



## Some Morphology Physico-Chemical Properties And Classification of Soils Formed on Limestone Parent Material in Safita Region (Tartous), Syria

Raed DAYOUB<sup>1\*</sup>, Adel RUKIA<sup>2</sup>

<sup>1,2</sup>Department of Soil and Water Sciences, Faculty of Agriculture, Latakia University, SYRIA

<sup>1</sup><https://orcid.org/0009-0003-3270-2322>, <sup>2</sup><https://orcid.org/0009-0009-8526-0402>

\*Corresponding author: [raed1dayoub@gmail.com](mailto:raed1dayoub@gmail.com) ; [read.a.dayoub@latakia-univ-edu.sy](mailto:read.a.dayoub@latakia-univ-edu.sy)

### Research Article

### ABSTRACT

#### Article History:

Received: 08 February 2026

Accepted: 23 May 2026

Published online: 25 May 2026

#### Keywords:

Soil Properties

Soil Classification

Soil Depth

Safita

Mollisols

Soils formed on limestone parent material occupy an important and large part of the agricultural land in Syria, it is essential to study some physical and chemical properties of these soils in the Safita region (Tartous). For this issue, six soil profiles derived from limestone parent materials were investigated. The results showed that profile depth ranged between shallow to medium (20 – 110) cm. sand and clay content increased with depth while silt content decreased. pH values ranged from neutral to alkaline (7- 8.09), high calcium carbonate contents were recorded throughout the soil profiles (28- 79.1) %, and also increase of organic matter contents in A horizon (1.91- 5.65%). The cation exchange capacity (CEC) ranged from 10 to 38.24 meq/100g. Exchangeable calcium was dominant on the surface of adsorption complex (3- 28.4 meq/100g), followed by magnesium (1.2- 10 meq/100g). Taxonomically , the studied soils were classified under orders: Entisols, Inceptisols, and Mollisols which have profiles types: A, A – C, A – AC– C, and A – (B) –C. Soil depth and its content of rock fragment content varied according to slope degree, plant cover intensity, and parent material hardness. Most soil properties were inherited from the parent material and the soils were slightly developed and formed recently.

**To Cite :** Dayoub R, Rukia A., 2026. Some Morphology Physico-Chemical Properties And Classification of Soils Formed on Limestone Parent Material in Safita Region (Tartous), Syria. Agriculture, Food, Environment and Animal Sciences, 7(1): 1-15. <https://doi.org/10.5281/zenodo.20369728>



## INTRODUCTION

Soil is an important part of any ecosystem and it is the result of slow process that occurs over the years through weathering of the rocks, accumulation of the organic matter, and interactions of physical, chemical, and biological processes with great spatial variation in its characteristic (Hu et al., 2019). The type of soil depends on the parent material, climate, topography, and time. Parent material can be considered one of the most important factors in soil formation (Peng et al., 2024). It provides the basic material upon which other soil-forming factors act.

Limestone is a sedimentary rock constituting approximately 10% of sedimentary rocks by volume. Its main components are calcium carbonate, (calcite or aragonite) and it may also contain a high percentage of magnesium carbonate, in addition to small amounts of other components such as feldspar, chloride, iron oxide hydrate and quartz (Bockheim and Douglass, 2006; Catoni et al., 2021).

As a soil forming factor, limestone parent material plays an important role in the formation and composition (Guimaraes et al., 2022; Silva et al., 2022), mineral composition (Schweizer et al., 2024), and chemical constituents of soil (da Silva et al., 2022). It affects soil physical properties (Murugasamy et al., 2023), water regime (Türk et al., 2025), thermal conductivity, transport of suspended materials and solution, mineralogy and chemistry, and pH sorption capacity. These, in turn, directly and indirectly affect soil chemical and physical processes (Michalet and Liancourt, 2024); soil microbial community structure (He et al., 2024; He et al., 2025), and the decomposition and accumulation of soil organic matter (SOM) (Li et al., 2024).

Limestone materials have a significant influence on soil morphology because of their calcium content and high base saturation which lead to alkaline soils, and because of their solubility in weak acids. The characteristics of soils formed from limestone rocks vary from shallow, young, calcareous soils to deep old and acidic soils (Muhs, 2001); they depend on quality and composition of parent materials (Silva et al., 2022); and are related to impurities in the parent material, especially the clay fraction and sand grains. Although these impurities constitute less than 10% of the limestone rocks, they accumulate rapidly during soil development, as the carbonates are easily dissolved and carried away (Jenny, 2005). Hard and relatively pure limestone rocks mostly yield red soils, while the softer, impure rocks produce dark-gray and brownish soils (Dokuchaev Soil Science Institute, 2008).

Although limestone rock is widespread in the coastal region of Syria, few studies have focused on it. In this context, (Rukia et al., 2012) reported a study on some soil properties formed on calcareous rocks in Baniyas region and their classification. They observed that most soil properties are parent material dependent, and the soils were slightly developed and formed recently. Hence, there is a need for more research

regarding soils formed from limestone in the Syrian coastal region. Against this backdrop, the objective of this research was to investigate some morphology, physical and chemical properties of soils formed on limestone parent material in Safita region (Tartous) /Syria.

## MATERIAL AND METHOD

### Study Location

The study was conducted in Safita region which is located in Tartous governorate in the western part of Syria (Figure 1). The climate is Mediterranean, which has an average annual precipitation of 800 mm. Temperatures are characterized by great daily and seasonal variation with average value of 10 °C in January and 29 °C in August, a mean annual evaporation of 4mm/year and relative humidity is high, ranging between (60-80)%. Six sites were selected from limestone deposit area along the Safita region (Table 1). At each site, three soil profiles were dug and then described. Soil samples were collected from each horizon and subjected to soil properties analysis. All samples were air-dried and ground to pass through a 2 mm sieve. Subsequently, selected physical and chemical analyses were carried out.

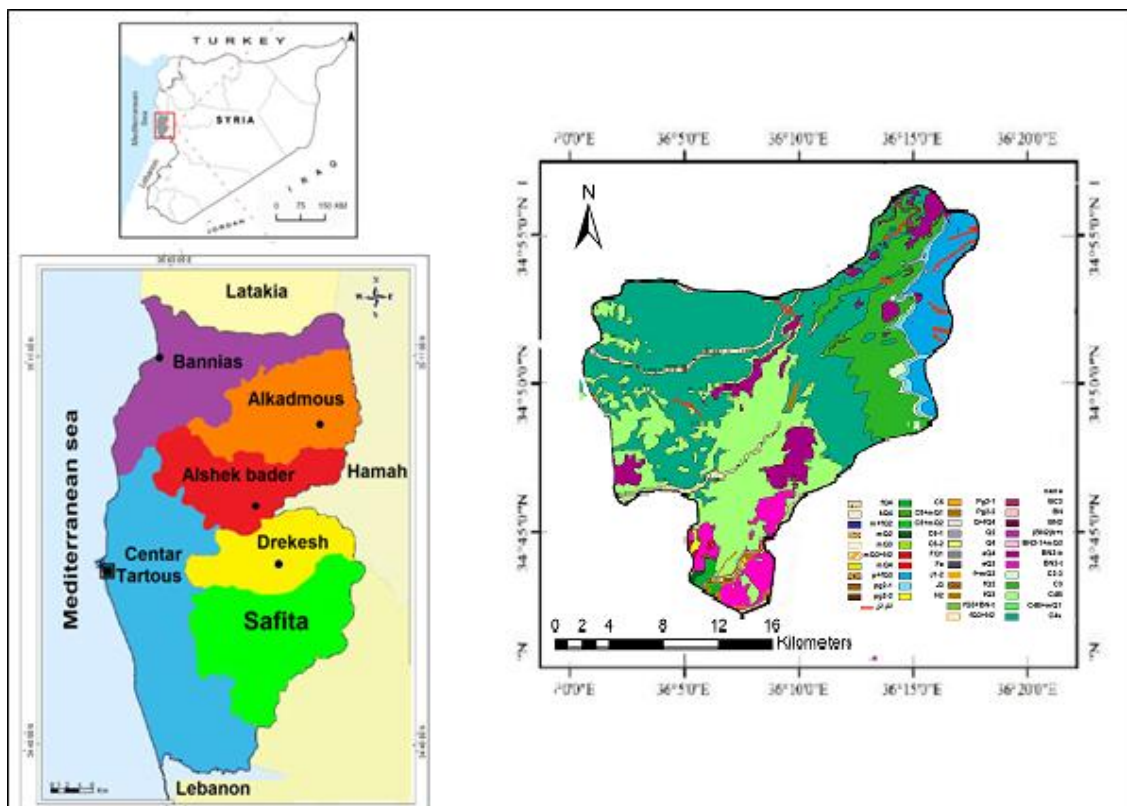


Figure 1. The study area (Safita region)

## Laboratory Analysis

Soil texture was done by the hydrometer method (Gilliam et al., 1993), Bulk density (BD) was determined by core method described by (Blake and Hartge, 1996), electrical conductivity (EC) was determined by Soil saturation extract (Leksungnoen et al., 2018), soil reaction pH of soil samples was determined by using a pH meter in a 1:5 soil-water suspension (Faria et al., 2023), organic matter (OM) was determined by wet combustion (Dong et al., 2020), calcium ( $\text{Ca}^{+2}$ ) and magnesium ( $\text{Mg}^{+2}$ ) were determined by using ammonium acetate ( $\text{NH}_4\text{OAc}$ ) saturation method (Thomas, 1982),  $\text{CaCO}_3$  was determined by using the titration method (Drouineau, 1942), cation exchange capacity (CEC) was determined by neutral (pH 7.0)  $\text{NH}_4\text{OAc}$  saturation method (Rhoades, 1982).

## RESULTS AND DISCUSSION

### The Morphological Characteristics of The Soils

Soil profile depth ranged from 20 to 110 cm (Table 3). The hilltop soils were deep, ranging from (49 -110cm). On side slopes, soil depth varied between (20 to 45 cm) being moderately shallow in Serstan (P1), and moderately deep in Alsanober (P2). Based on horizonation, the soils were divided into three groups. The first group (Serstan soils) exhibited only A horizons. The second group (Mhere Alrom, Alsanober, P2, P3, P4 and Sabe P5) soils. These soils have A and C horizons with or without their transitional horizons. The third group included Sabe soils. These soils have A, B and C horizons Soil colour value ranged from 2 to 8 under dry condition and increased with depth. Chroma varied between 2 to 6 under dry conditions. In general, the soils had brown colour mixed with shades of yellow; in some cases, shades of black and red were also observed. On the other hand, Mhere Alrom soil showed a hue of 7.5YR in all horizons Soil morphological characteristics are crucial features for horizonation and soil classification. The obtained results revealed that soil morphological characteristics were substantially influenced by topography. While the soils at hilltops were very deep. The variation in soil depth appears to be related to slope steepness, and vegetation cover. These factors are likely to determine the weathering intensity of the soil by controlling the amount of water percolating through the soil as well as its erosion intensity. The effect of slope position on soil depth has been reported in several studies (Petlušová et al., 2024).

Table 1. Soil profiles locations and altitude in the study area

Pedon	Site name	Altitude	Slope	Coordinates		Position
				E	N	
1	Serstan	300	25%	36° 02' 30.4"	34° . 50' 57.9"	S
2	ALsanober	168	37%	36° 02' 13.4"	34° . 52' 06"	N
3	Alsanober	90	5%	36° 02' 20.1"	34° . 51' 42"	S
4	Alsanober	305	-	36° 02' 15.6"	34° . 52' 01"	top
5	SABE	600	10%	36° 14' 50.5"	34° . 52' 20.7"	W
6	Mhere Alrom	830	14%	36°15' 05.3"	34° . 50' 50.9"	W

Soil color serves as a critical indicator of soil properties and conditions (Sirisathitkul and Sirisathitkul, 2025) offering quantitative fundamental characteristics to soil classification systems (Pegalajar et al., 2020). Organic matter content and calcium carbonate percentage often influence soil colour (Moritsuka et al., 2014). Brown colour mixed with shades of yellow in 10YR hue is the dominant soil colour in the study area. This colour might be attributed to the presence of hydrated iron oxides, like goethite. However, when hematite is present even at relatively low concentrations, it may impart a red color to the soil (Juita and Sudarsono, 2020). This may explain the redder hue observed in the surface horizons of Alsanober profiles (P2, P3, and P4), where the presence of hematite likely contributed to the stronger reddish coloration of the soil. Organic carbon is another important soil colouring agent. In the studied soils, organic matter is found to increase the darkness of soils surface horizon as compared to sub-layers (Lu et al., 2023).

Soil texture of all the pedons in both surface and subsurface horizon was clay loam (Table 2).

Table 2. Selected morphological properties of the pedons

Pedon	Horizon	Boundary <sup>1</sup>	Color	Texture	Structure <sup>2</sup>	HCL Effervescence
1	A	CSM	10YR2/2	clay loam	MO,FM,GR	2
	A	GW	5YR4/3	clay	MO,ME,GR	3
2	C	-	10YR6/3	clay loam	-	4
	A	GW	5YR4/3	clay loam	MO,ME,GR	3
3	C	-	10YR5/2	clay loam	-	4
	A	GW	5YR3/3	clay loam	MO,ME,GR	2
4	C	-	10YR5/2	clay loam	-	3
	A	CSM	10YR 3/3	clay loam	MO,ME,GR	1
5	B	GW	7.5YR 3/4	clay loam	ST,ME, B	2
	C	-	10YR 5/6	clay loam	ST,CO,B	2
6	A	CSM	7.5YR3/3	clay loam	MO,ME,GR	1
	AC	GW	7.5YR7/3	clay loam	MO,ME, B	2
	C	-	7.5YR8/3	clay loam	ST,CO, B	2

<sup>1</sup>W wavy, G gradual, SM smooth, C clear; <sup>2</sup>MO= Moderate; FM= Fine and medium; ME= Medium; CO = Coarse; GR= Granular; B block; HCl effervescence: 1 slight; 2 moderate; 3 strong; 4 very strong. ST= Strong

This texture might be attributed to their formation from the same parent material (limestone). The carbonate field test showed a strong reaction with the 10% HCl due to their calcareous nature (Table 2).

### **The Physical Properties of Soil**

The particle size distribution (sand, silt and clay) is shown in the (Table 3). The sand content of surface horizons ranged from 27% to 41.9% with an average of 34.45% while the sub-surface horizons values ranged from 29.5% to 40.2% with an average of 34.85%.

The lowest soil sand content was observed in the surface horizon and generally increased with soil depth except in Mhere Alrom soil where the highest sand content was found in the surface horizon. The silt content overall ranged from 23.5% to 38.8% with an average of 31.15%. The silt content of surface horizons ranged from 29.1% to 38.8% with an average 33.95% while the sub-surface horizon ranged from 23.5% to 33.7% with an average 28.6%. The clay content of the soil sample increased with profile depth in most of the studied profiles. The surface horizons had clay content ranging from 29 % to 39 % with an average of 34 % while the subsurface horizon ranged from 31% to 44.7% with an average of 37.85%.

From the data regarding sand, silt and clay content, it was observed that the clay and sand content showed an increasing trend while silt content showed a decreasing trend with soil depth in most of the studied profiles. The high clay content in subsurface horizons may be attributed to migration of clay from surface to subsurface horizons (Reira et al., 2024) and might also be attributed to the internal weathering processes led to the formation of (B) horizon with formed locally in situ (Rukia, 1991).

The results of BD are shown in (Table 3). The results showed that the BD increase with soil depth in most of the studied profiles. The value of BD of the surface horizons ranged from 1.18 to 1.37 g/cm<sup>3</sup> with average value of 1.27 g/cm<sup>3</sup> while the sub-surface horizon values ranged from 1.36 to 1.56 g/cm<sup>3</sup> with average value of 1.52 g/cm<sup>3</sup>. BD was low in the surface horizon may be attributed to more OM in the surface horizon as compared to the sub-surface horizon. The OM increases pore space which increases volume and decreases soil weight. Thus, BD increases with depth of the soil (Bitew et al., 2025; Asmare et al., 2023) and might also be attributed to the weight of the soil layer above (Bayle et al., 2023).

Table 3. Particle size distribution and bulk density of the sampled soils

Pedon	Horizon	Depth, cm	Clay%	Silt%	Sand%	BD (g·cm <sup>-3</sup> )
1	A	0-20	36	33	31	1.29
2	A	0-13	40	33	27	1.28
	C	13-45	44.7	25.8	29.5	1.42
3	A	0-15	39	31	30	1.18
	C	15-45	38	27	35	1.36
4	A	0-19	30	33.5	36.5	1.29
	C	19-39	31	30	39	1.38
5	A	0-25	31	38.8	30.2	1.34
	(B)	25-65	37.5	30	32.5	1.46
	C	65-100	35	33.7	31.3	1.56
6	A	0-25	29	29.1	41.9	1.37
	AC	25-55	34.4	25.4	40.2	1.4
	C	55-110	39.1	23.5	37.4	1.45

### The Chemical Properties of Soil

The results showed that the CaCO<sub>3</sub> contents of the soil sample increased with soil depth in most of the studied profiles (Table 4). CaCO<sub>3</sub> content of surface horizons ranged from 28% to 48.5% with an average of 35.2% while the sub-surface horizons values ranged from 40% to 79.1% with an average of 59.55%. The highest value of CaCO<sub>3</sub> was found in the parent material horizon.

The soils of the study area were formed on calcium carbonate-rich limestone parent material. Despite potentially high precipitation, carbonate leaching from the soil horizons appears to be limited. This may be attributed to the early stages of soil development and the effect of slope degree, which reduces water retention and downward percolation. However, partial leaching of CaCO<sub>3</sub> was observed in most horizons of the studied soil profiles, indicating that some carbonate translocation has occurred during pedogenic processes. Also the results showed that high content of CaCO<sub>3</sub> were observed in all horizons of studied profiles (Table 4), which might be due to the nature of calcareous parent material (Hu et al., 2025). The soil content of carbonates in parent material horizon of the profile (P2 to P6) was higher (58.53, 61.39, 36.91, 66.66 and 71.42) % than the A horizon, respectively, this might be mainly linked to the Mediterranean climate which has a role in the process of leaching of carbonates from surface horizons and accumulation in subsurface horizons and led to the early stages of B-horizon development (P5) which have high clay content, than A horizon.

The relatively short absolute age of this soil which in turn reduced the effect of climate on leaching of carbonates as well the role of topography in erosion of carbonates with water movement. All of these factors reduced the internal weathering and leaching processes. The data on OM in the soils is presented in (Table 3). The results showed wide variation in soil OM which ranged from 0.29% to 5.65 % with average value of 4.09% .The high OM content was found in the surface horizons of Mhere Alrom (5.65%) while the low organic matter content was found in the sub-surface horizons of Mhere Alrom (0.29%).

The high rates of organic matter in surface horizon may be attributed to the continuous accumulation of OM from plant and animal residues as well as root exudates that increases the mineralization and accumulation of OM in the surface layer (Puppini et al., 2025). It is also assumed that the relatively high clay content and CaCO<sub>3</sub> richness of the soils contribute to the preservation of organic matter through the formation of stable organo-mineral complexes, particularly calcium humates (Soil Survey Staff, 2014).

The results showed that the soils were neutral to slightly alkaline in reaction with pH values ranged from 7.00 to 8.09 with average value of 7.54 (Table 4). The pH increased with soil depth in most of the studied profiles. The higher pH was observed in Alsanober (p2) soil (8.09) while the lower was in Mhere Alrom soil (7.00). The pH value of the surface horizons ranged from 7 to 8.09 while sub-surface horizon values ranged from 7 to 8.06. The low pH at the surface layer may be attributed to the result of high OM content (Zhang et al., 2023); and also may be attributed to the leaching of basic cations from surface to subsurface horizon (Sadiq et al., 2021).

Table 4. Chemical properties of the soil of the sampled soils

Pedon	Horizon	pH	EC	CaCO <sub>3</sub> %	OM%	Ca+2meq/100g	Mg+2meq/100g	CECmeq/100g
1	A	7.5	0.3	36	4.25	25	4.8	35
2	A	8.09	0.11	44.6	3.98	28.4	5.51	38.24
	C	7.89	0.1	76.2	1.83	20.8	5.2	29.14
3	A	8.03	0.17	48.5	1.91	22	5.35	30.5
	C	8.06	0.11	79	1.12	22	5.15	29
4	A	7.71	0.17	29.2	3.2	22.2	4.8	34.21
	C	7.78	0.11	79.1	1.53	16.4	2.2	20.03
5	A	7.1	0.29	28	5.65	19	10	38
	(B)	7.1	0.27	40	2.13	15	7	28
	C	7.9	0.23	42	1.43	12	4	21.3
6	A	7	0.26	25	5.56	23	5	36
	AC	7.2	0.25	31	2.89	12	3.2	23.2
	C	7.2	0.22	35	0.29	3	1.2	10

The soil is characterized by low EC which ranged from 0.096 to 0.3 ds m<sup>-1</sup> with average value of 0.198 (Table 4). Soils surface horizons showed higher EC as compared to the sub-surface horizons. The higher EC was observed in Serstan soil (0.3 Ds m<sup>-1</sup>) while the lower was in Alsanober (p2) soil (0.096 Ds m<sup>-1</sup>).

The higher EC in surface horizons soils than in sub-surface horizons may be attributed to the accumulation of salts brought to the surface by the capillary movement of water as a result of evaporation and subsequent deposition of salts on the soil surface (Ibrahim et al., 2022).

Wide variation in the CEC was observed in the studied profiles (Table 4). Soil CEC ranged from 10 to 38.24 meq/100 g with average value of 24.12 meq /100g. The highest soil CEC was observed in the surface horizons as compared to the sub-surface horizons in most of the studied profiles. The higher CEC was observed in Serestan soil (38.24 meq /100g) while the lowest was in Mhere Alrom soil (10 meq /100g). The higher CEC in surface horizons soils than in subsurface horizons may be attributed of high OM content in surface horizons (Adugna and Abegaz, 2019).

The depth distribution of total concentration of Mg<sup>2+</sup> and Ca<sup>2+</sup> in soil profile is shown in (Table 3). The Ca<sup>2+</sup> was dominant in the exchange sites of the soil colloidal materials this was followed by Mg. The Ca<sup>2+</sup> content in the soil ranged from 3 meq /100g to 28.4 meq /100g with average value of 15.7%. Soils surface horizons showed higher Ca<sup>2+</sup> content as compared to the sub-surface horizons in most of the studied profiles. Serstan soils showed the highest Ca<sup>2+</sup> content (28.4 meq /100g) and the lowest content was found in Mhere Alrom soils (3 meq /100g). The Mg<sup>2+</sup> content in the soils ranged from 1.2 meq /100g to 10 meq /100g with average value of 5.6%. The Mg<sup>2+</sup> content decreased with soil depth in most of the studied profiles. Sabe soil showed the highest Mg<sup>2+</sup> content (10 meq /100g) and the lowest content was found in Mhere Alrom soils. The contents of both exchangeable Mg<sup>2+</sup> and Ca<sup>2+</sup> decreased with soil depth. This may be attributed to either local enrichment of base cations from the parent material or addition through plant and animal residues in surface horizons (Robinson et al., 2022) and also may be attributed to biological activity and OM accumulation due to plant residues that are found on the surface of soils (Kebebew et al., 2022; Yang et al., 2022).

## CONCLUSION AND RECOMMENDATION

The studied soil profiles were formed on limestone parent materials. Most soil profiles were poorly developed and still in the early stages of soil formation with weak profile development, light coloration, and limited carbonate leaching of calcium carbonate and the main surface horizons were Mollic and Ochric while the subsurface horizons were absent or in the early stages of formation such as (P5) profile. Soil forming processes were general processes such as addition and decomposition of organic

matter whereas leaching processes were relatively weak and the main processes of soil formation were removal of soil material from slopes and addition to bottom slope.

Most soil properties are highly dependent on the parent material; where the Mediterranean climate has no significant influence on that parent material due to strong and continuous erosion influenced by the steep relief.

The result showed that the most common soils of study area according to USDA Soil Taxonomy the soil classification was as follows:

1-Entisols:Sub-Order Orthents, represented by P1, P2, P3 and P4.

2- Inceptisols: Sub-Order Ochrepts, which represented by P5.

3- Mollisols: Sub-Order Rendolls, represented by P6.

We suggest that there is a need to expand the study of soils formed on limestone parent materials in different areas in Syria. Additionally, special attention should be given to high-elevation areas to control erosion for conserving the soil which would require soil conservation strategies such as conserving the existing natural vegetation cover, proper land leveling, afforestation, terracing further studies should be conducted in this region

## **ACKNOWLEDGMENT**

The authors would like to thank the Department of Soil and Water Sciences, Faculty of Agriculture, Latakia University, for providing the facilities and support necessary to complete this research.

## **Conflict of Interest**

The authors have declared that there are no competing interests.

## **Authors Contribution**

AR conceptualized the study. RD conducted the field experiments, laboratory analyses, and manuscript drafting. AR contributed to data interpretation and discussion of the results. All authors read and approved the final manuscript.

## REFERENCES

Adugna A, Abegaz A., 2019. Effects of soil depth on the dynamics of selected soil properties among the highlands resources of Northeast Wollega, Ethiopia: are these sign of degradation?. *Solid Earth Discuss*, 7:2011–2035 <https://doi.org/10.5194/sed-7-2011-2015>, 2015.

Asmare TK, Abayneh B, Yigzaw M., 2023. The effect of land use type on selected soil physicochemical properties in Shihatig watershed, Dabat district, Northwest Ethiopia. *Heliyon*, 9 (5): e16038. <https://doi.org/10.1016/j.heliyon.2023.e16038>

Bayle D, Feyissa S, Tamiru S., 2023. Effects of Land Use and Slope Position on Selected Soil Physicochemical Properties in Tekorsh Sub-Watershed, East Gojjam Zone, Ethiopia. *Open Agriculture*, 8 (1): 20220147. <https://doi.org/10.1515/opag-2022-0147>

Bitew A, Molla E, Meshesha DT, Wato T, Getnet K, Miju C., 2025. Land use dynamics and its effect on selected soil physicochemical properties in Necho watershed, northwest Ethiopia. *Agrosyst. Geosci. Env*, 8 (1). <https://doi.org/10.1002/agg2.70076>

Blake GR, Hartge KH., 1996. Bulk density – Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods, 5: 363-375.

Bockheim JG, Douglass DC., 2006. Origin and significance of calcium carbonate in soils of southwestern Patagonia. *Geoderma*, 136: 751–762

Catoni M, Falsone G, Bonifacio E., 2021. Assessing the origin of carbonates in a complex soil with a suite of analytical methods. *Geoderma*, 175(176): 47-57. <https://doi.org/10.1016/j.geoderma.2021.01.022>

da Silva RJAB, da Silva, YJAB, van Straaten P., 2022. Influence of parent material on soil chemical characteristics in a semi-arid tropical region of Northeast Brazil. *Environ Monit Assess*, 194 (331). <https://doi.org/10.1007/s10661-022-09914-9>

Dokuchaev Soil Science Institute., 2008. Field guide for Russian soils. V.V. Dokuchaev Soil Science Institute, Moscow, 182p.

Dong XJ, Sun HY, Wang JT, Liu XJ, Singh BP., 2020. Wheat-derived soil organic carbon accumulates more than its maize counterpart in a wheat–maize cropping system after 21 years. *European Journal of Soil Science*, 71(4): 695–705. <https://doi.org/10.1111/ejss.12900>

Drouineau G., 1942. Dosage rapid du calcire actif du sol, nouvelles donnies sur la reportation de la nature des fraction calcaires. *Annales Agronomiques*, 12: 441-450.

Faria M, Bertocco T, Barroso A, Carvalho M, Fonseca F, Delerue Matos C, Figueiredo T, Sequeira Braga A, Valente T, Jimenez-Ballesta RA., 2023. Comparison of Analytical Methods for the Determination of Soil pH: Case Study on Burned Soils in Northern Portugal. *Fire*, 6(6): 227. <https://doi.org/10.3390/fire6060227>

Gilliam FS, Yurish BM, Goodwin LM.,1993. Community composition of an old growth longleaf pine forest: relationship of soil texture – Bulletin of the Torrey Botanical Club, 287-294.

Guimaraes CCB, Dematte JA, de Azevedo AC, Sayao VM, da Silva RC, Poppiel RR, dos Santos Teixeira, AF., 2022. Assessing soil mineralogy and weathering degree by a multi-range sensor synergistic approach: From parent rock to topsoil. Journal of South American Earth Sciences, 116: 103855. <https://doi.org/10.1016/j.jsames.2022.103855>

He X, Wang R, Goll SD, Augusto L, Nunan N, Ellwood F MD, Gao Q, Huang J, Qian S, Zhang Y, Shu Z, Li B, Chu C., 2025. Bedrock modulates the elevational patterns of soil microbial communities. Geoderma, 343: 117136. <https://doi.org/10.1016/j.geoderma.2024.117136>

He X, Zeng L, Zhu G, Ellwood MDF, Zhou L, Huang J, Wang C, Li W, Lin D, Wei P, Liu S, Luo M, Zhang Y, Yang Y., 2024. Parental material and climate jointly determine the biomass and diversity of soil microbial communities along an elevational gradient on a subtropical karst mountain. Journal of Biogeography, 51(7):1185-1198. <https://doi.org/10.1111/jbi.14814>

Hu H, Li M, Wang G, Drosos, M, Li Z., 2019. Water-soluble mercury induced by organic amendments affected microbial community assemblage in mercury-polluted paddy soil. Chemosphere, 236: 124405. <https://doi.org/10.1016/j.chemosphere.2019.124405>

Hu P, Zhang W, Wanek W., 2025. Calcium-rich parent materials enhance multiple soil functions and bacterial network complexity. Communications Earth & Environment, 6(1): 797. <https://doi.org/10.1038/s43247-025-02761-9>

Ibrahim IA, Jabbour AA, Abdulmajeed AM, Elhady ME, Almaroai YA , Hashim AM., 2022. Adaptive Responses of Four Medicinal Plants to High Altitude Oxidative Stresses through the Regulation of Antioxidants and Secondary Metabolites. Agronomy, 12: 3032. <https://doi.org/10.3390/agronomy12123032>

Jenny H., 2005. Factors of soil formation a system of quantitative pedology. University of California, Berkeley, 190.

Juita N, Sudarsono I., 2020. The role of soil minerals in red and black Vertisol in Jeneponto Regency. Earth Environ. Sci, 486: 012139. <https://doi.org/10.1088/1755-1315/486/1/012139>

Kebebew S, Bedadi B, Erkossa T , Yimer F, Wogi L., 2022. Effect of Different Land-Use Types on Soil Properties in Cheha District, South-Central Ethiopia, Sustainability, 14(3): 1323. <https://doi.org/10.3390/su14031323>

Leksungnoen N, Andriyas T, Andriyas S., 2018. EC<sub>e</sub> prediction from EC<sub>1:5</sub> in inland salt-affected soils collected from Khorat and Sakhon Nakhon basins, Thailand.

Communications in Soil Science and Plant Analysis, 49(21):2627–2637.  
<https://doi.org/10.1080/00103624.2018.1524900>

Li ZY, Bao LX, Tang XS, Xiao QK, Ged JC, Xie TH, He BH, Mueller WC, Liang C., 2024. Toward soil carbon storage: The influence of parent material and vegetation on profile-scale microbial community structure and necromass accumulation. *Soil Biology and Biochemistry*, 193: 109399. <https://doi.org/10.1016/j.soilbio.2024.109399>

Lu Y, Wang X, Wang M, Zhu B, Zheng M, Li S , Song K., 2023. Soil color mapping based on Munsell system in the northeast of China. *Geoderma*, 439: 116669. <https://doi.org/10.1016/j.geoderma.2023.116669>

Michalet R, Liancourt P., 2024. The interplay between climate and bedrock type determines litter decomposition in temperate forest ecosystems. *Soil Biology and Biochemistry*, 195: 109476. <https://doi.org/10.1016/j.soilbio.2024.109476>

Moritsuka N, Matsuoka K, Katsura K, Sano S, Yanai J., 2014. Soil color analysis for statistically estimating total carbon, total nitrogen and active iron contents in Japanese agricultural soils. *Soil Science And Plant Nutrition*, 60: 475-485. <https://doi.org/10.1080/00380768.2014.906295>

Muhs D., 2001. Evolution of soils on Quaternary reef terraces of Barbados, West Indies. *Quat. Res*, 56: 66–78.

Murugasamy V, Kaliaperumal R, Pazhanivelan S, Maragatham S, Prabhu S., 2023. Influence of Parent Material and Land Use Types on Soil Properties of Tamil Nadu, India. *International Journal of Environment and Climate Change*, 13(9): 2689-2696. <https://doi.org/10.9734/IJECC/2023/v13i92500>

Pegalajar M C, Ruiz LGB, Sanchez-Maranon M, Mansilla L., 2020. A Munsell colour-based approach for soil classification using fuzzy logic and artificial neural networks. *Fuzzy Sets and Systems*, 401:38–54 . <https://doi.org/10.1016/j.fss.2019.11.002>

Peng Y, Chahal I, Hooker DC, Van Eerd LL., 2024. Comparison of equivalent soil mass approaches to estimate soil organic carbon stocks under long-term tillage. *Soil Tillage Res*, 238: 106021. <https://doi.org/10.1016/j.still.2024.106021>

Petlušová V, Hreško J, Mederly P, Moravčík M, Petluš P., 2024. Spatial distribution of soil depth in relation to slope as a consequence of erosion-accumulation processes in loess lowland hills of Slovakia. *Folia Oecologica*, 51 (2):196–207. <https://doi.org/10.2478/foecol-2024-0019>

Puppini A ,Tognin D, Ghinassi M, Franceschinis E, Realdon N, Marani M, D'Alpaos A., 2025. Depth-Distribution Patterns of Soil Organic Matter in the Tidal Marshes of the Venice Lagoon (Italy): Signatures of Depositional and Environmental Conditions. *Journal of Geophysical Research: Biogeosciences*, 130(2): e2024JG008327. <https://doi.org/10.1029/2024JG008327>

Reira MG, de Oliveira FS, da Silva RC, Junior CR, da Silva Neto EC, de Souza JJ, Schiavo JA, de Souza Oliveira N, do Nascimento CW., 2024. Parent materials influence in the formation of vertical textural differentiation in humid tropical landscapes. *Catena*, 242: 108127. <https://doi.org/10.1016/j.catena.2024.108127>

Rhoades JD., 1982. Cation exchange capacity. In Page, A.L., Miller, R.H. and Keeney, D.R. (eds). *Methods of Soil Analysis. Part 2 Agron 9*. Madison WI, 149-157.

Robinson DA, Thomas A, Reinsch S, Lebron CJ, Maskel LC, Wood CM, Seaton FM, Emmett BA, Cosby BJ., 2022. Analytical modelling of soil porosity and bulk density across the soil organic matter and land-use continuum. *Scientific Reports*, 12(1): 7085. <https://doi.org/10.1038/s41598-022-11099-7>

Rukia A, 1991. Diagnostic properties and classification of cinnamonic soil. PhD Thesis, T.C.X.A., Moscow. pp:220.

Rukia A, Mufaddal B, Mufaddal I., 2012. Study of some soil properties formed on calcareous rocks in Baniyas region and its classification. *Tishreen University Journal for Research and Scientific Studies, Biological Sciences Series*, 35 (3):150-166.

Sadiq FK, Maniyunda LM, Anumah AO, Adegoke KA., 2021. Variation of soil properties under different landscape positions and land use in Hunkuyi, Northern Guinea savanna of Nigeria. *Environ Monit Assess*, 193(4): 178.

Schweizer SA, Aehnelt M, Bucka F, Totsche KU, Kögel-Knabner I., 2024. Impact of bare fallow management on soil carbon storage and aggregates across a rock fragment gradient. *J. Plant Nutr. Soil Sci*, 187 (1): 118–129.

Silva B PC, Silva MLN, Silva SHG, Silva AC, da Rocha HR, Inda AV, Curi N., 2022. From rock to soil: Elemental mobility during pedogenesis in a deep Ultisol profile at the Mantiqueira Mountain Range, Southeastern Brazil. *Geod. Reg*, 31: e00576.

Sirisathitkul Y, Sirisathitkul C., 2025. Decoding Soil Color:Origins, Influences, and Methods of Analysis. *AgriEngineering*, 7(58).

Soil Survey Staff., 2014. *Illustrated guide to soil taxonomy*, U.S. Department of Agriculture, Natural Resources Conservation Service. National Soil Survey Centre. Lincoln, Nebraska.

Thomas GW., 1982. Exchangeable cations. In: AL, Page, RH, Miller, and DR, Keeney (eds.) *Methods of Soil Analysis. Part 2. Chemical and microbiological properties*. 2nd ed. Agronomy. Monogram. 9. Agronomy Society America and Soil Science Society American. Madison, WI, 159-165.

Türk G, Gey CJ, Schöne BR, Floriancic MG, Kirchner JW, Leonard L, Gourdol L, Keim R, Pfister L., 2025. Bedrock geology controls on new water fractions and catchment functioning in contrasted nested catchments. *EGUsphere*, 2025: 1-30.

Yang Y, Berhe AA, Barnes ME, Moreland KC, Tian Z, Kelly AE, Bales RC, O'Geen AT, Goulden ML, Hartsough P., 2022. Climate Warming Alters Nutrient Storage in Seasonally Dry Forests: Insights From a 2,300 m Elevation Gradient. – *Global Biogeochemical Cycles*, 36: e2022GB007429.

Zhang YS, Luo KN, Li YX, Gu QY, Fu ZF, Zhang XX, Feng HW., 2023. Canonical Correlation Analysis and Optimum Proposals of Soil Nutrients and Fruit Quality of Ningxian Yellow-Flesh Peach. *Non-Wood For. Res*, 41: 38–48.