The sand fraction varies between 68% to 91% with low clay content (1% to 6%). These soils are classified as sandy soils, which suggests that they are well-drained and may have lower nutrient retention. According to the literature (Kleber et al., 2021) sandy soils are typically low in organic matter but drain quickly, which could influence the irrigation and fertilization strategies for vineyards in the area. Soils from the second location (L2), Tri Cheshmi, place Vucevi Livadi, are characterized by a sandy loam texture, with sand content between 58% and 77%, clay content ranging from 2% to 3%, and silt between 21% to 27%. These soils are classified as sandy loam. Bulk density values range from 1.2 g/cm^3 to 1.5 g/cm^3, indicating that these soils are slightly denser that the ones from L1 location but steel exhibit good drainage properties. The higher clay content in location L2, compared to location (L1) suggests that these soils may have a better ability to retain nutrients and moisture, potentially leading to slightly higher fertility compared to the sandy soils from location (L1). The third location (L3), Dolno Trogerci has soils with significantly higher clay content, ranging from 17% to 20%, and much lower sand content between 18% and 31%. These soils are classified as silty clay loam (L3S1, L3S2, L3S3 and L3S4), with bulk density ranging from 1.1 g/cm^3 to 1.4 g/cm^3. The higher clay content and relatively lower sand fraction indicate that these soils have slower drainage rates and higher water and nutrient retention capacities (Filipovski, 2006). These properties are typically of clay-rich soils, which can retain more moisture but may also lead to drainage issues if not managed.The geological characteristics of the region play a crucial role in shaping the texture and overall fertility of vineyard soils. The Ovche Pole viticultural region is known for its ancient riverbed deposits, which contribute to the sandy texture of the soils. These soils tend to have lower clay and organic matter content, which can result in relatively lower water-holding capacity. The high sand content in location (L1), suggests that these location experiences good drainage, which is favorable for crops that require less water but can be challenging in terms of nutrient retention, requiring more frequent fertilization. On the other hand, location L3 has a more complex geological history with sedimentary deposits and clay-rich parent material.

This contribute to the high clay content in soils from Dolno Trogerci, making them more fertile and capable of retaining water and nutrients. The clay-rich soils in L3, in particular, are more prone to waterlogging if not properly managed especially during heavy rains. These soils would benefit from proper drainage systems and soil amendments to optimize their structure for agricultural use (Jovanov et al., 2012).

Table 2. Texture classification of soil samples according to FAO/WRB classification system (2015) and USDA soil texture triangle (1999).

Sample	Coarse Sand, %	Clay and Silt, %	Clay, %	Fine Sand, %	Silt, %	Total Sand, %	Bulk Density, g/cm^3	Soil Type
L1S1	36	51	**4**	12	**47**	**48**	1.5	Sandy Soil
L1S2	34	16	**1**	50	**15**	**84**	1.6	Sandy Soil
L1S3	24	14	**1**	62	**13**	**86**	1.6	Sandy Soil
L1S4	21	9	**1**	70	**8**	**91**	1.7	Sandy Soil
L1S5	27	35	**6**	41	**29**	**68**	1.7	Sandy Soil
L1S6	30	14	**1**	56	**13**	**86**	1.5	Sandy Soil
L1S7	43	14	**1**	43	**13**	**86**	1.6	Sandy Soil
L1S8	35	12	**1**	53	**13**	**88**	1.5	Sandy Soil
L1S9	22	16	**2**	62	**14**	**84**	1.6	Sandy Soil
L1S10	32	18	**2**	50	**16**	**82**	1.6	Sandy Soil
L2S1	17	23	**2**	60	**21**	**77**	1.5	Sandy Loam
L2S2	17	24	**2**	41	**22**	**58**	1.4	Sandy Loam
L2S3	19	30	**3**	51	**27**	**70**	1.3	Sandy Loam
L2S4	16	25	**2**	59	**22**	**75**	1.2	Sandy Loam
L3S1	30	69	**20**	1	**49**	**31**	1.3	Powdery Clay Loam
L3S2	28	64	**20**	8	**44**	**29**	1.2	Powdery Clay Loam
L3S3	15	79	**17**	6	**62**	**21**	1.4	Powdery Clay Loam
L3S4	12	82	**10**	6	**72**	**18**	1.1	Powdery Clay Loam

L-location, S-sample

Chemical analysis

The chemical analysis of soil samples collected from Tri Cheshmi and Dolno Trogerci as part of Ovche Pole Vine District reveals a diversity in soil characterization influences by both anthropogenic processes and geological formations. The results from chemical analysis of soil samples are presented in (Tab. 3).

The studied locations are part of Ovche Pole Vine District, which is part of the Vardar Zone of North Macedonia. This region is characterized by Neogene-Quaternary sediments composed of marls, clays, sandstones, and occasional volcanic materials. The soils in this region are typically alluvial and colluvial, developed under semi-arid to arid conditions, which is reflected in the calcareous nature of the parent material. The pronounced presence of calcium carbonate ($CaCO_3$), especially in Tri Cheshmi and Dolno Trogerci, is typical of soils derived from limestone-rich deposits. These conditions directly influence soil pH, nutrient retention and structure. The pH-H_2O across all samples ranged between 7.09 and 8.66, with most samples falling within the slightly to moderately alkaline range. This alkalinity is consistent with the calcareous composition of the soils, as corroborated by $CaCO_3$ content ranging from 0.31% to 25.4%. Samples from Dolno Trogerci (L3S3, L3S4 and L3S3) exhibit particularly high carbonate concentrations (>25%), likely due to the influence of lacustrine limestone sediments and reduced leaching in the semi-arid climate (Wilson, 1998). The high pH could limit the availability of micronutrients such as Fe, Zn and Mn, which is a typical concern for viticulture in alkaline soils. The electrical conductivity (EC) ranged from 250 to 481 $\mu S/dm^3$, suggesting low to moderate salinity across the sites. Although all values are within acceptable limits for grapevine cultivation, elevated EC in samples such as L3S3 and L3S4 may reflect the accumulation of soluble salts due to limited rainfall and poor drainage, common in regions with high evaporation rates and loamy-clay texture. Nitrogen levels were relatively low (0.98 to 1.22 mg/kg), aligning with semi-arid character and low organic matter content (OM ranging from 1.14% to 2.64%). The low organic carbon (OC ranging from 0.7% to 1.2%) further indicates limited organic input and microbial activity.

Table 3. Results from chemical analysis of soil samples.

Sample	pH-H_2O	pH-KCl	EC µS/cm	N g/kg	P_2O_5 mg/100g	K_2O mg/100g	OM %	OC %	$CaCO_3$ %	HM %	KH %
L1S1	7.86	7.46	394	0.99	19.2	24.8	2.13	1.16	1.22	0.50	1.005
L1S2	8.02	7.53	377	1.17	13.3	40.1	2.24	1.25	0.41	0.91	1.009
L1S3	7.48	6.79	323	0.98	24.8	65.5	1.74	1.05	7.13	0.85	1.008
L1S4	7.79	7.11	335	1.10	8.44	30.4	1.96	1.15	0.51	1.12	1.011
L1S5	8.09	7.41	326	1.15	42.9	50.1	2.22	1.25	0.31	1.16	1.011
L1S6	7.97	7.46	310	1.12	28.3	39.7	1.95	1.12	0.73	1.17	1.011
L1S7	8.02	7.51	298	1.01	19.9	41.3	1.83	1.11	0.75	1.21	1.012
L1S8	8.23	7.42	250	1.11	10.8	40.6	2.05	1.20	1.75	0.54	1.005
L1S9	7.82	7.46	442	1.01	9.06	42.7	1.71	0.95	2.11	0.54	1.005
L1S10	8.66	7.05	462	1.02	9.82	34.6	1.42	0.85	2.83	0.91	1.009
L2S1	7.74	7.42	314	1.17	26.6	30.1	1.24	0.72	7.79	1.21	1.012
L2S2	7.21	7.11	334	1.06	13.4	28.9	1.42	0.80	11.7	0.75	1.007
L2S3	8.16	7.41	341	1.07	28.5	43.6	1.96	1.16	10.5	2.82	1.029
L2S4	7.11	6.91	325	1.10	29.2	36.4	1.78	1.10	11.1	1.16	1.011
L3S1	7.78	7.41	377	1.22	24.6	46.5	2.46	1.45	8.69	0.95	1.008
L3S2	7.36	7.31	441	1.17	18.7	41.1	2.09	1.20	12.9	0.64	1.006
L3S3	7.62	7.42	481	1.12	9.99	45.2	2.04	1.20	25.4	0.56	1.005
L3S4	7.68	7.43	460	1.14	23.5	49.6	1.93	1.12	18.2	0.42	1.004

OM-organic matter, OC-organic carbon, HM- hygroscopic moisture, KH- coefficient of hydroscopicity

This suggests that nitrogen availability is likely to be a limiting factor for plant growth, especially in the absence of fertilization or cover cropping (Schleuss et al., 2020). Phosphorus (P_2O_5) was highly variable, ranging from 8.44 to 42.96 mg/100g. The highest levels were observed in sample (L1S5), possibly due to localized fertilization or natural phosphorus enrichment. However, due to the alkaline pH and high CaCO3, a significant portion of phosphorus may be present in forms less available to plan (Van Leeuwen & Seguin, 2006). Potassium (K2O) levels were generally high (24.52 to 65.51 mg/100g), particularly in samples from Tri Cheshmi (L1S3), potentially due to the presence of potassium rich minerals (feldspars, micas) in the parent rock or historical fertilization. High variability in $CaCO_3$ content (0.31% to 40.8%) further supports the geological heterogeneity of the study sites. Samples (L3S3, L3S4) suggest the influence of local calcareous bedrock or dust deposition from surrounding areas, consistent with aeolian input. The hygroscopic moisture (HM) and the coefficient of hydroscopicity (KH) values indicate that most soils have moderate moisture retention potential, thought the low organic content might reduce aggregation and structural stability.

Exploratory factor analysis (EFA) was performed on soil data collected from the Tri Cheshmi and Dolno Trogerci sites within the Ovche Pole Vine District. The analysis extracted four latent factors, collectively explaining 99.5% of the total variance (Tab. 4). This high cumulative variance suggests that the selected variables comprehensively capture the variability in the soil system influenced by both natural and anthropogenic factors. The four-factor analysis derived from the exploratory factor analysis (EFA) effectively summarized the multidimensional variability of the analyzed soil parameters from the Tri Cheshmi and Dolno Trogerci. Each factor captures distinct pedochemical and geogenic processes that influence soil formation and fertility in this semi-arid viticultural region.

Factor 1: This factor shows strong negative loadings for Organic Matter (OM = -0.95) and Organic Carbon (OC = -0.99) (Tab. 4). These variables are indicative of the biological activity and humification processes in soil. The high loadings suggest that this factor encapsulates the organic fertility status, likely influenced by both natural vegetation cover and anthropogenic inputs, such as vineyard practices. Soil richer in OM and OC typically show improved water retention, microbial activity and nutrient cycling (Reichenbach et al., 2021).

Factor 2: Dominated by Electrical Conductivity (EC = 0.78) and $CaCO_3$ ($CaCO_3$ = 0.81), this factor reflects the salinity and calcareous nature of the soils, which are strongly tied to the underlying geology (Tab. 4). The Tri Cheshmi region, in particular is characterized by Neogene-Quaternary lacustrine sediments rich in carbonates including marls, clays and sporadic limestone's. These substrates contribute to the accumulation of secondary carbonates and salts, resulting in the higher EC and $CaCO_3$ values. The soil exhibit low leaching potential due to the semi-arid climate, further favoring salt concentration. This factor is a geochemically significant indicator of pedogenesis in carbonate-rich, semi-arid environments.

Factor 3: This component is defined by pH-H2O and pH-KCl identifying the acid-base status and buffering capacity on the soil (Tab. 4). The positive loadings suggest that soils with higher pH values contribute more to this factor. The presence of carbonate minerals, particularly in the Tri Cheshmi area (L1, L2), loads to alkaline pH levels which affect nutrient solubility especially for phosphorus and micronutrients like Zn, Fe and Mn (Zhang, 2024). The buffering effects also stabilized pH across spatial and temporal scales. Geologically, this factor reflects the weathering of carbonate and parent materials, which are abundant in both study sites, though more prominent in Dolno Trogerci.

Factor 4: Factor 4 is positively associated with potassium (K_2O = 0.48) and negatively with nitrogen (N = -0.41) (Tab. 4). This suggests that may be governed by both soil mineralogy and anthropogenic inputs such as fertilization. Potassium is often present in primary minerals (feldspar and mica), while nitrogen is present in organic matter. The contrast between these nutrients may point to site-specific soil management practices, particularly in cultivated vineyards plots where fertilization regimes differ (Rashimi et al., 2020).

Table 4. Factor loading Matrix-Factor analysis (FA) of the analyzed soil samples.

Parameter	F1	F2	F3	F4	Comm.
pH-H_2O	-0.17	-0.26	**0.70**	0.15	0.62
pH-KCl	-0.56	0.01	**0.41**	-0.32	0.58
EC (µS/cm)	-010	**0.78**	0.32	0.14	0.74
N (g/kg)	-0.29	0.12	-0.06	**-0.41**	0.27
P_2O_5 (mg/100g)	-0.21	-0.29	-0.46	-0.04	0.35
K_2O (mg/100g)	-0.54	0.03	-0.22	**0.48**	0.57
OM (%)	**-0.95**	0.04	0.06	-0.04	0.91
OC (%)	**-0.98**	-0.01	-0.02	0.01	0.98
$CaCO_3$ (%)	-0.19	**0.81**	-0.21	0.09	0.75
E-Value	**0.98**	**0.84**	**0.70**	**0.55**	**0.64**
Variability (%)	**31.63**	**27.12**	**27.85**	**17.58**	

F1-loading of Factor 1, F2-loading of Factor 2, F3-loading of Factor 3, F4-loading of Factor 4, E-Eingene value, Comm-Communality, OM-organic matter, OC-organic carbon

Factor 4: Factor 4 is positively associated with potassium (K_2O = 0.48) and negatively with nitrogen (N = -0.41) (Tab. 4). This suggests that may be governed by both soil mineralogy and anthropogenic inputs such as fertilization. Potassium is often present in primary minerals (feldspar and mica), while nitrogen is present in organic matter. The contrast between these nutrients may point to site-specific soil management practices, particularly in cultivated vineyards plots where fertilization regimes differ (Rashimi et al., 2020).

The observed factor structure is consistent with the geological diversity of the studied area. The Tri Cheshmi location lies on carbonate-rich Neogene sediments contributing to elevated levels of $CaCO_3$ and electrical conductivity. The presence of marls, clay, lacustrine deposits, and sporadic tuffaceous material explains the buffering capacity and salinity of the soils. In Dolno Trogerci location includes soils developed on alluvial terraces, potentially with more heterogeneous mineral input, leading to more moderate levels of pH, EC and $CaCO_3$. These findings align with earlier studies on the Vardar Zone, where soils typically form over Proterozoic-Paleozoic granitites, and alluvial Quaternary sediments rich in base cations. The geogenic influences on Factor 2 and 3 loadings highlight the importance of substrate type in shaping soil chemistry especially in regions with limited precipitation and high evapotranspiration.

CONCLUDING REMARKS

The physicochemical, pedological and agrochemical assessment of vineyard soils from the Ovche Pole Vine District, specifically from Tri Cheshmi and Dolno Trogerci, reveals clear spatial variability shaped by underlying geology and semi-arid climatic conditions. Soils from Tri Cheshmi are predominantly sandy to sandy loam in texture, with high electrical conductivity, elevated calcium carbonate content and moderately low organic matter and nitrogen levels. These properties reflect the influence of Neogene-Quaternary lacustrine sediments rich in carbonates and marls, characteristic of Vardar Zone. In contrast, soils from Dolno Trogerci are fined-textured (silty clay loam), with higher clay content improved nutrient levels, shaped by colluvial-alluvial deposit influenced by metamorphic and volcanic rocks.

Soil pH in both locations ranged from slightly to moderate alkaline, consistent with the calcareous nature of the parent material, and may limit the bioavailability of certain micronutrients. The overall low nitrogen and organic carbon content across most samples suggest limited biological activity and a need for targeted organic matter enhancement. While phosphorus and potassium levels were more variable, their distribution appears influenced by both natural mineralogy and localized agricultural practices.

Factor analysis father emphasize the importance of organic matter, carbonate content, salinity and mineral buffering as key dimensions of soil variability in the region. These findings provide a critical baseline for the implementation of site-specific soil management practices, particularly in addressing water retention, nutrient supplementation and pH regulation. Such investigations are especially valuable for identifying micro-locational differences within vineyard sites, enabling precision viticulture adapted to the specific needs of each plot. Reorganizing the pedological and geological complexity of the Ovche Pole Vine District is essential for improving viticultural productivity and sustaining long-term soil health under semi-arid conditions.

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АГРОХЕМИСКА КАРАКТЕРИЗАЦИЈА НА ПОЧВИТЕ ОД ЛОЗАРСКИОТ РЕГИОН ОВЧЕ ПОЛЕ: СТУДИЈА НА СЛУЧАЈ ОД ТРИ ЧЕШМИ И ДОЛНО ТРОГЕРЦИ

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Резиме

Оваа студија обезбедува физичко-хемиска и агрохемиска карактеризација на почвите за винова лоза во лозарски регион Овче Поле, кој се наоѓа во рамките на Повардарскиот вински регион на Северна Македонија. Две репрезентативни лозја, Три Чешми и Долно Трогерци, беа избрани за компаративна проценка врз основа на нивните различни геолошки услови. Анализата се фокусираше на клучните параметри на почвата, вклучувајќи pH вредност, електрична спроводливост (EC), органска материја (OM), органски јаглерод (OC), содржина на калциум карбонат ($CaCO_3$), текстура, како и достапен азот (N), фосфор (P) и калиум (K). Почвите во Три Чешми, развиени над неогени езерски седименти богати со лапор и варовничка глина, покажаа алкална pH вредност, умерени нивоа на карбонат и покачена EC, што одразува силно педогено влијание од основниот материјал богат со карбонат. Спротивно на тоа, почвите во Долно Трогерци, формирани од колувијално-алувијални наслаги со придонеси од вулкански и метаморфни карпи од Вардарската зона, покажаа поголема текстурна варијабилност и повисоки нивоа на содржина на $CaCO_3$. Полусушната клима на регионот, карактеризирана со топли, суви лета и умерено ладни зими, дополнително го обликува развојот и плодноста на почвата. Оваа студија обезбедува основно разбирање за физичко-хемиските и нутритивните својства на почвите во лозовите насади од лозарскиот регион Овче Поле и поддржува развој на локациски специфични и одржливи практики за управување со лозјата.

Клучни зборови: *лозарски регион Овче Поле, вински регион Повардарие, почви за винова лоза, физичко-хемиски карактеристики.*

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