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臺灣南仁山地區長期生態研究試驗地地形土序中土壤之化育

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摘 要

在臺灣地區的研究中，對於瞭解地形在土壤的發生、分類與土壤性質之分布的影響是較爲不足。地景形態對於土壤剖面發育的影響非常重要，因爲在森林的地景中，地景形態是瞭解土壤之風化作用、淋洗作用與養份或其它可溶性溶質的再分布等過程的重要因子。本篇研究的主要目的爲探討南仁山之地形土序中土壤的化育與辨別地形位置對於土壤發生與分類的影響。研究地點位於臺灣南部南仁山長期生態研究試驗地的北邊，即在南仁山的西南脊，面積爲 1 公頃之沿海拔分布的截線樣帶。研究結果指出：土壤性質的分布、土壤化育及土壤分類與地景形態之間有強烈的一致性變化。土壤的分類結果在水平距離 500 公尺的範圍內有相當大的變化，包括山頂位置的典型厚育濕潤極育土(Typic Paleudults)及下背坡與麓坡位置的典型低鹽基濕潤弱育土(Typic Dystrudepts)；土壤性質的分布隨土壤化育作用而變化，且與地形位置有強烈的相關。一般而言，砂粒、坋粒、有機碳、可交換性鹽基(鉀、鈉、鈣、鎂)與鹽基飽和度(%)隨地形位置的降低而逐漸增加，但是包括土體厚度、黏粒、總體密度與 pH (H_2O)值卻隨地形位置的降低而逐漸減少。季風與颱風兩者對於本研究地區之生態系與森林外貌都有影響。

關鍵詞：土壤化育、極育土、弱育土、地形土序、長期生態研究

Genesis of Soils Along a Toposequence in Nanjenshan Long-Term Ecological Research Site, Taiwan

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Abstract

The influence of topography on soil development, classification and the distribution of soil properties are poorly understood in Taiwan. The influence of landscape morphology on soil profile development is important in understanding the processes responsible for weathering, leaching, and redistribution of nutrients and other dissolved solutes within forested landscape. Our objectives, therefore, were to examine the genesis of soil along a toposequence in Nanjenshan and to determine the effect of topographic position on soil development and classification. The study site is a one-hectare, altitudinal transect, established on the northwestern ridge of Nanjenshan, the north part of the Nanjenshan Long-Term Ecological Research Site in southern Taiwan. Results indicate that strong correspondences were found between the landscape morphology, distribution of soil properties, soil genesis, and soil classification in this study area. Soils ranged from a Typic Paleudults in the summit position, through a Typic Dystrudepts in lower backslope position, and finally a Typic Dystrudepts in footslope position; this is considerable variability within a horizontal distance of 500 m. The distribution of soil properties varied with soil genesis and was strongly related to landscape position. In general, sand, silt, organic carbon, exchangeable bases (K, Na, Ca, and Mg), and base saturation (%) increased downslope, while solum thickness, clay, bulk density, and pH (H_2O) generally decreased downslope. Monsoon winds and typhoon both have impacts on the ecosystem and forest physiognomy of this study area. Additional research is needed to more fully understand the interactive relationships among landscape position, soil properties, and vegetal composition.

Key Words: Soil genesis, Ultisols, Inceptisols, toposequence, long-term ecological research

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Introduction

There have been many approaches to the study of soils and soil distribution. The importance of landscape in these studies seems to have been tacitly accepted by soil scientists rather than rigorously explored. It has been noted (Curtis et al., 1965; Bridges, 1967) that site description has always been a feature of the field study of soils, and thus generally involves a description of topography. Topography is invariably cited as one of the 'soil-forming factors' and Milne (1935) has used the 'catena' concept with various interpretations since its introduction.

Soil properties follow systematic patterns of distribution on the landscape (Malo et al., 1974). Soil properties may be evaluated and variations of these properties related to landscape position. King et al. (1983) indicated that while soil distribution varied in terms of slope position, slope length, slope gradient and sequence, the most significant relationship lies between soil distribution and shape of slopes. Properties such as organic matter content, bulk density, texture, pH, aggregate stability, and the thickness of the organic, A, and Bt horizons all vary with landscape position (Gregorich and Anderson, 1985; Pennock et al., 1987; Frolking, 1989; Kreznor et al., 1989; Pierson and Mulla, 1990; Keck et al., 1993; Brubaker et al., 1993; Webb and Burgham, 1997)

The impact of landscape on soil properties under forest is different, in that the forest cover reduces microclimate variations, and the mineral soil is protected by a litter layer (Imeson and Jungerius, 1974; Frolking, 1989). Information on the effect of landscape morphology on the distribution of soil properties in forested landscapes is scarce; furthermore, studies on nutrient cycling in forested soils often neglect landscape morphology and topography as factors that affect the distribution of soil properties and their impact on soil nutrient status (Sollins et al., 1980). Establishing the relationship between landscape morphology and the distribution of soil properties in forest soils is important. Little such information exists for the Nanjenshan monsoon rain forest in southern Taiwan. The objectives of this study were to examine the genesis of soil along a toposequence within a local Nanjenshan landscape and to determine the effect of topographic position on soil development and classification.

Materials and Methods

Study area

The study site (22°03'37''N, 120°51'10''E) is a one-hectare, altitudinal transect , which is 500 m long and 20~40 m wide, was established on the northwestern ridge of Nanjenshan, the north part of the Nanjenshan Nature Reserve Region of Kenting National Park in southern Taiwan (Fig.1) (Liao, 1995).

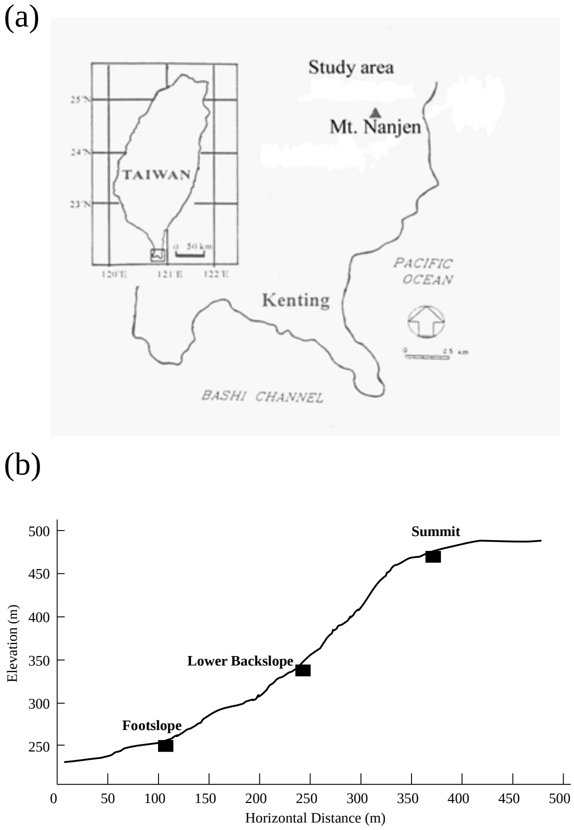

Fig. 1 (a) Map of the Hengchung Peninsula with the location of the study plot in Nanjenshan Nature Reserve Region (denoted by a black square); (b) Cross section of the altitudinal transect. Three soils along a toposequence are located in summit (S), lower backslope (UB) and footslope (F) positions (denoted by black squares).

The elevation ranged from 295 to 480 m; this site has moderate to severe relief with slopes mostly ranging from 17% to 89%, and average slope is 74%. Parent materials of soils are residuum or colluvium derived from sandstone and shale of Miocene age. The annual rainfall varied between 3,252 to 3,818 mm during October 1996 to March 2000 and about 80% of the total rainfell between May and October. The mean annual temperature is 22°C and mean monthly temperature varies from 17.4 °C (January) to 26.1 °C (August). In general, this study site has a hyperthermic soil temperature regime and an udic soil moisture regime.

The high precipitation of this area is due to northeasterly monsoon winds in winter and typhoons in summer and autumn. The northeasterly monsoon winds are particularly strong and persistent in the Nanjenshan forest area because of an orographic funneling effect. Winter monsoons usually start in late October and last until late February of the following year. Typhoons are very common in this area. They arrive as early as May and as late as November, but most occur during July and August. Monsoon winds do not cause massive and direct destructive damage to the forest, but it does have impacts on the ecosystem and forest physiognomy of this area. For examples, at sites exposed to monsoon winds, trees show low status and have small, leathery, and scleromorphic leaves. On the other hand, at wind-shielded ravines, trees are taller and have characteristics of tropical rain forest such as buttress roots, stilt roots, and cauliflory, lianas. Typhoons can be very destructive and probably greatly influence regeneration of forest.

A total of 139 woody species, belonging to 49 families and 91 genera, were recorded (Liao, 1995). Among them 99 were trees, 30 shrubs, and 10 lianas. The most dominant species is Ilex cochinchinensis, the second dominant one is Syzygium euphlebium. The results of Liao (1995) has also suggested that the transect can be divided into three vegetation zones along the altitudinal gradient. Zone I is located near river valley with elevations between 220 m and 330 m, and dominated by *Ficus benjamina*, *Dysoxylum kuskuensis*, and *Drypetes hieranensis*. Zone II is located at elevation 330-390 m, and dominated by *I. cochinchinensis*, *Schefflera octophylla*, and *D. hieranensis*. Zone III is located at elevation 390-470 m, and then *S. euphlebium*, *I. cochinchinensis*, and *Cyclobalanopsis longinux* are dominant species.

Field soil description, sampling and laboratory analyses

Three pedons were examined in each landscape position of summit (S), lower backslope (LB) and footslope (F) positions along a toposequence, with 18%, 71%, and 32% slopes, respectively (Table 1). Profile description was carried out according to soil survey manual (Soil Survey Staff, 1993). Representative bulk soil samples (about 2 kg) were collected from the horizon of each pedon, air dried, grounded to pass through a 2 mm sieve, and used for the analysis of physical and chemical properties.

Table 1 Environmental description and soil classification of soils in three landscape positions.

Position	Elevation	Slope	Aspect	Parent material	Soil Classification[1]
Summit	470 m	18%	Southwest	Sandstone and shale	Clayey, mixed, hyperthermic, Typic Paleudults
Lower Backslope	340 m	71%	Northwest	Sandstone and shale	Loamy-skeletal, mixed, hyperthermic, Typic Dystrudepts
Footslope	280 m	32%	Southwest	Sandstone and shale	Loamy-skeletal, mixed, hyperthermic, Typic Dystrudepts

[1]: Based on Keys to Soil Taxonomy (Soil Survey Staff, 2006)

Bulk density was determined by collecting soil cores from the horizon of each pedon, then oven the core samples overnight at 105℃ (Blake and Hartge, 1986). Soil pH was measured potentiometrically in the condition of soil/water (1:1, w/v) and soil/1M KCl (1:2.5, w/v). Particle-size analysis was performed by the pipette method (Gee and Bauder, 1986). Organic C was analyzed following the Walkley-Black method (Nelson and Sommers, 1982). Cation exchange capacity ($CEC_{7)}$ and exchangeable bases (K, Na, Ca and Mg) were analyzed by 1M NH_4OAc (pH 7) (Thomas, 1982; Rhoades, 1982). Base saturation (BS) was calculated using the formula, BS(%)＝(exch. K, Na, Ca, Mg)/CEC_7×100. Atomic absorption spectroscopy (Hitachi 180-30 type) was used to determine K, Na, Ca, and Mg. For each soil physical and chemical property, analysis was done in duplicate.

Results and Discussion

Soil morphology

Pedon 1 located at summit (S) position, with elevation 470 m and strongly slope (18%) (Table 1). The soil classification is Typic Paleudults, indicated that the soil has well genesis and strong illuviation occurred. Pedon 2 located at lower backslope (LB) position, with elevation 340 m and very steeply slope (71%). The very steeply slope may be resulted in greatly slope wash and runoff, so the soil was classified into Typic Dystrudepts. Pedon 3 located at footslope (F) position, with elevation 280 m and steeply slope (32%). The soil classification was the same with LB soil, Typic Dystrudepts, which was also contributed to the steeply slope effects.

Table 2 shows that soils in the summit and footslope landscape positions have identified, incomparable soil morphology, but soil in lower backslope position shows as transition morphology. S soil has a deep soil depth (101.2~152.4 cm) and exists no rock fragments in each horizon of profile. The thickness of A horizon of S soil is thickest than other two soils. The well-developed soil structures, moderate fine and medium angular blocky structures, were occurred in 35-120 cm. The texture ranged from sandy clay loam in the A horizon to clay loam in the Bt horizons. The soil had a color of dark yellowish brown in the A horizon, brownish yellow in the BA horizon, and strong brown in the Bt horizons. From the filed investigation, medium to thick prominent clay skins were found in 35-120 cm, suggesting higher clay illuviated down through the profile and accumulated in lower horizons. The morphology of S soil has indicated that the great soil weathering and clay illuviation have occurred in this profile. Because of the diagnostic horizon was argillic horizon (Bt), we classified the S soil into Typic Paleudults (Soil Survey Staff, 2006).

LB soil also has a deep soil depth, but more than 60% of gravels (0.2~7.5 cm) and stones (7.5~25 cm) was found under 40 cm. The mixtures of very fine and fine granular structure and angular blocky structure were distributed in each horizon of LB soil. The higher organic matter distributed in LB soil may be resulted in the occurrence of granular structure. The texture ranged from sandy clay loam in the A horizon to sandy clay loam or clay loam in the Bw horizons. The soil had a color of olive brown in the A horizon, and yellowish brown in the Bw horizons. We also can find the medium distinct clay skin between 25 to 90 cm. The occurrence of clay skin has suggested the clay illuviation in LB soil, but the degree of illuviation was not enough to form an argillic horizon. We classified the LB soil into Typic Dystrudepts.

F soil only has moderately deep soil depth (50.8~101.6 cm). Higher than 10% stones (7.5~25 cm) exist in A, Bw, and BC horizons indicated that the poorly sorted, gravitationally transported material were accumulated in F soil. The moderate developed, very fine and fine granular structures are the main soil structures in each horizon, mixed with 10% very fine angular blocky structure in Bw and BC horizons. The granular structure occurred in each horizon may also resulted from higher organic matter mixed with mineral soils. The textures of all horizons were the same, sandy clay loam, indicating the less clay illuviation occurred. The soil color ranged from olive brown to light olive brown, which was quite different from S and LB soils. No clay skin was found in soil profile. From the morphology, we classified the F soil into Typic Dystrudepts, the same classification with LB soil.

The parent materials of three soils are all derived from sandstone and shale, but the regolith types are different. Graham and Buol (1990) and Graham et al. (1990) has reported that slope regolith can be divided into two fundamental categories: colluvium and residuum. Furthermore, residuum can be differentiated as saprolite and soil residuum. The pedogenic transformation of saprolite to soil residuum resulted in higher clay contents and redder hues through in situ weathering and illuvial accumulations. They also indicated that Dystrudepts, or very weakly expressed Hapludults, have developed entirely in colluvium, whereas soils with at least a partial component of residuum are Hapludults. According to the filed investigation and morphological characteristics (Table 2), the regolith type of S soil and F soil could be soil residuum and colluvium, respectively. But for LB soil, the morphological characteristics seem to have both type of S and F soil, that is, the transition morphology. We estimated that the LB soil was derived from the mixture of soil residuum and colluvium.

Table 2 Morphological properties of three representative soil profiles in the study area.

Horizon	Depth (cm)	Structure[1]	Texture[2]	Color	Clay skin[3]
		Summit (Typic Paleudults)			
A	0-18	2fgr, 2f&mabk	SCL	10YR 4/6	
BA1	18-35	2vf&fabk	CL	10YR 6/8, 7.5YR 5/8 (10%)	
BA2	35-50	2f&mabk	SCL	10YR 6/8	2p
Bt1	50-70	2f&mabk	CL	10YR 5/8	3p
Bt2	70-90	2f&mabk	CL	7.5YR 5/8	3p
Bt3	90-120	2f&mabk	CL	7.5YR 5/8, 2.5Y 6/6 (20%)	3p
Bt4	>120	3m&cabk			
		Lower Backslope (Typic Dystrudepts)			
A	0-12	2vf&fgr, 2vfabk	SCL	2.5Y 4/4	
BA	12-25	2vf&fabk, 2vf&fgr	CL	10YR 5/6	
Bw1	25-60	2vf&fgr, 2vf&fabk	SCL	10YR 5/8	2d
Bw2	60-90	2vf&fgr, 2f&mabk	CL	10YR 5/6	2d
BC	90-115	2vf&fgr, 2vfabk(few)	CL	7.5YR 5/8	
		Footslope (Typic Dystrudepts)			
A	0-8	2vf&fgr	SCL	2.5Y 4/3	
Bw1	8-22	2vf&fgr	SCL	2.5Y 4/4	
Bw2	22-40	2vf&fgr, 2vfabk(10%)	SCL	2.5Y 5/4	
BC	40-64	2vf&fgr, 2vfabk(10%)	SCL	2.5Y 5/4	
C	64-100	2vf&fgr, 2vfabk	SCL	2.5Y 5/4	

[1]: 3=strong, 2=moderate, f=fine, vf=very fine, m=medium, c=coarse, gr=granular, abk=angular blocky.

[2]: CL = clay loam, SCL = sandy clay loam.

[3]: 2 = medium, 3 = thick, d = distinct, p = prominent.

Soil physical and chemical properties

The clay content of S soil ranged from 272 to 368 g/kg. (Table 3). There have significant clay increases from BA2 horizon to Bt horizon, and the highest clay content was occurred in Bt1 horizon. The LB and F soils have relatively lower clay content, ranging form 268 to 324 g/kg and 230 to 301g/kg, respectively. There exists no significant clay increase in soil profile, so the diagnostic horizon was identified as cambic horizon (Bw) for these two soils. The relatively low bulk density was showed in LB and F soils except for A horizon. The higher contents of gravel and stone and organic matter in LB and F soils could be in explanation of these results. The trend of Bd slightly increasing with soil depth of S soil also attributed to the great clay illuviation.

The LB and F soils were very strongly acidic as indicated by pH (H_2O) ranging from 4.7 to 5.0. The upper parts (0~35 cm) of S soil were strongly acidic, but the lower parts (35~120 cm) were strongly acidic. The changes and distribution of pH may be attributed to the organic matter contents. The values between pH (H_2O) and pH (KCl) of three soils almost higher than 1 to 2 units indicated that the exchangeable acidity could be very high in soils. Organic carbon was highest in F soil, followed by LB soil and S soil. The distribution of organic carbon seems to accumulate in surface soil, then decrease with soil depth. Relatively higher organic carbon accumulated in the upper parts (0~25 cm) of LB and F soil indicated that the great slope wash or soil creep has occurred. The steeply and very steeply slopes of LB and F soils were resulted in this hillslope effects. As described above, the granular soil structures of LB and F soils were attributed to the higher organic carbon content existed in soils.

All soils have low cation exchange capacity (CEC) (<10 cmol(+)/kg soil) and have the trend decreasing with depth. Exchangeable base (K, Na, Ca, Mg) were also very low resulting in a low base saturation except for the topsoil. The higher base saturation of topsoil of three soils was in consistent with the organic carbon distribution. The contents of exchangeable K, Na and Ca of S soil were relative lower than LB and F soils. The results also indicated the great soil weathering and illuviation have occurred in summit position. S soil has relatively low CEC/Clay value, but the values of LB and F soils seem to have uniform distribution with soil depth between BA horizon and BC horizon. The values of CEC/Clay of three soils all ranged from 17~35 (cmol(+)/kg clay) which suggested that the main clay minerals could be kaolinite and illite, the main compositions existed in strong weathered soils. The result of CEC/Clay has supported another proof to certify great soil weathering has occurred in this study area.

Soil genesis in different landscape positions

The results of Kleiss (1970) has reported that particle size variations within the soil A horizon are due to the sedimentological sorting, and the distribution of hillslope sedimentation has also influenced accumulation of organic matter, bulk density (Bd), and cation exchange capacity (CEC) in the soils formed at various positions on the slope. Progressive study by Donald et al. (1993) also suggested that the influence of landscape morphology on soil profile development is important in understanding the processes responsible for weathering, leaching, and redistribution of nutrients and other solutes within forested landscapes. In this study, according to the morphological characteristics, physical, and chemical properties, and soil classification of three soils located in different landscape positions, we find that the soil genesis, clay illuviation, and redistribution of nutrients have showed the spatial pattern along the altitudinal transect. The gently to strongly slope of summit position supported the relative flat and stable environment for soil genesis which developed an Ultisols. In contrast, the steeply to very steeply slope in lower backslope and footslope positions resulted in less weathered soil which were classified into Inceptisols.

In general, S soil has thicker A horizon, higher clay contents and pH (H_2O) than LB and F soils. Sand, silt, organic carbon, exchangeable bases (K, Na, Ca, and Mg), and base saturation (%) generally increased downslope, while solum thickness, clay, bulk density, and pH (H_2O) generally decreased downslope. The same results have reported by Pierson and Mulla (1990) and Brubaker et al. (1993). The thickness of topsoil (A horizon) is greatest on summit and generally decreases to footslope. These results differ from the findings of Webb and Burgham (1997) who found the thickness of topsoils is greatest on footslopes and generally decrease to shoulderslopes. We estimated the different results might be due to the effects or changes of microrelief in different study area.

Table 3 Soil physical and chemical properties of three representative soil profiles in the study area*.

		Total				Bulk	pH				Exchangeable				Sum of		
Horizon	Depth	Sand	Silt	Clay	Texture[1]	density	H_2O	KCl	O.C.	CEC	K	Na	Ca	Mg	Cations	BSP	CEC/Clay
	(cm)	-----g/kg------				Mg/m^3			g/kg	--------cmol(+)/kg soils--------						%	cmol(+)/kg clay
Summit																	
A	0-18	461	267	272	SCL	0.9	5.0	3.3	19.2	9.6	0.66	0.02	0.39	0.70	1.77	18	35
BA1	18-35	433	278	289	CL	1.3	4.9	3.4	7.9	7.2	0.24	0.11	0.02	0.22	0.59	8	25
BA2	35-50	505	217	278	SCL	1.4	5.1	3.4	4.7	5.8	0.18	0.06	nd	0.20	0.44	8	21
Bt1	50-70	448	184	368	CL	1.5	5.2	3.4	3.5	6.3	0.15	0.04	nd	0.29	0.48	8	17
Bt2	70-90	376	264	360	CL	1.5	5.3	3.5	4.6	7.2	0.12	0.02	nd	0.45	0.59	8	20
Bt3	90-120	374	286	340	CL	1.5	5.4	3.5	3.7	7.5	0.14	nd	nd	0.50	0.64	9	22
Lower Backslope																	
A	0-12	463	261	276	SCL	0.9	4.9	3.4	20.8	8.8	0.44	0.11	0.70	0.82	2.07	24	32
BA	12-25	423	309	268	CL	0.9	4.7	3.5	42.7	7.4	0.21	0.16	0.07	0.39	0.83	11	28
Bw1	25-60	454	271	275	SCL	1.2	4.9	3.5	7.6	6.8	0.16	0.22	nd	0.29	0.67	10	25
Bw2	60-90	428	280	292	CL	1.0	5.0	3.4	5.6	6.6	0.17	0.14	nd	0.28	0.59	9	23
BC	90-115	433	223	324	CL	1.0	4.9	3.5	4.6	6.3	0.17	0.16	nd	0.27	0.60	10	19
Footslope																	
A	0-8	535	164	301	SCL	0.9	4.9	3.6	30.9	9.8	0.52	0.13	1.45	1.28	3.38	34	33
Bw1	8-22	481	225	294	SCL	1.0	4.7	3.5	43.7	7.3	0.30	0.11	0.60	0.46	1.47	20	25
Bw2	22-40	473	233	274	SCL	1.0	4.8	3.5	11.6	6.5	0.25	0.15	0.36	0.35	1.11	17	24
BC	40-64	497	273	230	SCL	1.0	4.8	3.5	13.7	7.1	0.20	0.11	0.18	0.25	0.74	10	31
C	64-100	454	287	259	SCL	--	4.8	3.5	12.7	7.2	0.19	0.15	0.17	0.25	0.76	11	28

* Abbreviations: O.C. = organic carbon; CEC = cation exchangeable capacity; BSP = base saturation percentage

[1]: CL =clay loam; SCL = sandy clay loam

[2]: nd = not detected

Conclusions

The genesis of soil and distribution of soil properties in a landscape are the result of the complex interaction of many soil-forming factors. The results of this study show that the genesis of soil and distribution of soil properties, varied as a function of landscape morphology. Greatest profile development, the thickest A horizon and solum and the great illuviated Bt horizons occur in summit soil where the landscape morphology shows gently to strongly slope and flat surface. Profile development and soil properties in lower backslope and footslope positions are strongly affected by steeply to very steeply slope and concave or convex microrelief.

In general, S soil has thicker A horizon, higher clay contents and pH (H_2O) than LB and F soils. S soil was classified into Paleudults, and LB and F soils were classified into Dystrudepts, depending on the morphological characteristics and soil physical and chemical properties. The distributions of soil properties suggest a spatial pattern along the altitudinal transect. Sand, silt, organic carbon, exchangeable bases (K, Na, Ca, and Mg), and base saturation (%) generally increased downslope, while solum thickness, clay, bulk density, and pH (H_2O) generally decreased downslope.

Monsoon winds and typhoon both have impacts on the ecosystem and forest physiognomy, which have caused the divisions of three vegetation zones along the altitudinal gradient of this study area. Additional research is needed to more fully understand the interactive relationships among landscape position, soil properties, and vegetal composition.

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