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Morphological Feature and Physicochemical Characteristics of Soils under *Festuca* spp. Dominant Steppe at High Mountain and Mountain of Khuvsgul, Mongolia

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Abstract

The morphology, physicochemical, humic substances and micromorphological characteristics of four soil profiles of the steppe dominant by *Festuca lenensis* (*F. lenensis*) at the high mountain and mountain of Khuvsgul, Mongolia were studied. Soils were classified as Regosols and Leptosols at high mountain steppe, Leptosols and Cambisols at mountain steppe. On a high mountain, the plant root distribution, OC, N and moisture contents were high due to its high precipitation and low temperature. The soils show immature characteristics with low available nutrients, weakly developed crumb structure, many semi- and undecomposed plant residues, and few little organic pigments with few excrements. The humic acids with immature to degraded characteristics indicate that the climatic condition of high mountains inhibits the soil decomposition process. Due to extremely different landform positions, there a sharp difference was observed between studied soils on high mountain steppe. On the summit with a flat position, the soil of TSO1 showed finer soil texture with higher CEC, exchangeable Mg^{2+} and humification degree of SOM compared with the soil of TSO2, which located on the steep slope. This confirms that the abrupt changes in landform on high mountain strongly affect the properties of topsoil. On the mountain steppe, the soil contains higher exchangeable Na^{+}, exchangeable K^{+} and water soluble NO_3^- at topsoil; however, the plant root distribution, OC, N and moisture contents were lower than that of high mountain soil. Because of warmer air and soil temperature in comparison with that of high elevation, active turnover in humic horizon and chemical weathering process lead to higher available nutrients in mountain steppe. The degraded to well humified characteristics of humic acid, moderately developed crumb structure, a higher component of little organic pigment and many intact excrements indicate that the soil decomposition process and biological activity were higher than that of the high mountain steppe. Our finding suggests that the climatic condition dependent on altitude and landform position at the high mountain and mountain of Khuvsgul had a large impact and played a key role in the soil properties and characteristics of steppe dominant by *F. lenensis*.

Keywords

Soil Micromorphology, Soil Physicochemical, *Festuca lenensis*, Mountain Steppe, Khuvsgul

1. Introduction

Festuca lenensis (*F. lenensis*) is an edificatory of Fescue steppe communities distributed in central Asia–south Siberian origin and forms a large circumpolar range in the Holarctic [1]. The species is most resistant to drought, cold [2], and the impact of anthropogenic factors [3]. Besides being of high ecological importance, *F. lenensis* is also precious rangeland plant species. Due to its high feed value and good for fatting livestock, the sheep, goats, and horses graze excellently throughout the year, and cattle graze well to fairly [4].

Over the last ~50 years, the sharp decrease in Poaceae grasses, such as *F. lenensis*, *Poa attenuata*, and *Koeleria altaica* has been associated with overgrazing in combination with the effects of a drying climate [5] [6]. Because of the increasing anthropogenic impact of severe climate condition that leads to grazing pressure and an alteration in the steppe, the previous studies of *F. lenensis* were mostly focused on its biomass, plant production and response to several biotic and abiotic factors. In Transbaikalia steppe, Boikov and Kharitonov [7] evaluated the biomass production of *F.lenensis* at both above- and below-ground organs and estimated the distribution of root biomass in soil layers. Another study shows the change in plant community dominant by *F.lenensis* with a reduction of abundance and productivity in different degradation levels in Mongolia [8]. Casper [9] studied how *F. lenensis* respond to soil moisture variation and the importance of legumes as N fixers across the topographic landscape, whereas Liancourt [10] observed the interplay between abiotic factors and biotic interactions and the potential role of *F. lenensis* response to climate change across the landscape to understand the ecological significance. Although the importance and conservation methods of steppe dominant by *F. lenensis* are being studied, its soil characteristics have not received much attention. Without the baseline data on soil diversity, it is difficult to understand its feature and find ways to conserve them further.

F. lenensis is a dominant characteristic species of the high mountain and mountain steppe in Khuvsgul, northern Mongolia [10] [11] [12]. On the high mountain, the soil of steppe vegetation dominant by *F. lenensis* is mainly distributed on the summit and steep slope position above the mountain taiga. While on the mountain steppe the *F. lenensis* is mostly distributed on the eastern and southern middle slopes. It is because the mountain steppe is bordered by mountain taiga on the top and north side of the mountain. Although the high mountain and mountain soils of this area have been studied previously, the results are presented in very few research papers published in Russian and Mongolian [13]-[19]. Previous pedological studies in the mountainous areas of Khuvsgul have focused on mountain forests [20]; however, very few studies have been conducted in high mountain and mountain steppe zones [21].

Depending on the feature of Fescue steppe distribution there are elevation and landform differences between high mountain and mountain steppe. Due to the large differences, there are dramatic variations in climatic and topographical factors. Those factors affecting the soil properties [22] [23] [24] [25] [26], such as physicochemical characteristics [27] [28] humification process [29], and biological activities [30], lead to different soil characteristics at high mountain and mountain steppe.

Environmental conditions, mainly climatic conditions, have a variable effect on the formation of soil humic substances [31]. Humic substances in soil organic matter (SOM) are traditionally separated into humic acid (HA), fulvic acid, and humin, based on the solubility characteristics of each fraction [32]. The analysis of humus composition and the classification of HA [33] [34] are used to determine the chemical properties of HA, such as the degree of humification. These techniques are a first step in elucidating the SOM characteristics in high mountain and mountain steppe under different environmental and altitudinal conditions.

Previous pedological studies in the mountainous area of Khuvsgul focused on morphology and physicochemical characteristics [20]. However, to date, there has been no investigation into the micro morphological characteristics of the soil. Soil micro morphological analysis is a useful method for assessing soil quality [35]. The microstructure, voids, organic composition, and excrement pedofeatures of soil, can elucidate the alteration process, decomposition rate, and biological activities of the soil at different elevations, under varying environmental conditions in the high mountain and mountain steppe of Khuvsgul.

Therefore, the aim of this study was to characterize the physicochemical properties, humic substances, and micro morphological characteristics of soil under the Fescue steppe. We primarily focused on the differences of soil properties between high mountain and mountain steppe dominant by *F. lenensis* in Khuvsgul in order to contribute to further studies of the Fescue steppe characteristics and its conservation.

2. Materials and Methods

2.1. Study Site

This study was conducted in Khuvsgul Province (**Figure 1**), a mountainous area in the most northern part of Mongolia along the border of Siberia. The elevations

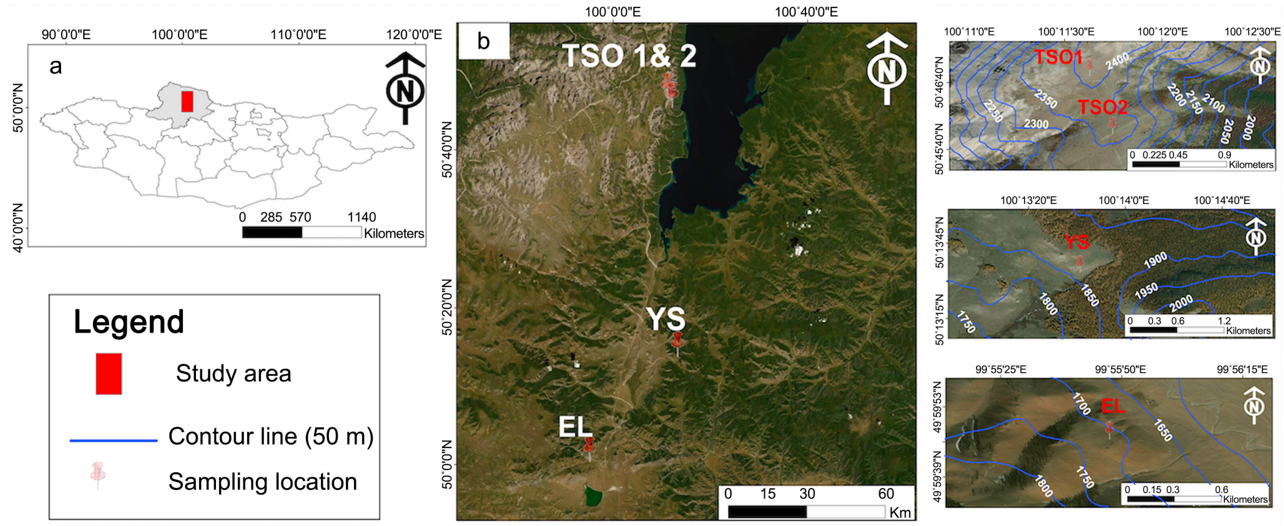

Figure 1. Map and satellite image showing the locations of the study sites. (a): country map, (b): study area.

range between 1500 m and 3000 m above sea level (m.a.s.l.) [36]. The geology of the area is related to the ancient Siberian platform and the young Central Asian Mobile Belt [37]. The Khuvsgul Mountain Range is underlain by volcanic rocks and carbonates [21] [38].

The climate of the study area is characterized as extremely continental with large annual and diurnal air temperature fluctuations and uneven distribution in atmospheric precipitation between the seasons [37]. Humid cold and semi-humid mild cold climate zones are distributed throughout the Khuvsgul region [12] [39]. The high mountain steppe relates to humid cold zone with an average air temperature lower than −25˚C in winter and 15˚C in summer. The area receives rainfall between 350 and 400 mm·yr^{-1} with maximum precipitation of 400 - 500 mm in July. On the mountain steppe the average air temperature is about −25˚C in winter while 20˚C in summer. The average annual precipitation in the mountain steppe is about 300 mm [12] [38].

According to our research objectives, we chose the steppe sites which are dominant by *F. lenensis*. Soil samples were collected from four representative sites at the high mountain which is poorly accessible and mountain steppe. Due to the feature of the high mountain and mountain steppe distribution that bordered with mountain taiga and forest steppe in Khuvsgul, the soils were collected from different mountains. The study sites were located on the Tsots High Mountain (TSO1 and TSO2), Yargis Mountain (YS) and Erkhel Mountain (EL) (**Figure 1**, **Table 1**). Soil samples of TSO1 and TSO2 were collected on July 28, 2016, whereas YS and EL samples were collected on August 3, 2018, and August 2, 2018, respectively. The topographical positions of study sites are summit, steep slope, and middle slopes for TSO1, TSO2, YS and EL, respectively. Based on our field survey, the vegetation types at TSO1, TSO2, YS and EL are best defined as Dryas oxyodonta-Carex high mountain (alpine) steppe, fescue-forb high mountain (alpine) steppe, fescue-grass mountain petrophyte steppe and fescue-grass mountain steppe, respectively.

Table 1. Information of the study sites.

Study sites	Location	Elevation (m.a.s.l)	Natural zone	Landform
TSO1	N50˚46'04.08" E100˚11'38.40"	2407	High mountain steppe	Summit
TSO2	N50˚45'45.55" E100˚11'46.45"	2356	High mountain steppe	Steep slope
YS	N50˚13'39.65" E100˚13'39.20"	1870	Mountain steppe	Middle slope
EL	N49˚59'45.96" E099˚55'44.89"	1703	Mountain steppe	Middle slope

2.2. Determination of Soil Properties

2.2.1. Analysis of Morphological and Physicochemical Characteristics

Soil profile morphological characteristics were described according to the Guidelines for Soil Description [40] and classified using the WRB [41]. Soil samples were collected from each soil horizon at the four study sites, except for the deepest horizon BC at TSO2, which was mainly bedrock. Samples were gently crushed with a mortar and pestle for the analysis of physicochemical properties after being air-dried and sieved through a 2-mm sieve. The moisture content of the sample was determined shortly before the soil analysis [42]. The particle size was confirmed using the pipette method [42]. Soil textures were classified using the clay: silt: sand ratio and interpreted using a textural triangle [40]. The organic carbon (OC) and nitrogen (N) content of the samples were measured by the dry combustion method using an NC analyzer (SUMIGRAPH NC-900, Sumika Chemical Analysis Service, Tokyo, Japan) following pretreatment with 20% of H_3PO_4 to remove inorganic carbon. Calcium carbonate content was determined using the acid neutralization method [42]. The pH values of the samples were determined for 1:2.5 air-dried soil: distilled water solutions using a glass electrode pH meter (HM-30R, DKK-TOA Co., Tokyo, Japan) and electric conductivity (EC) was determined for a 1:5 air-dried soil: distilled water solution using a platinum electrode (CM-30R, DKK-TOA Co., Tokyo, Japan). Exchangeable bases of 1 M CH_3COONH_4 (pH 7.0) extracts were measured using atomic absorption spectrophotometry, and cation exchange capacity (CEC) was measured in a 1 M CH_3COONH_4 (pH 7.0) sample using the semi-micro Schollenberger method [43]. Water-soluble ions were extracted from a 1:5 soil: distilled water solution. The Ca^{2+}, Na^+, Mg^{2+}, and K^+ were determined by atomic absorption spectrophotometry (AA-6200, Shimadzu Corp., Kyoto, Japan). The concentrations of Cl^-, NO_3^-, SO_4^{2-}, and PO_4^{3-} were determined using high-performance liquid chromatography (LC-10A, Shimadzu Corp., Kyoto, Japan).

2.2.2. Humic Substance

Air-dried soils (≤0.5 mm particle size) were used for the humic substance analysis. The extraction method, based on [33], was performed using the following procedure. Sixty milliliters of 0.5% NaOH were added to the weighted soil samples containing 200 mg of carbon, and heated at 100˚C for 30 min. After heating, the soil suspension was cooled to room temperature. Next, 20 mL of the extract was placed in 50 mL plastic centrifuge tubes and centrifuged at 4000 rpm for 20 min. The extracts were acidified with 0.2 mL of concentrated H_2SO_4 for 1 h. The precipitate was dissolved in 0.1% NaOH (HA fraction) after the extracts were filtered using filter paper (Advantec No 5 C) (fulvic acid fraction). The extracted humic and fulvic acid fractions were measured using the $KMnO_4$ oxidation method.

For HA, ΔlogK and RF values based on the spectrophotometric properties of HAs are used as indexes of humification degree. The indexes are defined as follows: $\Delta\log K = \log E400 - \log E600$, where E400 and E600 are the absorbances at 400 and 600 nm using a spectrophotometer (Jasco V-660, Tokyo, Japan), respectively. And $RF = E600/K \times 2247$ where K is the mL of titration by 0.1N $KMnO_4$ for 30 mL HA solution [34] [44]. HAs were classified into A, B, Rp, and P types according to [34].

2.2.3. Preparation and Description of Soil Thin Sections

To analyze the soil thin sections, 100 mL core samples were collected from 0 - 5 cm undisturbed surface soils in the three soil profiles. As per [45], the intact soil samples were freeze-dried and impregnated with a polyester resin (Polyester resin A and B, MARUTO, Japan) and benzyl peroxide (Embedding agent, MARUTO, Japan). Following vacuum impregnation over three days, the samples were cured under a fume hood for up to three months, and soil thin sections were cut using a diamond cutter. The samples were then ground using abrasion (C3000, MARUTO) (first polishing) and bonded onto a glass slide (5 cm × 5 cm) with epoxy resin. A second polishing was performed with abrasive paper and a lapping machine was used to reduce the thickness of the samples to 30 μm. Thin sections were examined using optical microscopy (OLYMPUS BH-2). Soil thin section descriptions are based on the Handbook for Soil Thin Section Description [35].

Optical microscopy images of soil thin section were used to measure the void distribution. The ImageJ software (National Institutes of Health, USA) was used for quantifying voids. Images were treated using gray scale (conversion of RGB image into 8 bits), segmentation through the threshold, and conversion of images into binary images which transparent minerals were manually marked by comparing the original images in PPL and XPL. The total void of 10 random images per sample was calculated as the sum of the areas of all the voids divided by the total area of the field and expressed as a percentage [46].

3. Results

3.1. Soil Profile Morphology and Physicochemical Characteristics

Description of soil profile morphology (**Table 2**) showed that soil profile depths were shallow, ~35 cm at TSO1 and TSO2, ~25 cm at YS and ~60 cm at EL.

Table 2. Description of soil profile morphology.

Horizon	Depth (cm)	Color	Texture[a]	Structure[b]	Root[c]	Hardness (mm)	HCl[d]
TSO1							
A1	0 - 10	10YR 2/2	SiC	ST-FI-CR	VF-M, F-C, MC-F	13	N
A2	10 - 19	10YR 3/3	SiC	ST-ME-CR	FF-C	20	MO
Bk1	19 - 28	2.5Y 4/2	SiC	MO-FI-SB	FF-V	16	ST
Bk2	28 - 35	2.5Y 4/3	SiL	MO-FI-SB	FF-V	15	EX
TSO2							
A	0 - 7	7.5YR 2/2	SiL	MO-ME-CR	FF-M	11	N
Bk1	7 - 16	10YR 3/4	SiL	WM-ME-SB	VF-M	15	ST
Bk2	16 - 29	10YR 3/2	SiL	MA	FF-F	11	EX
BC	29 - 35	-	-	-	-	-	-
YS							
A1	0 - 9	10YR 3/2	SiC	ST-VF-SB	VF-C	9	ST
A2	9 - 15	10YR 4/3	SiC	MO-FI-AB	VF-F	10	EX
Bk1	15 - 20	10YR 5/4	SiL	ST-FI-AB	N	17	EX
Bk2	20 - 25	10YR 5/3	SiL	MA	N	23	EX
EL							
A1	0 - 11	10YR 3/4	SC	ST-VF-GR	F-C	15	N
A2	11 - 19	10YR 3/3	SL	ST-VF-GR	VF-F	17	N
A3	19 - 25	7.5Y 4/3	SL	ST-VF-GR	VF-F	18	N
AB	25 - 45	10YR 4/4	SL	MO-FI-GR	VF-F	16	N
BC	45 - 60	7.5YR 5/4	SL	MO-FI-GR	N	23	N

Descriptions of soil profile morphology were made according to FAO (2006). [a] SiC: silty clay, SC: sandy clay, SiL: silt loam, SL: sandy loam. [b] WE: weak, MO: moderate, ST: strong, MW: weak to moderate, VF: very fine, FI: fine, ME: medium, CR: crumbly, GR: granular, SB: subangular blocky, AB: angular blocky, MA: massive. [c] VF: very fine, F: fine, M: medium, C: coarse, FF: very fine and fine, MC: medium and coarse, V: very few, F: few, C: common, M: many, N: none. [d] N: non-calcareous, MO: moderately calcareous, ST: strongly calcareous, EX: extremely calcareous.

Among the A horizon, TSO2 was considerably thinner than TSO1, YS and EL reaching depths of ~7 cm. TSO1, YS and EL reached 19 cm, 15 cm and 45 cm, respectively. A brownish black to dark brown soil color was present in the topsoil at study sites, changing to olive brown with depth (2.5Y 4/3) at TSO1, to brownish black (10YR 3/2) at TSO2, to dull yellowish-brown (10YR 5/3) at YS and to dull brown (7.5YR 5/4) at EL. In the field survey, a silty clay texture was observed in the top horizons and changed to silt loam in sub horizons at TSO1 and YS. The horizons of TSO2 maintained silt loam textures while EL shows sandy clay texture at the top horizon and changed to sandy loam texture in sub horizon. A crumb structure in top horizons was strongly developed in TSO1 and moderately developed in TSO2. A subangular blocky structure was strong developed and granule structure was strongly to moderately develop at top horizons of YS and EL, respectively. The plant root distribution in topsoil was more frequent at TSO1 than TSO2, YS and EL. Generally, the roots were distributed throughout almost all horizons, except B, at YS and EL. Soil hardness were increased from top horizon to the sub horizons all sites except TSO2. The $CaCO_3$ accumulation were observed at TSO1, TSO2 and YS. By adding some drops of 10% hydrochloric acid (HCl) to the soil, a strongly to extreme reaction showed in Bk horizon of TSO1, TSO2 and in all horizons of YS. The carbonate crust was accumulated on the rock fragments in soil profile of TSO1, TSO2 and YS. The non-reaction showed in EL.

Tables 3-5 list the physicochemical characteristics of the studied soils. The clay contents were decreased to the B horizons at all sites and showed 14.18%, 19.02%, 15.10% and 19.99% in the topsoil of TSO1, TSO2, YS and EL, respectively. The highest silt content was observed at A horizon of TSO1 (47.55%), followed by TSO2 (21.96%), YS (16.13%) and EL (19.35%). The fine sand contents were increased with soil depth at TSO1 and TSO2, while decreased at YS and EL. Among the topsoil the highest fine sand content was detected at YS (41.79%). The coarse sand fraction was decreased to the sub soil at TSO1 and TSO2, while increased at YS and EL. The lowest content of coarse sand in surface soil was found at TSO1 (10.65%) followed by YS (26.99%), EL (31.81%) and TSO2 (34.74%). Based on the analysis performed in laboratory the soil textures were classified as loam to fine sandy loam, coarse sandy loam to loam, fine sandy loam to coarse sandy loam and sandy clay loam to coarse sandy loam in TSO1, TSO2, YS and EL, respectively. Among the topsoil of studied area, the finest and coarsest soil textures were observed in the high mountain steppe; however, there was no difference was observed in soil texture classes between high mountain and mountain steppe.

OC contents were highest in the top horizons and linearly decreased toward the bottom horizons at all sites. The contents in A horizon of TSO1 (94.25 $g \cdot kg^{-1}$) and TSO2 (68.01 $g \cdot kg^{-1}$) are much higher than those of YS (30.52 $g \cdot kg^{-1}$) and EL (30.01 $g \cdot kg^{-1}$). The N content were 9.06 $g \cdot kg^{-1}$, 7.89 $g \cdot kg^{-1}$, 5.27 $g \cdot kg^{-1}$ and 4.31 $g \cdot kg^{-1}$ in the topsoil of TSO1, TSO2, YS and EL, respectively and showed a similar tendency with OC. Based on the OC and N contents, the C:N ratio of topsoil was highest in TSO1 (10.41), followed by TSO2 (8.62), EL (6.97) and YS (5.80).

The moisture contents were decreased to the subsoil at all sites. Among the A horizon the highest moisture content was observed at TSO1 (64.73 $g \cdot kg^{-1}$) followed by TSO2 (47.71 $g \cdot kg^{-1}$), EL (23.63 $g \cdot kg^{-1}$) and YS (21.54 $g \cdot kg^{-1}$). The soil moisture was very strongly correlated with OC at the high mountain steppe ($R^2 = 0.9704$) while strongly correlated with clay at the mountain steppe ($R^2 = 0.6518$).

$CaCO_3$ contents were increased to the Bk horizons at TSO1, TSO2 and YS. The highest contents were observed at YS, ranged from 46.86% to 61.99%, while the lowest contents were detected at EL ranged from 1.43% to 2.22%.

Table 3. The average value of particle size analysis.

Horizon	Clay	Silt	Fine sand	Coarse sand	Texture classes[a]
	%				
TSO1					
A1	14.18	47.55	27.63	10.65	L
A2	12.07	44.54	37.42	5.96	L
Bk1	9.78	34.75	47.13	8.34	FSL
Bk2	12.82	29.32	54.82	3.04	FSL
TSO2					
A	19.02	21.96	24.28	34.74	CSL
Bk1	10.88	32.07	33.77	23.29	MSL
Bk2	13.68	38.45	26.22	21.65	L
YS					
A1	15.10	16.13	41.79	26.99	FSL
A2	12.96	13.97	40.84	32.23	FSL
Bk1	11.36	16.61	39.45	32.58	FSL
Bk2	12.65	17.82	34.07	35.46	CSL
EL					
A1	19.99	19.35	28.85	31.81	SCL
A2	13.65	12.13	23.45	50.77	CSL
A3	14.66	15.05	27.11	43.18	CSL
AB	18.84	19.06	37.55	24.55	FSL
BC	7.51	6.88	15.68	69.93	CSL

Soil textures were classified according to FAO (2006). [a] L: loam, SCL: sandy clay loam, FSL: fine sandy loam, MSL: medium sandy loam, CSL: coarse sandy loam.

Table 4. Average values of soil chemical analysis.

Site	OC	N	C:N	Moisture	$CaCO_3$	pH (H_2O)	EC	Exchangeable bases					CEC
								Ca^{2+}	Na^{+}	Mg^{2+}	K^{+}	sum	
	$g \cdot kg^{-1}$			$g \cdot kg^{-1}$	%		$dS \cdot m^{-1}$	$cmol(+)kg^{-1}$					$cmol(+)kg^{-1}$
TSO1													
A1	94.25	9.06	10.41	64.73	30.55	8.00	0.21	13.90	0.56	7.98	1.07	23.51	42.62
A2	75.90	7.67	9.90	61.06	31.78	8.20	0.12	14.16	0.47	8.97	0.95	24.55	40.25
Bk1	27.80	1.18	23.53	21.06	39.23	8.50	0.06	20.68	0.38	9.86	0.53	31.44	9.14
Bk2	31.74	1.37	23.18	21.77	39.19	8.50	0.06	32.59	0.25	13.24	0.43	46.51	9.35
TSO2													
A	68.01	7.89	8.62	47.71	13.88	7.60	0.17	20.14	1.23	2.01	0.64	24.01	29.33
Bk1	24.50	3.04	8.06	24.29	35.28	8.20	0.10	30.55	0.30	3.62	0.38	34.86	10.15
Bk2	16.21	1.98	8.20	14.18	36.34	8.40	0.11	27.28	0.61	3.32	0.46	31.66	9.20

Continued

YS													
A1	30.52	5.27	5.80	21.54	46.86	7.74	0.60	32.96	3.61	3.79	2.39	42.74	39.36
A2	17.99	3.07	5.86	16.25	54.08	8.58	0.20	33.45	1.14	3.42	1.94	39.94	23.60
Bk1	15.21	2.14	7.09	12.25	59.54	8.77	0.17	37.89	1.23	4.10	0.78	44.00	13.74
Bk2	12.92	2.08	6.20	12.45	61.99	8.83	0.16	35.48	0.75	3.80	0.81	40.84	14.72
EL													
A1	30.01	4.31	6.97	23.63	2.22	6.86	0.38	17.26	3.41	3.90	3.47	28.04	38.43
A2	11.95	1.97	6.05	17.55	1.55	7.52	0.08	11.14	0.90	2.42	1.23	15.69	31.24
A3	9.16	1.74	5.26	20.01	1.78	7.39	0.06	16.01	1.18	2.98	0.72	20.89	31.72
AB	7.88	1.31	6.01	20.13	1.60	7.42	0.06	25.44	1.32	4.46	2.87	34.09	33.59
BC	3.99	0.91	4.37	14.21	1.43	7.38	0.05	13.73	1.05	2.34	1.36	18.49	12.51

Table 5. Average values of water-soluble ions in studied soils.

Horizon	Water-soluble ions							
	Ca^{2+}	Na^{+}	Mg^{2+}	K^{+}	Cl^{-}	NO_3^{-}	SO_4^{2-}	PO_4^{3-}
	cmol(+)kg^{-1}				cmol(-)kg^{-1}			
TSO1								
A1	0.94	0.09	0.81	0.12	0.06	0.21	0.02	n.d.
A2	0.57	0.04	0.53	0.04	0.05	0.07	0.02	n.d.
Bk1	1.12	0.04	0.67	0.03	0.05	0.02	0.04	n.d.
Bk2	1.15	0.04	0.66	0.04	0.05	0.02	0.04	n.d.
TSO2								
A	0.84	0.05	0.18	0.12	0.11	0.30	0.03	0.07
Bk1	0.58	0.03	0.14	0.02	0.05	0.15	0.04	n.d.
Bk2	1.29	0.01	0.65	0.03	0.02	0.12	0.02	n.d.
YS								
A1	1.23	0.08	0.24	0.17	0.07	0.87	0.03	n.d.
A2	1.24	0.04	0.26	0.05	0.06	0.12	0.02	n.d.
Bk1	1.04	0.04	0.23	0.04	0.06	0.06	0.03	n.d.
Bk2	1.56	0.04	0.29	0.05	0.05	0.06	0.05	n.d.
EL								
A1	0.43	0.14	0.15	0.10	0.15	0.54	0.06	n.d.
A2	0.23	0.08	0.07	0.04	0.05	0.07	0.04	n.d.
A3	0.21	0.08	0.07	0.05	0.09	0.09	0.03	n.d.
AB	0.18	0.06	0.06	0.04	0.07	0.05	0.02	n.d.
BC	0.18	0.08	0.06	0.04	0.10	0.02	0.06	n.d.

Table 6. Average values of humic substances.

Horizon	Ct[a]	Cf[b]	Ch[c]	Humin	Extracted humus	Ch/Cf	PQ[d]	Humic acid[e]		
		g·kg^{-1}			%	RF	%	ΔlogK		Type
TSO1										
A1	94.25	22.71	25.05	46.49	50.68	1.10	52.45	0.99	67.26	B
A2	75.90	19.57	23.13	33.20	56.27	1.18	54.17	0.92	75.71	B
Bk1	27.80	5.48	5.05	17.27	37.89	0.92	47.98	1.10	45.55	B
Bk2	31.74	6.16	5.67	19.91	37.26	0.92	47.91	1.20	32.50	Rp
TSO2										
A	68.01	15.82	14.51	37.69	44.58	0.92	47.84	0.99	49.28	B
Bk1	24.50	5.22	4.83	14.45	41.01	0.93	48.07	1.81	20.35	Rp
Bk2	16.21	3.16	2.88	10.17	37.27	0.91	47.66	1.48	25.47	Rp
YS										
A1	30.52	7.78	7.65	15.10	50.53	0.98	49.57	0.91	66.67	B
A2	17.99	4.89	4.53	8.57	52.34	0.93	48.09	0.93	55.12	B
Bk1	15.21	3.87	3.64	7.71	49.32	0.94	48.48	0.99	45.46	B
Bk2	12.92	3.18	2.95	6.79	47.43	0.93	48.13	0.96	53.31	B
EL										
A1	30.01	7.52	7.27	15.22	49.28	0.97	49.19	0.75	119.67	A
A2	11.95	3.26	3.13	5.57	53.43	0.96	48.96	0.73	139.23	A
A3	9.16	2.63	2.42	4.11	55.09	0.92	47.87	0.76	125.40	A
AB	7.88	2.18	1.98	3.72	52.75	0.91	47.66	0.89	72.77	B
BC	3.99	0.86	0.87	2.25	43.50	1.01	50.27	1.22	26.37	Rp

[a] Ct: total organic carbon content, [b] Cf: carbon extracted from fulvic acids, [c] Ch: carbon extracted from humic acids, [d] PQ: percentage of humic acids in extracted humus (humic acids and fulvic acids), [e] Humic acid types A, B and Rp are shown in Figure 2.

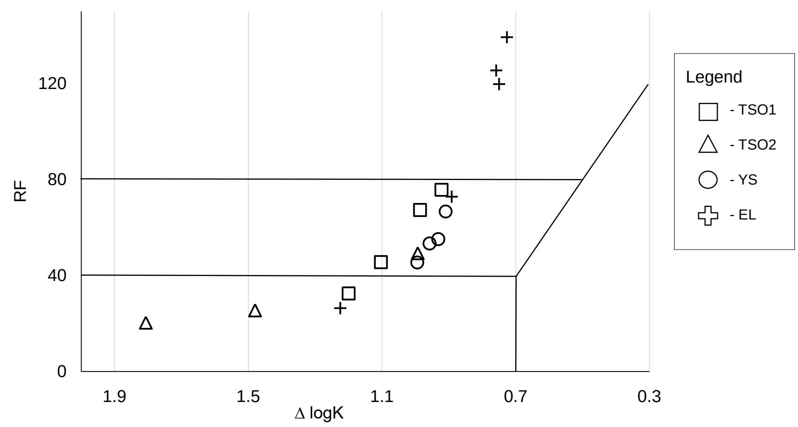

Figure 2. Classification of HA types according to [34].

Soil pH (H_2O) values were neutral to strongly alkaline. The highest pH value among the A horizons was detected at YS (8.58), while the lowest value was found at EL (6.86).

Values of EC decreased with increasing soil depth at all sites. The result of the top horizon of TSO1 (0.21 dS·m^{-1}) is higher than TSO2 (0.17 dS·m^{-1}) but remarkably lower than YS (0.60 dS·m^{-1}) and EL (0.38 dS·m^{-1}).

The highest concentrations among the determined exchangeable bases were noted in Ca^{2+} and Mg^{2+}, which increased with $CaCO_3$ accumulation horizons at TSO1, TSO2 and YS; however, decreased to the subsoil at EL. The highest values of exchangeable Ca^{2+} were detected at YS, ranging from 32.96 to 37.89 cmol(+)kg^{-1}. The remarkably high content of exchangeable Mg^{2+} was observed at all horizons of TSO1. The values of exchangeable Na^+ and K^+ were decreased with soil depth at all sites. The contents of exchangeable Na^+ and K^+ in topsoil of YS and EL were considerably higher than TSO1 and TSO2. Among the topsoil highest sum of exchangeable bases were observed at YS (42.74 cmol(+)kg^{-1}) which was dominant by Ca^{2+}.

CEC values were highest in the A horizons and sharply decreasing in the B horizons at all sites. Among the topsoil highest value was 42.62 cmol(+)kg^{-1} at the top horizon of TSO1; and the A horizon of TSO2 showed a value of 29.33 cmol(+)kg^{-1}, *i.e.*, a lower capacity than the other sites. There was no noticeable change between the B horizons of TSO1 and TSO2, either. No remarkable difference was observed between topsoil of YS and EL which showed 39.36 cmol(+)kg^{-1} and 38.43 cmol(+)kg^{-1} values respectively. In high mountain steppe CEC was very strongly correlated with OC (R^2 = 0.9544), while strongly correlated with clay particle (R^2 = 0.6806) at mountain steppe.

The water-soluble ion content was dominated by Ca^{2+} and Mg^{2+} at all sites. Na^+, K^+, Cl^-, and NO_3^- contents decreased with soil depth at all sites. The highest and lowest value of Mg^{2+} were detected on the high mountain steppe. The A horizon at YS (0.87 cmol(−)kg^{-1}) and EL (0.54 cmol(−)kg^{-1}) had higher NO_3^- values than TSO1 (0.21 cmol(−)kg^{-1}) and TSO2 (0.30 cmol(−)kg^{-1}).

The soils were classified according to World Reference Base for Soil Resources [41]. The weakly developed mineral soils with no significant profile development and not very thin or very rich in coarse fragments were observed at TSO1. Due to its calcium carbonate rich parent material, high OC content and evidence of pedogenic carbonate accumulation in the soil at sub horizon, the soil is classified as Calcaric Regosols (Humic, Protocalcic). Very thin profile and extremely rich in coarse fragments feature showed in TSO2. Due to its significant differences in soil particle-size distribution, calcaric material distribution and evidence of secondary carbonate accumulation in the soil of TSO2 were classified as Lithic Calcaric Leptosols (Protocalcic). The thin, fragile soil profile with calcaric material and evidence of secondary calcium carbonate accumulation was observed at YS in mountain steppe. Therefore, the soil was classified as Calcaric Leptosols (Protocalcic). The transformation of parent material was evident from the soil structure formation and mostly brownish discoloration at EL. The soil horizon differentiation was weak and consolidated, relatively continuous parent material was observed in this soil. The soil texture was mainly sandy clay loam to sandy loam texture. Therefore, the soil of EL was classified as Leptic Cambisols (Loamic).

3.2. Humic Substance

Table 6 shows the properties of humic substances in the soil. Among the topsoil highest content of carbon extracted fulvic (Cf) and humic (Ch) acid was detected at TSO1, followed by TSO2, YS and EL. The percentage of extracted humus contents were decreased from A to B horizons at all sites. At the surface soil, the Ch/Cf ratio was highest (1.10) in TSO1 and lowest (0.92) in TSO2. No remarkable difference was observed between YS (0.98) and EL (0.97). The PQ value in topsoil indicated the highest HA content at TSO1, followed by YS, EL and TSO2. According to HA classification using the ΔlogK and RF value, HA of the topsoil at all sites were classified as B-type except EL which relates to A-type. To the subsoil the HA types were changed to Rp-type at TSO1, TSO2 and EL while B-type remained at YS.

3.3. Micromorphological Characteristics of the Top Horizon

Table 7 shows the micromorphological characteristics of the topsoil. In thin section results, TSO1 and TSO2 were dominated by a complex structure with granules (Figure 3(a)) and Figure 3(d)) and intergrain micro-aggregate structures (Figure 3(b), Figure 3(c) and Figure 3(f), Figure 3(g)). The granular material of TSO1 and TSO2 is not typical and is the transitional result of plant residue fragmentation. The crumb structure observed in TSO2 was very friable (Figure 3(e)). The dominant structure at YS and EL included complex structures with crumb (Figure 3(h) and Figure 3(k)) and intergrain micro-aggregate structures (Figure 3(i), Figure 3(j) and Figure 3(l), Figure 3(m)).

Weakly developed crumb structures were distributed at TSO1 and TSO2 with 0.2 - 0.5 mm, 0.3 - 2.0 mm diameter, respectively while moderately developed crumb structures were observed at YS and EL with 0.5 - 3.0 mm diameter. The distribution of crumb structure was lower at TSO1 (15%) and TSO2 (10%) than YS (35%) and EL (45%). Strongly developed granule structures were found at high mountain steppe while strongly to moderately developed granule structures were observed at mountain steppe. The distribution of granule structures were 85%, 90%, 65% and 55% at TSO1, TSO2, YS and EL, respectively.

The root residues were mainly found in the thin section. The coarse organic fraction (>10 μm) of TSO1 is dominant by well-decomposed (Figure 4(a)), semi-decomposed (Figure 4(b)), and undecomposed (Figure 4(c), Figure 4(d)) plant residues (45%). In TSO2, the coarse organic components are dominant by well-decomposed (Figure 4(e)) and semi-decomposed plant residue (Figure 4. f) and showed the lowest distribution value (20%) among the topsoil of study sites.

In YS, the coarse organic components are dominant by well-decomposed (Figure 4(g)) and semi-decomposed (Figure 4(h)) plant residues (30%). In EL, the coarse organic components are more frequent (32%) compared with YS and dominant by well-decomposed (Figure 4(i)) and semi-decomposed (Figure 4(j)) plant residues.

Table 7. Micromorphological characteristics of topsoil.

		TSO1 (0 - 5 cm)		TSO2 (0 - 5 cm)		YS (0 - 5 cm)		EL (0 - 5 cm)	
Dominant microstructure[a]		Gr and Ima		Gr and Ima		Cr and Ima		Cr and Ima	
	c/f $10_{\mu m}$[b]	En		En		En and Ge		Ge	
Aggregation	Peds[c]	Cr	Gr	Cr	Gr	Cr	Gr	Cr	Gr
	Grade of pedality[d]	We	St	We	St	Mo	Mo-St	Mo	Mo-St
	Abundance (%)	15	85	10	90	35	65	45	55
	Diameter (mm)	0.2 - 0.5	<0.2	0.3 - 2.0	<0.5	0.5 - 3.0	<0.2	0.5 - 3.0	<0.2
Voids	Type[e]	Cdp		Cxp		Cxp		Cxp	
	Abundance (%)[f]	39.13 (±6.82)		34.83 (±6.82)		27.86 (±6.54)		28.89 (±5.63)	
Basic organic components	Coase fraction (>10 μm)								
	Type[g]	Ptr		Ptr		Ptr		Ptr	
	Abundance (%)	45		20		30		32	
	Fine material (<10 μm)								
	Type[h]	Lop		Lop		Lop		Lop	
	Abundance (%)	2		2		5		8	
Excrement pedofeature	Type[i]	AE		did not clearly observed		AE and IE		IE	
	Abundance[j]	24				30		34	

[a] Cr: crumb, Gr: granule, Ima: intergrain micro-aggregate. [b] En: enaulic, Ge: gefuric. [c] Cr: crumb, Gr: granule. [d] We: weakly, Mo: moderately, St: strongly. [e] Cdp: compound packing, Cxp: complex packing. [f] Mean (±standard deviation). [g] Ptr: plant residue. [h] Lop: little organic pigment. [i] IE: intact excrement; AE; aging excrement. [j] Number of observed excrement in the thin section.

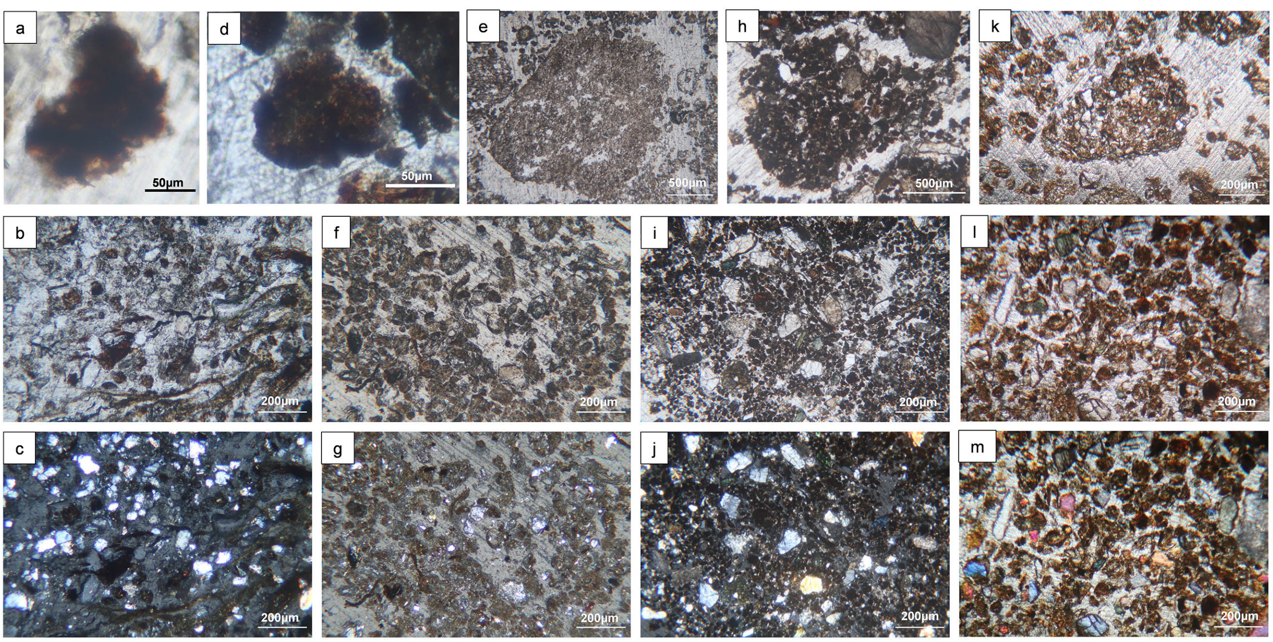

Figure 3. Microstructure of top horizon: (a) granule structure in TSO1 by PPL. (b) (c) intergrain micro-aggregate structure in TSO1 by PPL and XPL. (d) granule structure in TSO2 by PPL. (e) very friable crumb structure in TSO2 by PPL. (f) (g) intergrain micro-aggregate structure in TSO2 by PPL and XPL. (h) crumb structure in YS by PPL. (i) (j) intergrain micro-aggregate structure in YS by PPL and XPL. (k) crumb structure in EL by PPL. (l) (m) intergrain micro-aggregate structure in EL by PPL and XPL.

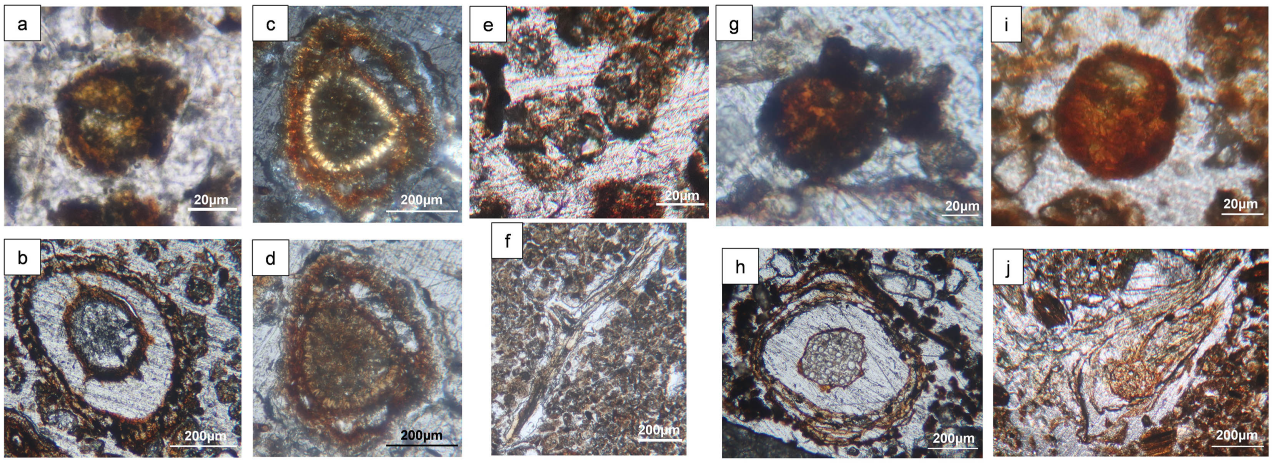

Figure 4. Organic components of the top horizon: (a) well-decomposed plant residue in TSO1 by PPL. (b) semi-decomposed plant residue in TSO1 by PPL. (c) (d) undecomposed plant residue in TSO1 by XPL and PPL. (e) well-decomposed plant residue in TSO2 by PPL. (f) semi-decomposed plant residue in TSO2 by PPL. (g) well-decomposed plant residue in YS by PPL. (h) semi-decomposed plant residue in YS by PPL. (i) well-decomposed plant residue in EL by PPL. (j) semi-decomposed plant residue in EL by PPL.

The distribution of fine organic components (<10 μm) of TSO1 and TSO2 are only 2%, while in YS and EL are 5% and 8%, respectively, which are more distributed than those of TSO1 and TSO2.

Excrement was observed in TSO1, YS and EL. In TSO1, aging excrement (**Figure 5(a)**) was observed. In YS, aging (**Figure 5(b)**) and intact excrements (**Figure 5(c)**) were detected while intact excrements were found in EL (**Figures 5(d)-(f)**). In TSO2, excrement was not evident; however, several granules, which might be residual aging excrement, were observed. The result shows the number of excrements was lower at TSO1 (24) than YS (30) and EL (34).

TSO1 was characterized by compound packing voids, whereas TSO2, YS and EL were characterized by complex packing voids. From the Image J software, the mean percentage of voids were found as 39.13%, 34.83%, 27.86% and, 28.89% in TSO1, TSO2, YS and EL, respectively (**Figure 6**).

4. Discussion

4.1. Soil Morphology and Physicochemical Characteristics at High Mountain and Mountain Steppe Dominant by *F. lenensis*

The studied soil profiles are thin and fragile. The soil profile of TSO2 showed thinner topsoil than TSO1, YS and EL. According to the studies [47] [48], the mountain soil on a steep slope is regularly truncated and in a constant state of soil erosion and rejuvenation. Root distribution in topsoil of TSO1 and TSO2 were much higher than YS, and EL. Several studies have shown a close relationship between the distribution of SOM content and elevation gradient [49] [50] [51]. The vegetation at higher elevations is characterized by higher cover due to precipitation, temperature, and moisture. Thus, elevation gradients influence plant distribution [52] [53] [54] [55]. The $CaCO_3$ was mainly concentrated in the lower

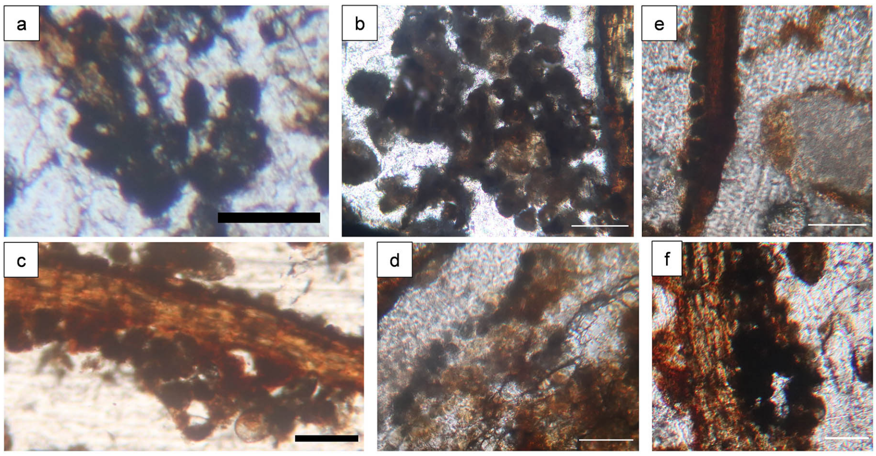

Figure 5. Excrement pedofeature of the top horizon: (a) aging excrement in TSO1 by PPL. (b) aging excrement in YS by PPL. (c) intact excrement in YS by PPL. (d) (e) (f) intact excrement in EL by PPL. (Scale: 50 μm).

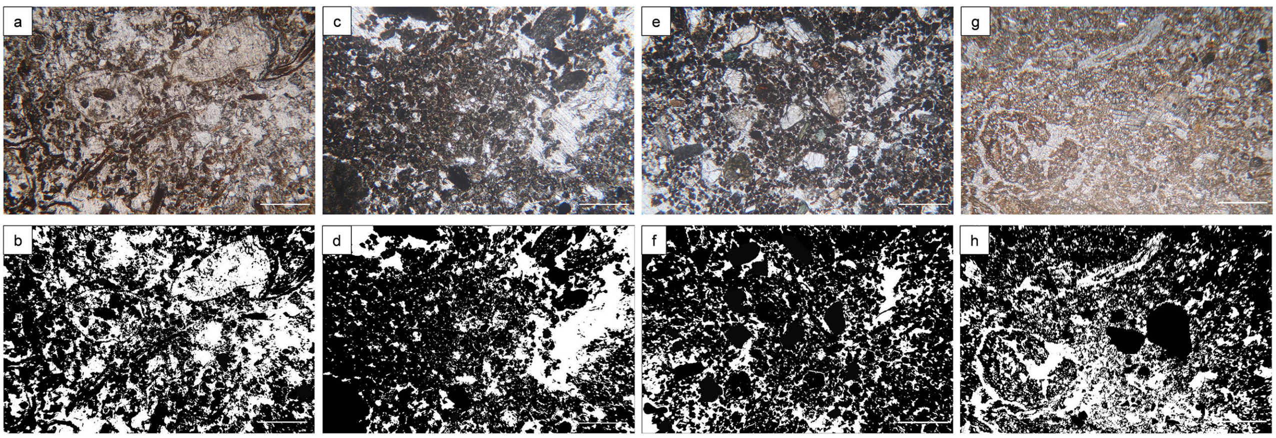

Figure 6. Measurement of void abundance by image J: (a) (b) Compound packing void in TSO1 by PPL and binary (39.13% (±6.82)). (c) (d) Complex packing void in TSO2 by PPL and binary (34.83% (±6.82)). (e) (f) Complex packing void in YS by PPL and binary (27.86% (±6.54)). (g) (h) Complex packing void in EL by PPL and binary (28.89% (±5.63)). (Scale: 500 μm).

soil horizons of TSO1, TSO2 and YS. Calcium carbonate-rich parent material, and the layers of carbonate crust were accumulated by advanced pedogenesis, due to carbonate leaching from the upper to the lower part of the soil profile [56] [57] [58]. Due to the abundance of non-carbonate and Al rich parent material (syenite) [59] [60] the soil of EL barely showed a reaction with HCl.

When comparing the high mountain and mountain steppe there was no remarkable difference observed in clay content. Silt content in soils can result from the admixture of aeolian material [61] or from eolian saltation and abrasion, as well as salt, frost, and insolation weathering [62]-[68]. Among the topsoil, the silt particle accumulation is highest at TSO1 on summit, while TSO2 on the steep slope shows higher silt content in the B horizon than in its top horizon. It is possible due to its position, causing the silt to be partially eroded and mixed into the soil, even in deeper horizons [61]. Steep slope erosion is a selective process that can remove fine particles and leave the coarse fragments behind. Li

[69] also observed a linear decrease in fine particle content and a corresponding increase in sand content on a steeper slope due to the selective removal of fine particles by water. The upper slope positions were found to be generally erosional, whereas the lower slope positions were depositional. The topsoil at YS and EL showed a sandy texture, possibly due to its accumulation after transportation from the upper slope. Previous studies have shown that gravity-driven transportation of material from the upper parts of the slope leads to newly deposited soil material [61] [70]. Alternatively, such deposits may be caused by the geological layering of various weathered materials [61] [71]. Among the studied topsoil in Fescue high mountain and mountain steppe, the finest and coarsest soil texture was observed in the high mountain steppe due to its extremely different slope position. There were no remarkable differences observed in soil texture between high mountain and mountain steppe which show the soil texture is strongly dependent on their feature of slope position in each study.

The contents of OC and N indicate the accumulation of SOM. According to [72], this increase in SOM with altitude can mainly be attributed to the high temperature sensitivity of decomposition rates rather than photosynthetic production rates. Because of low temperature and high precipitation at high altitudes, the low decomposition rate of SOM leads to higher OC and N content in TSO1 and TSO2 than YS and EL. This result is also confirmed by the C:N ratio, which is an important indicator of the quality and degree of decomposition of SOM [73]. Soil moisture is one of the important factors that influence soil properties [74] [75]. According to [76] the soil moisture in the high mountain is connected with its vegetation pattern. But when the amount of SOM decreases to the mountain steppe, the clay particles have an effect on soil moisture (**Figure 7**).

The carbonate contents indicated by our field surveys were confirmed by HCl reactions. $CaCO_3$ contents at TSO1 and TSO2 are primarily attributed to pedogenic (secondary) carbonate, whereas the highest content observed in YS shows evidence for pedogenic and lithogenic (primary) carbonate content, the result of accumulation from the upper slope mixed with weathered parent materials. The contents are also confirmed by the soil pH (H_2O) results. [77] and [78] found EC to be a good measure of available nutrients as well as for the progressive mineralization of SOM. Because of low temperature, the slow SOM decomposition process in surface soil of TSO1 and TSO2 might lead to lower available soil nutrients. However, in topsoil of YS and EL at mountain steppe contained more available nutrient than that high mountain steppe. Among exchangeable bases the Ca^{2+} was the most dominant cation in all study sites. The parts of Ca^{2+} in the $CaCO_3$ accumulation horizons could be derived from the dissolution of $CaCO_3$ by CH_3COONH_4 (pH 7.0) extraction [79] at TSO1, TSO2 and YS. The exchangeable Mg^{2+} content was remarkably high at TSO1 which might be influenced by its finer soil texture than other study sites. [80] reported that Mg^{2+} deficiency is most common in sandy soil. YS and EL contained higher exchangeable Na^+ and

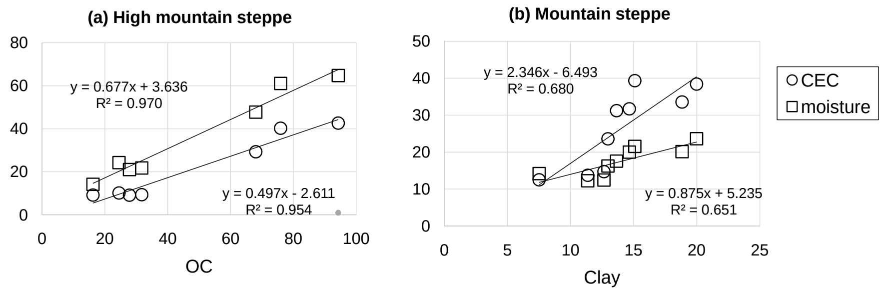

Figure 7. (a) Correlation between soil moisture, CEC, and OC at high mountain steppe, (b) correlation between soil moisture, CEC, and clay particles at mountain steppe.

K^+ compared with TSO1 and TSO2. Mavris [81] and Öborn [82] mentioned the higher temperature can directly enhance soil K^+ release, thus the higher air and soil temperature at mountain steppe might lead to higher contents of exchangeable K^+ compared with that of high mountain steppe. Increasing exchangeable Na^+ concentration reflects the chemical weathering process with increasing temperature [83] at mountain steppe. Jaremko [84] indicated that the CEC is a good indicator of soil quality and productivity. The topsoil of TSO1 which developed on more stable landform condition showed higher CEC value however, a steeper slope might result in greater soil erosion, reducing soil nutrients especially at TSO2. There was no observable difference found between subsoil of TSO1 and TSO2. But remarkable difference observed in surface soil shows the landform factor is strongly affected by the CEC of topsoil at high mountain steppe. In the high mountain the soils have relatively different CEC, while the mountain steppe soils show no remarkable difference at surface. According to [85] [86] CEC depends mainly on the organic matter content and clay content of the soil, however in our study, the factors that influence on CEC were different for both high mountain and mountain steppe (**Figure 7**). Regarding to the value of total water-soluble ions, there was no remarkable difference was observed between high mountain and mountain steppe. The soluble Mg^{2+} contents were lower in sandy textured soil in studied area. Senbayram [87] mentioned the Mg^{2+} originates from inputs by mineral weathering. Therefore, the contents of water-soluble Mg^{2+} might be influenced by its soil texture. The water-soluble NO_3^- values in the A horizons of the YS and EL at mountain steppe were relatively higher than TSO1 and TSO2 possibly due to the active turnover in the humic horizon [88].

The high mountains of the Khuvsgul region are characterized by short periods of warmer temperatures, long winters, and arid conditions in soils during the spring to early summer period; these factors are responsible for the physical weathering [37]. These conditions are favorable for the formation of incomplete developed, shallow, and skeleton-rich soils, such as Regosols and Leptosols, which are typical mountain systems. The lower elevation at mountain steppe of young landscape age [37] and coarse parent material lead to early stage of soil formation. Therefore, the soil at this area shows young, the pedogenesis is inhibited by slow rates of weathering and horizon formation such as Cambisols. According to [37] [89] such soils are abundant in mountain region, Mongolia.

4.2. The Humic Substances of Soil at High Mountain and Mountain Steppe Dominant by *F. lenensis*

Because of increasing humin content from A to B horizon at all sites the percentage of extracted humus contents decreased with soil depth. The Ch/Cf ratio has been used as an indicator to describe the humification degree of SOM, with a larger value indicating a higher degree of humification [90]. One of the interesting results of topsoil study was that both the highest and lowest humification degree of SOM was detected at high mountain steppe. The degree of soil humification tends to increase with decreasing elevation [29], however at our study sites, this correlation does not fit. Previous studies have shown that the degree of humification in mountain soils is not significantly influenced by elevation [91] [92]. The high elevation and flat landform of TSO1 increased the exposure of soil to sunlight. This led to warmer air and soil temperatures, and therefore, the soil was much more humified than TSO2. Because of its steep slope position, less natural light and constant state of soil rejuvenation the degree of humification in TSO2 was the lowest among topsoil of study sites. Due to warmer air and soil temperatures at middle slope of mountain steppe, the degrees of humification of YS and EL were slightly higher than TSO2.

In Kumada's classification, ΔlogK and RF from the spectrophotometric properties of HA were used as indices of the humification degree of HA. HA is a mixture of a continuum of HA molecules, with chemical characteristics dependent on the level of humification. Using these indices, [34] categorized HA into four types: A, B, P, and Rp. HA of the A-type are the most stable against chemical and biological oxidation [34] [44], and type B is degraded humic substances. Type Rp includes decomposing matter in the primary stages of humification [93]. The humification of HA progresses from type Rp to type B or P, and eventually type A, and the degree of humification is in the order of type A > B > P > Rp [34]. However, the humification degree of SOM and PQ values were highest at A horizon of TSO1, the HA type was related to degraded and not well humified. Because of its unstable soil development condition, the lowest values of RF were observed at TSO2 among the topsoil and subsoil of study sites. Due to its thin soil profiles the subsoil YS remained B-type as similar type of its surface horizon. In comparison to other examined soils, the HA in the topsoil in EL had the most stable properties because of the warmer climate and soil temperature at lower elevation on the mountain steppe than those of higher elevation. Comparing the results, type of the HA showed from immature to degraded characteristics at high mountain steppe while from degraded to well humified characteristics were observed at mountain steppe. Thus, the comparison of HA classification between high mountain and mountain steppe shows the climatic condition that dependent on their altitude leads to different HA type in the soil.

4.3. The Micromorphological Characteristics of Topsoil at High Mountain and Mountain Steppe Dominant by *F. lenensis*

The thin section of TSO1 and TSO2 showed typical features of high mountain soil. However, the results showed immature soil properties at high mountain steppe and the difference in the soil characteristics with landform. On the summit TSO1 showed a higher abundance of crumb structure, observable aging excrement and higher accumulation of plant residues which led to a higher compound packing void than TSO2. It indicates that the soil development condition of TSO1 is relatively stable than TSO2. According to thin section results very friable crumb structures, few plant residues, and barely recognizable excrement pedofeatures in TSO2 indicate that the soil is regularly truncated and in a constant state of soil erosion due to the steep slopes [47].

Comparing the soil characteristics of mountain steppe, they differed by elevation factor. However, the coarse organic fraction and void showed no remarkable difference. Because of the higher elevation with lower air and soil temperature, thin section of YS showed fewer crumb structure, fine organic components, and excrements than EL. At the lower elevation in EL, higher crumb structure distribution, fine organic components, and intact excrements were evident which indicate the soil decomposition process and biological activity is more active than YS.

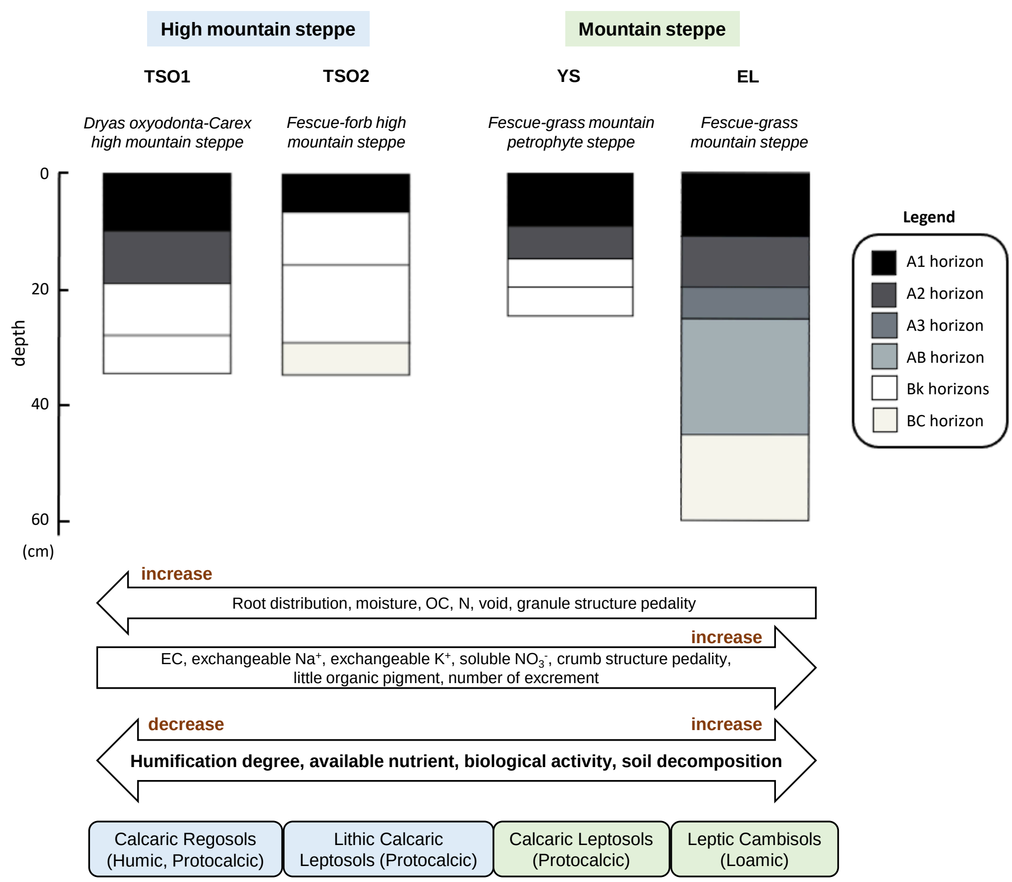

Figure 8. Summary of the characteristics of studied soils.

The topsoil features of the high mountain and mountain steppe differ mainly from air and soil temperature factor that is controlled by altitude. The topsoils of high mountain steppe show immature characteristics with loose crumb structure, many semi- and undecomposed plant residue, very few little organic pigments, and little aging and barely recognizable excrement pedofeature. It indicates that low air and soil temperature at high elevation inhibits the soil decomposition process and faunal activity. Our findings agree with those of previous studies [94] [95] showing that the climate in the mountains at higher elevations strongly influences soil biological activity and the structure of soil microorganisms and fauna. At the lower elevation of the mountain steppe, the soils were more mature than that of the high mountain steppe. Moderately developed crumb structure, the higher component of little organic pigment and intact excrements indicate that the soil decomposition and biological activity were increased with warmer temperatures at the mountain steppe; however, the soil contained abundant fine sand particles, leading to lower porosity than that of high mountain steppe.

5. Conclusions

The morphology, physicochemical, humic substance, and micro morphological characteristics of soils were summarized in **Figure 8**. We found that the soils of the high mountain and mountain steppe dominant by *F. lenensis* in Khuvsgul show immature characteristics with a thin and fragile soil profile. Due to the feature of the soil parent material and advanced pedogenesis process the soils of TSO1, TSO2 and YS have high $CaCO_3$ content. However, EL barely contains $CaCO_3$ because of the Al-rich parent material. The soils are classified as Regosols and Leptosols in the high mountain steppe, Leptosols and Cambisols in the mountain steppe.

Because of high annual precipitation, low air and soil temperature the studied soil of the Fescue high mountain steppe contains high plant root distribution with high accumulation of OC, N, moisture and low available nutrient content. The climatic condition leads to a slow soil decomposition process. Therefore, the soil shows immature characteristics with weakly developed crumb structure, many semi- and undecomposed plant residues, very few little organic pigments, and few aging and barely recognizable excrement pedofeature. The degraded to immature characteristics of HA in these soils confirm the climatic condition of high mountains inhibits the soil decomposition process. Because of the extremely different landform position at Fescue high mountain steppe, there a sharp difference was observed between the topsoil of TSO1 and TSO2. On the summit with a flat position, the soil of TSO1 showed the finest soil texture with the highest CEC, exchangeable Mg^{2+} and highest humification degree of SOM. On the steep slope the soil of TSO2 shows the coarsest soil texture which leads to the lowest CEC, exchangeable Mg^{2+} and slowest humification degree of SOM. This feature indicates that the abrupt changes in landforms on high mountains strongly affect the properties of topsoil.

However, the lower plant root distribution with lower OC, N, moisture contents and sandy texture were observed at YS and EL, the higher soil decomposition process in mountain steppe leads to higher available nutrient in soil. Due to active turnover in the humic horizon and chemical weathering process at lower elevation the soil contains higher exchangeable Na^+, exchangeable K^+ and water soluble NO_3^- at topsoil than Fescue high mountain steppe. The degraded to well humified characteristics of HA, moderately developed crumb structure, the higher component of little organic pigment and intact excrement indicate that the soil decomposition process and biological activity are higher than that of the high mountain steppe.

The soil moisture and CEC were very strongly influenced by OC accumulation at high mountain steppe, while strongly influenced by clay at mountain steppe. This indicates that the factors affecting the soil properties such as moisture content and CEC are different depending on the feature of climatic and environmental condition. Our finding suggests that due to the feature of *F. lenensis* distribution at high mountain and mountain steppe, the climatic condition dependent on altitude and landform position play a key role in soil properties and characteristics. Weakly developed, thin and skeletal soils such as Regosols, Leptosols and Cambisols in mountain regions are very vulnerable to environmental impacts. Therefore, to conserve the Fescue steppe at high mountains and mountains its soil condition must be highly considered.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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