SLOPE GRADIENT AND SHAPE EFFECTS ON SOIL PROFILES IN THE NORTHERN MOUNTAINOUS FORESTS OF IRAN

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Abstract

In order to obtain some measurements of the original variability of the soil profiles at two shapes (concave and convex) and five positions (summit, shoulder, back slope, footslope and toeslope) of slope, a study of a virgin area was made in a Beech stand of mountain forests, northern Iran. Across the slope positions, the soil profiles demonstrate significant changes due to topography for two shape slopes. The solum depth of convex slope was higher than the concave one in all five positions and it decreases from the summit to shoulder and increases from the mid to lower slope positions for both convex and concave slopes. The thin solum at the upper positions and concave slope demonstrates that pedogenetic development is least at upper slope positions and concave slope where leaching and biomass productivity are less than at lower slopes and concave slope. A large decrease in the thickness of O and A horizon from summit to back slope was noted for both concave and convex slopes, but it increased from back slope toward down slope for both of them**.** The average thickness of B horizons increased from summit to down slopes in the case of concave slope, but in the case of convex slope it decreased from summit to shoulder and afterwards it increased to the down slope. The thicknesses of different horizons vary in part in different position and shape slope because they have different plant species cover and soil features which are related to topography.

Keywords: Slope shape, Slope position, Soil profile, Soil horizon, Topography.

Introduction

Topography is an important factor affecting the nature and distribution of soils [12]. The influence of topography on soils may be due to the combined effects of slope aspect, water dynamics, and/or erosion and deposition [32]. The processes that occur in soils at higher positions along a slope often influence the soils at lower position within the same hill slope system [13]. Slope curvature has two distinct vertical and horizontal components. The geometry of width and length are defined for a given section of slope as linear, convex, or concave [25]. Convex vertical curvatures result when the gradient increases along the slope [28]. On the contrary, when the gradient decreases towards the lower part of the slope, concave vertical curvatures exist (Fig. 1). Frequently there is a change in soil type where the vertical curvature changes from convex to concave shapes in different position of a slope. Horizontal curvature exists where the direction of exposure is changing or in other words where the contour lines are curved instead of straight. Where the slope direction converges toward the lower part of the slope, concave horizontal curvature exists. Where the opposite is true, convex curvature exists. A slope, seen in two-dimensional profile, can be divided into summit, shoulder, back slope, footslope, and toeslope components according to the model by [26]. Thus, on a landscape, soils along a toposequence can be differentiated on the basis of various characteristics [22, 29].

Certain soil properties in these slope units are characteristically different and therefore reflect different processes. The upper, generally convex sections have a predominantly erosional character with significant correlations between gradient and the soil properties examined. Lower concave sections, associated with depositional processes, are characterized by a greater variability in soil properties [21, 30].

Slope length, direction and curvature in addition to gradient play an important role in soil formation [20, 15]. For this reason, topography represents an important 'state factor' in conceptual model of soil formation [14]. Horizon development is a result of the addition, loss, transfer and transformation of chemical, physical and biological elements within the soil profile [2]. These changes may either promote or retard horizon differentiation [13] and can be noted and evaluated at the landscape level by measuring attributes of the soil profiles in various topographic locations.

The influence of slope on soil moisture is known to affect soil profile development [19]. The amount of runoff increases while water infiltration decreases as the slope gradient increases. This results in a parabolic decrease in the depth of the clay accumulation zone with increasing slope gradient [19]. Slope gradient may also result in a particle size sorting effect such that coarser particles preferentially accumulate on steeper slope segments while finer particles are transported to lower slope segments [26]. This was confirmed by

Van den Bygaart (2001) who, by means of ^{137}Cs tracing method, evidenced that topsoil on a hill slope in Ontario, Canada was eroded from upslope positions, mainly the shoulder, and deposited in down slope positions, mainly the footslope where thicker B horizons were found [31]. Based in these processes, different delimited slope units may therefore exhibit different soil properties [11]. Manning et al. (2001) observed that, at landscape scale, taxonomically and functionally distinct soils form due to variable levels of accumulation of sediments and that the net effect of downward movement of water is controlled by the nature of the slope (convergent or divergent) [18]. King et al. (1983) observed marked differences in profile characteristics affected by slope morphology in a cultivated landscape in Saskatchewan. They identified shallow, deep or gleyed soils in correspondence with convex upper slopes, concave areas or depressional areas, respectively.

Because of the lack of information on the genesis of soils on catenas, particularly in the large area of catenas in Hyrcanian forests that is a specific result of topographic condition in these forests, a study was conducted to investigate soils on sloping landscapes. The aim of this research was to assess the extent of soil profile change in a sloping landscape due to erosion and compaction (as a consequence of topography). We therefore evaluated changes in soil profiles as a function of slope position (summit, shoulder, back slope, footslope, and toeslope components) and shape (convex vs. concave slopes).

Objects and methods

Site location

This research was carried out within the TMU (Tarbiat Modares University) Experimental Forest Station located in a temperate forest of the Mazandaran province in northern Iran, between 36˚31´56˝ N and 36˚32´11˝ N latitude and 51˚47´49˝ E and 51˚47´56˝ E longitude (Fig. 2). The parent material is limestone and dolomite limestone, which belong to the upper Jurassic and lower Cretaceous periods. The soil type is Inceptisols with suitable penetration and biological activity, and silty clay loam textures. The mean annual temperature, rainfall and relative humidity for the region are 10.5˚ C, 858 mm and 75.2%, respectively. The climate is classified as humid-temperate, based on the Koppen's classification [9]. The study was conducted in a multistoried, multi-aged beech stand, dominated by *Fagus orientalis* Lipsky, *Carpinus betulus* L., *Alnus subcordata* C.A.Mey., and to a lesser extent, *Acer velutinum* Boiss and *Tilia platyphyllos* Scop. Other tree species present in the area include *Quercus castaneifolia* C.A.Mey, *Fraxinus excelsior* Bovéex and *Acer cappadocicum* Gled [8]. The herbaceous species that were dominated in this area were *Asperula odorata*, *Solanum kieseritkii, Viola alba, Lamium album, Euphorbia amygdaloides*, and *Vicia cracca*. Other herbaceous species were *Tamus communis*, *Cephalanthera caucasica, Rubus hyrcanus*, *Polygala anatolica, Hypericum androsaemum, Carex pendula*, *Festuca drymeia*, *Fragaria vesca,* *Mercurialis perennis, Salvia glutinosa, Sanicula europaea, Circaea lutetiana, Epimedium pinnatum, Cardamine tenera, Daphne mezereum, Periploca graeca, Carex remota* and *Amaranthus hybridus* [8].

Soil pedon description and sampling

In the summer of 2013, we opened a total of 10 pits in each major topographic unit that encompassed two slopes (concave and convex) and five slope positions (the summit, shoulder, back slope, footslope and toeslope) identified along a transect 20 m in width [27]. All pits were dug up to 1.5 meters depth or to bedrock. A detailed *in situ* profile description was completed for each pit, and the genetic soil horizons were determined and their thicknesses measured. Site data at the pit location were collected. This consisted of geographical position using a Garmin model GPSMAP 60Cx, % slope using a Sounto inclinometer, slope complexity, slope length (effective and natural), slope aspect, slope position classes (summit, shoulder, back slope, footslope and toeslope) and elevation. Digital photographs of the soil landscape and profiles at each location were taken to document the site. Aspect values were assigned to one category: north-east, in order to standardize aspect direction. The solum depth was fixed as the bottom of the AC horizon. For A and B horizons, the thickness and color were determined.

Results

The soil profile descriptions were collected to serve as a detailed reference for each landscape position in each catena shape. Pedons were described at the upper and lower positions of two shape catenas. On summit of convex slope we had 6 horizons including Oi, Oe, Oa, A, Bt1, Bt2. On average the combined Oi, Oe and Oa horizon's had a thickness of 5.55 cm while that of the A horizon was about 34 cm, rich in small roots (7.5 YR 4/4). After initial soil profile description, the Oi, Oe and A horizons were combined for trend analysis because of the difficulty in separating and analyzing three distinct horizons from a very small thickness. Since these horizons are genetically closely related by the addition and incorporation of organic matter, they can be treated in a similar context without diminishing the genetic interpretation. The thickness of Bt1 and Bt2 was about 101cm (5 YR 3/2 and 2.5 YR 3/2). On shoulder of convex slope we had three horizons including O, A and B. The thickness of O was about 3.65cm and the thickness of A was 29 cm (5Y 3/1) and B horizon was 81cm (5 Y 5/1). On back slope of convex slope there were four horizons including O, A, B1 and B2. The thickness of O horizon was 2.49 cm and the thickness of A horizon was 25 cm (2.5 YR 4/2). The thickness of B1 and B2 was about 13 and 79cm (2.5 YR 5/2 and 2.5 YR 4/2). On footslope of convex slope seven horizons were observed including Oi, Oe, Oa, A, Bt1, Bt2 and Bk. The thickness of Oi, Oe and Oa horizons were 3.35, 2.11 and 3.32 cm, respectively. The thickness of A horizon was 31cm (5 YR 3/2). The thickness of Bt1, Bt2 and Bk were 23, 47 and 49 cm respectively (5 YR 3/2, 5YR 3/1 and 2.5 YR 7/2). On the toeslope of convex slope six horizons were identified including Oi, Oe, Oa, A, Bht and Bk. The thickness of Oi, Oe, Oa horizons were 4.28, 1.42 and 3.12 cm respectively. The thickness of A horizon was 27cm (5 YR 4/2). The thickness of Bht and Bk were 101 and 22 cm respectively (5YR 3/2 and 2.5 YR 7/2) (Table. 1).

On summit of concave slope we identified 6 horizons including Oi, Oe, Oa, A and Bt. The thickness of Oi, Oe, Oa horizons were 4.57, 1.49 and 1.65 cm respectively. The thickness of A horizon was 58 cm (10 YR 3/2) and the thickness of Bt horizon was 37 cm (10 YR 3/1). On shoulder of concave slope, we observed 4 horizons including Oi, Oe+a, A and Bt horizons. The thicknesses of Oi and Oe+a were 4.27 and 4.35cm respectively. The thickness of A and Bt were 42 and 61cm respectively (10YR 5/1 and 10 YR 3/1). On back slope of concave slope, we observed three horizons including O, Ap and Bht. The thickness of O horizon was about 3.42cm and the thickness of Ap horizon was 20 cm (5Y 5/1). The thickness of Bht horizon was 67cm (5YR 3/1). On footslope of concave slope, we had four horizons including O, A, Bt1 and Bt2. The thickness of O horizon was 5.42cm and the thickness of A horizon was 31cm (5YR 5/2). The thickness of Bt1 and Bt2 horizons were 41 and 44cm respectively 9 5YR 4/4 and 5YR 5/4). On toeslope of concave slope there were six horizons including Oi, Oe and Oa, A, Bht1 and Bt2. the thickness of Oi, Oe and Oa horizons were 4.82, 2.27 and 4.19cm respectively. The thickness of A horizon was 43cm (5YR 2.5/1) and the thickness of Bht1 was 25cm (5YR 3/1). The thickness of Bt2 was 55cm (5YR 4/1) (Table. 2).

The solum depth of convex slope was 135cm at the summit, and it was 95cm at the summit of concave slope. For the shoulder of concave slope the solum depth was 103cm, but for the convex slope it was 110cm. For back slope position the solum depth of two shape catenas was approximately the same (117 and 116 cm for convex and concave slopes, respectively). There was a significant difference for footslope position between these two shapes of catena (150 and 116cm for convex and concave slopes, respectively). The difference between these two shapes was less in toeslope position (150 and 123cm for convex and concave slopes, respectively) (Table. 1 and 2).

Discussion

This study was undertaken to evaluate differences in soil profiles associated with different landscape positions and shapes (concave and convex slopes). Across slope positions, the soil profiles evidenced significant changes due to topography for both slope shapes. The solum depth of convex slope was higher than the concave slope in all five positions. The natural erosive forces of wind and water cause the removal and redistribution of surface organic and mineral soil materials [13] resulting in a decreasing solum depth on going from ridges to valleys and an increase from the ridges to valleys (concave slope). This accumulation of soil material in concave slope characterized the development of these soil profiles and reflected their natural pedogenic history [13]. A larger increase in the thickness of O and A horizons was noted at all the positions of concave slope with respect to the convex one. The genesis of these horizons may be favored by the high soil moisture present in concave slope. Noticeable exceptions to the above trends occurred in the case of average thickness of B horizons that was higher in all the positions of convex with respect to the concave slope. Better drainage conditions present in convex slope could have favored the development of this horizon.

The comparison of the top to mid and mid to lower slope positions suggest that erosion and redistribution due to topographic position significantly affected all soil profiles [7, 22]. Along the slope the horizon thicknesses demonstrated significant changes due to topography. For both convex and concave slopes, the solum depth decreased from the summit to the shoulder, and increased from the mid to lower slope positions. This suggested that the upper slope segment of the landscape is being eroded and compacted by the effects of topography [33]. Pedogenetic development at the upper slope positions was probably limited due to less leaching and biomass productivity with respect to the lower slope positions [14]. Upslope soils had higher slope gradients, which likely decreased the rate of water infiltration, thereby limiting the depth of soil formation [23]. The erosion and redistribution of upslope materials by wind, water and cultivation result in the accumulation of sediments in the lower slope positions [6]. Soils at footslopes and toeslopes probably received greater amounts of organic material, although potentially experiencing faster rates of decomposition due to a soil moisture content at or near field capacity.

Upslope soils had higher slope gradients, which likely decreased the rate of water infiltration, thereby limiting the depth of soil formation. These results are consistent with the result that were revealed in 2012 [14] and 2001 [18], they stated that "soil properties may be predicted as a function of topography, through mathematical models". They argued that at the landscape scale, soils form that are taxonomically and functionally distinct due to variable levels of accumulation of sediments and that the net effect of downward movement of water is controlled by the nature of the slope (convergent or divergent). The authors concluded that the analysis of landform element complexes (*i.e.* upper, mid and lower slope positions) detected differences in soil properties for convergent and divergent slope positions. Their results are consistent with the results of this study. The horizon thickness differences between slope positions and catena shapes were also likely influenced by erosion and deposition [22].

An important decrease in the thickness of O and A horizon from summit to back slope was noted for both concave and convex slopes, but it increased from back slope towards down slope for both of them. Erosion events may have resulted in the physical relocation of soil organic matter from eroded positions to depositional positions [24]. This may have further promoted organic matter

inputs at footslopes and toeslopes due to higher fertility from erosional deposition. Similar trends were observed by Kleiss (1970) [16] and Malo et al. (1974) [17] who reported an increase in the fine-to-coarse particle size ratio of the A horizon from summit to shoulder and from back slope to toeslope. It was likewise found that organic matter content of A horizons followed the trend of particle size sorting, indicating that the same sedimentary processes may have caused both trends. The differences in organic matter content may also relate to the different moisture regimes present at different slope positions [10]. Our results are consistent with those reported by Ruhe and Walker (1968) and Bergstrom (2001) who showed that the depth of the horizon of maximum clay content decreases exponentially, and the A horizon gets thinner with increasing slope gradient between summit and back slope [26, 1].
The average thickness of B horizons increased from summit to down slopes in the case of concave slope. In contrast, in the case of convex slope it decreased from summit to shoulder and subsequently increased to the down slope. With increasing slope gradient enhanced soil erosion and less infiltration generally causes a restricted solum depth and a thinner, less intensely developed B horizon [5, 34]. Lateral movement of soil water across soil horizons may also occur and cause a decrease in B horizon expression with increasing slope gradient. Our observations are supported by the findings of Van den Bygaart (2001) who reported that the process of topsoil erosion from upslope positions, mainly the shoulder, and deposition in down slope positions, mainly the footslope, can lead to the development of thicker B horizons in down slopes [31].
Generally, steeper slope gradients such as summit and shoulders also have higher effective surface areas by virtue of the cosine law. This effect may cause a decrease in illuviation on steep versus less steep slopes because of less effective precipitation per unit area on steep slopes [3]. If this reduction in effective precipitation is accumulated over many years, steep slopes would be expected to have thinner weakly developed illuvial horizons, as we observed in this study. Another factor that may cause differences in soils across slope is the influence of past erosion. Erosion on steep slopes may have continued for a longer time period following periglacial erosion compared to lesser slopes because it takes longer to re-establish a vegetative cover on steep slopes [4]. A thinner solum depth and B horizon thickness within steep slope gradients would result from this longer period of erosion. However, theories on the influence of more recent erosion by natural disasters such as fire or drought, or the influence of slow visibly unnoticeably changes such as soil creep must also be further tested to explain differences in B horizon thickness and solum depth [3].

Conclusion

The soil profile descriptions for each landscape position integrate the effects of landscape position, and slope shape on soil profiles and horizon characteristics and allow evaluation of whether these are indicative of normal or regressive pedogenesis having occurred. From the evaluation of five slope positions and two slope shapes we concluded that topography is a contributing process in the change of soil profiles and solum depth. All the sites are characterized by long uniform mid slopes and there is evidence of change in soil properties for all sites due to landscape position. If it is assumed that all other factors remain constant *i.e.* climate (precipitation and temperature), parent materials, and the effects of organisms, then the differences in soil profiles are dependent on topography. In the lower slope position where the redistributed upslope materials were redeposit, an increase in solum depth and horizon thickness was observed. The net result of the erosion and redistribution due to topography is the removal of soil material from the upslope positions and the accumulation of sediments in the lower landscape position. The upslope portion was not as severely eroded as the mid slope due to the lower slope values. From the comparisons of the descriptions and analysis of the detailed soil pits for each landscape position in each site, complete in situ representations of the soil development characteristics of each site and slope can be developed. The use of the soil horizon descriptions for each slope and each position (derived and interpreted information) allows comparison between sites for each landscape position and assists with the identification of eroded phases of the soil series.

References

1. D. W. Bergstrom, C. M. Monreal and E. St. Jacques, "Spatial dependence of soil organic carbon mass and its relationship to soil series and topography," Can J Soil Sci. 81 (1), 53-62 (2001).
2. S.W. Buol, R. J. Southard, R. C. Graham and P. A. McDaniel, *Soil genesis and classification*. (John Wiley & Sons, Lowa state, US, 2011).
3. B. J. Carter, and E. J. Ciolkosz, "Slope gradient and aspect effects on soils developed from sandstone in Pennsylvania," Geoderma. No. 49, 199-213. (1991).
4. B. J. Carter and J. Ciolkosz, "Sorting and thickness of waste mantle material on a sand stone Spur in central Pennsylvania," Catena. 13 (3), 241-256 (1986).
5. E. S. Corbett, Hydrologic evaluation of the storm flow generation process on a forested watershed Doctoral Dissertation (US, 1979).
6. S. De Alba, M. Lindstrom, T.E. Schumacher and D.D. Malo, "Soil landscape evolution due to soil redistribution by tillage: a new conceptual model of soil catena evolution in agricultural landscapes," Catena. 58 (1), 77-100 (2004).
7. R.C. De Rose, "Slope control on the frequency distribution of shallow landslides and associated soil properties, North Island, New Zealand," Earth Surf Proc and Land. 38 (4), 356-371 (2013).

8. M. Fazlollahi Mohammadi, S. G. Jalali, Y. Kooch and T. Theodose, "The influence of landform on the understory plant community in a temperate Beech forest in northern Iran," Ecol Res. No. 30, 385–394 (2015).
9. F. W. Gerstengarbe and P. C. Werner, "A short update on Koeppen climate shifts in Europe between 1901 and 2003," Climatic Change. No. 92, 99–107 (2009), DOI 10.1007/s10584-008-9430-0.
10. B. J. Fu, S. L. Liu, l. D. Chen, Y. H. lU, J. Qiu, "Soil quality regime in relation to land cover and slope position across a highly modified slope landscape," Ecol Res. 19 (1), 111-118 (2004).
11. P. A. Furley, "Relationship between slope from and soil properties developed over chalk parent materials," Slopes, Form and Process. No. 3, 141-163 (1971).
12. A. Gómez-Plaza, M. Martınez-Mena, J. Albaladejo and V. M. Castillo, "Factors regulating spatial distribution of soil water content in small semiarid catchments," J Hydrol. 253 (1), 211-226 (2001).
13. D. J. K. B. S. Hons, Changes in soil properties due to topography, tillage and time in the guelph soil catena at the Ontario benchmark, Doctoral Dissertation (Carleton University, Ottawa, 2004).
14. H. Jenny, *The soil resource origin and behavior* (Springer Science & Business Media, New York, 2012).
15. G. J. King, D. F. St. Acton and R. J. Arnaud, "Changes in soil properties due to topography, tillage and time in the guelph soil catena at the Ontario benchmark," Can J Soil Sci. No. 63, 657-670 (1983).
16. H. J. Kleiss, "Hillslope sedimentation and soil formation in northeastern Iowa," in *Proceedings of Soil Science Society of America* (America, 1970) No. 34, pp. 287-290.
17. D. D. Malo, B. K. Worcester, D. K. Cassel and K. D. Matzdorf, "Soil-landscape relationships in a closed drainage system," in *Proceedings of Soil Science Society of America* (America, 1974) No. 38, pp. 813-818.
18. G. Manning, L. G. Fuller, R. G. Eilers and I. Florinsky, "Topographic influence on the variability of soil properties within an undulating Manitoba landscape," Can J Soil Sci. 81 (4), 439-447 (2001).
19. E. A. Norton and R. S. Smith, "The influence of topography on soil profile character," J Am Soc Agron. No. 22, 251-262 (1930).
20. V. Olaya, "Basic land-surface parameters," Developments in Soil Science. No. 33, 141-169 (2009).
21. S. J. Park, K. Mc Sweeney and B. Lowery, "Identification of the spatial distribution of soils using a process-based terrain characterization," Geoderma. 103 (3), 249-272 (2001).
22. D. J. Pennock, "Terrain attributes, landform segmentation, and soil redistribution," Soil Till Res. 69 (1), 15-26 (2003).
23. T. Rhanor, Topographic position and land cover effects on soil organic carbon distribution of loess-veneered hillslopes in the central United States,

Master of Science Degree Thesis (Southern Illinois University Carbondale, United States, 2013).
24. D. L. Rowell, *Soil science: Methods & applications* (Routledge, New York, 2014).
25. R. V. Ruhe, *Quaternary landscapes in Iowa* (Iowa State University Press, Iowa State, 1969)
26. R. V. Ruhe and P. H. Walker, "Hillslope models and soil formation: I. Open systems. Trans," in *Proceeding of 9th International Congress of Soil Science* (Adelaide, 1968), pp. 551-561.
27. P. J. Schoeneberger, D. A. Wysocki, E. C. Benham and W. D. Broderson, *Field book for describing and sampling soils* (National Soil Survey Center, United States, 2002).
28. P. A. Shary, L. S. Sharaya and A. V. Mitusov, "Fundamental quantitative methods of land surface analysis," Geoderma. 107 (1), 1-32 (2002).
29. R. W. Simonson, "Outline of a generalized theory of soil genesis," Soil Sci Soc Am J. 23(2), 152-156 (1959).
30. R. W. Simonson, "A multiple-process model of soil genesis," in *Quaternary Soils. Geo. Abstracts, University of East Anglia, England*. (W.C. Mahaney 1978), pp. 1-25.
31. A. J. Van den Bygaart, "Erosion and deposition history derived by depth-stratigraphy of ^{137}Cs and soil organic carbon," Soil Till Res. No. 61, 187-192 (2001).
32. K. Van Oost, G. Govers and P. Desmet, "Evaluating the effects of changes in landscape structure on soil erosion by water and tillage," Landscape ecology. 15 (6), 577-589 (2000).
33. D. E. Walling, "Recent advances in the use of environmental radio nuclides in soil erosion investigations," in *Proceedings of Nuclear Techniques in Integrated Plant Nutrient, Water and Soil Management* (Vienna, Austria, 2002), pp. 279-301.
34. C. R. Wood, *Summary groundwater resources of Centre County, Pennsylvania* (The U. S. Geological Survey, Water Resources Division, in cooperation with the Pennsylvania Geological Survey, United States, 1980).

Table1. The genetic horizons thicknesses along convex slope and five positions of catena

Slope positions	Soil type	Horizon	Thickness (cm)	Description of soil horizon
Summit	Inceptisols	Oi	3.20	It contains organic matter with litter layer of plant residues in relatively non-decomposed form.
		Oe+a	2.35	It contains highly decomposed and moderately decomposed plant residuals.
		A	0-34	It is a combination of mineral, organic matter and high amount of small roots, and it can be seen in 7.5 YR 4/4 color.
		Bt1	34-98	It is a sticky horizon because of having high amount of clay, and it can be seen in 5YR 3/2, it contains fewer amounts of small roots.
		Bt2	98-135	The amount of clay is lesser in this horizon than Bt1, and it can be seen in 2.5YR 3/2 color;it has lesser small roots than the previous layer.
Shoulder	Inceptisols	O	3.65	It contains different plan residuals and litter.
		A	0-29	It is a combination of mineral and organic matter with high amount of small roots, and it can be seen in 5Y 3/1color.
		B	29-110	Clay can be found irregularly in this horizon and it can be seen in 5Y 5/1 color, the amount of small roots is lesser here.
Back Slope	Inceptisols	O	2.49	It contains different plan residuals and litter.
		A	0-25	It is a combination of mineral and organic matter with high amount of small roots, and it can be seen in 2.5 YR 4/2 color.
		B1	25-38	Soil has bigger particles in this horizon, and it can be seen in 2.5 YR 5/2, the amount of small roots is lesser here.
		B2	38-117	Soil contains slightly smaller particle in this horizon than the previous layer, and it can be seen in 2.5 YR 4/2, there is no small roots in this layer.
Footslope	Inceptisols	Oi	3.35	It contains organic matter with litter layer of plant residues in relatively non-decomposed form.
		Oe	2.11	It contains fibers before rubbing and underlain by a partially decomposed layer.
		Oa	3.32	It contains highly decomposed plant matter and litter.
		A	0-31	It is a combination of mineral and organic matter with high amount of small roots, and it can be seen in 5YR 3/2 color.
		Bt1	31-54	It is a sticky horizon because of having high amount of clay, and it can be seen in 5YR 3/2, it contains fewer amounts of small roots.
		Bt2	54-101	The amount of clay is lesser in this horizon than Bt1, and it can be seen in 5YR 3/1 color; it has lesser small roots than the previous layer.
		Bk	101-150	Some symptoms of Carbonated compounds can be seen in this horizon, and it can be seen in 2.5YR 7/2 color; it contains lesser amount of small roots than the previous layer.
Toeslope	Inceptisols	Oi	4.28	It contains organic matter with litter layer of plant residues in relatively non-decomposed form.
		Oe	1.42	It contains fibers before rubbing and underlain by a partially decomposed layer.
		Oa	3.12	It contains highly decomposed plant matter and litter.
		A	0-27	It is a compound of mineral and organic matter with high amount of small roots, and it can be seen in 5 YR 4/2color.
		Bht	27-128	It is a sticky horizon because of containing high amount of clay, and it can be seen in 5YR 3/2 color, it contains less amount of small root and Aggregation of clay illuviation can be seen in this horizon.
		Bk	128-150	Some symptoms of Carbonated compounds can be seen in this horizon, and it can be seen in 2.5YR 7/2 color; it contains lesser amount of small roots than the previous horizon.

Table2. The genetic horizons thicknesses along concave slope and five positions of catena

Slope positions	Soil type	Horizon	Thickness (cm)	Description of soil horizon
Summit	Inceptisols	Oi	4.57	It contains organic matter with litter layer of plant residues in relatively non-decomposed form.
		Oe	1.49	This horizon contains fibers before rubbing and underlain by a partially decomposed layer.
		Oa	1.65	It contains highly decomposed plant matter and litter.
		A	0-58	It is a compound of mineral and organic matter with high amount of small roots, and it can be seen in 10YR 3/2 color.
		Bt	58-95	It is a sticky horizon because of having high amount of clay, and it can be seen in 10YR 3/1, it contains fewer amounts of small roots than the previous horizon, some gravel can be seen in this horizon.
Shoulder	Inceptisols	Oi	4.27	It contains organic matters with litter layer of plant residues in relatively non-decomposed form.
		Oe+a	4.35	It contains highly decomposed and moderately decomposed plant matter.
		A	0-42	It is a compound of mineral and organic matter with high amount of small roots, and it can be seen in 10YR 5/1 color.
		Bt	42-103	It is a sticky horizon because of having high amount of clay, and it can be seen in 10YR 3/1, it contains fewer amounts of small roots than the previous horizon, some gravel can be seen in this horizon.
Back Slope	Inceptisols	O	3.24	It contains different plan residuals and litter.
		Ap	0-20	It is a compound of mineral and organic matter with high amount of small roots, and it can be seen in 10YR 5/1 color, some symptoms of plowing can be seen in this horizon.
		Bht	20-87	It is a sticky horizon because of containing high amount of clay, and it can be seen in 5YR 3/1 color, it contains lesser amount of small roots than the previous horizon and Aggregation of clay illuviation can be seen in this horizon, it has high percentage of gravel.
Footslope	Inceptisols	O	5.42	It contains different plan residuals and litter.
		A	0-31	It is a compound of mineral and organic matter with high amount of small roots, and it can be seen in 5YR 5/2 color.
		Bt1	31-72	It is a sticky horizon because of having high amount of clay, and it can be seen in 5YR 4/4, it contains fewer amounts of small roots than the previous layer.
		Bt2	72-116	The amount of clay is lesser in this horizon than Bt1, and it can be seen in 5YR 5/4 color; it has a lesser small roots than the previous layer, it has some gravel.
Toeslope	Inceptisols	Oi	4.82	It contains organic deposit with litter layer of plant residues in relatively non-decomposed form.
		Oe	2.27	This horizon contains moderately decomposed plant matter and litter.
		Oa	4.19	It contains highly decomposed plant matter and litter.
		A	0-43	It is a compound of mineral and organic matter with high amount of small roots, and it can be seen in 5YR 2.5/1 color.
		Bht1	43-68	It is a sticky horizon because of containing high amount of clay, and it can be seen in 5YR 3/1color, it contains lesser amount of small root than the previous layer, and Aggregation of clay illuviation can be seen in this horizon.
		Bt2	68-123	The amount of clay is lesser in this horizon than in Bt1, and it can be seen in 5YR 4/1color; it has lesser small roots than the previous layer, it has some gravel.

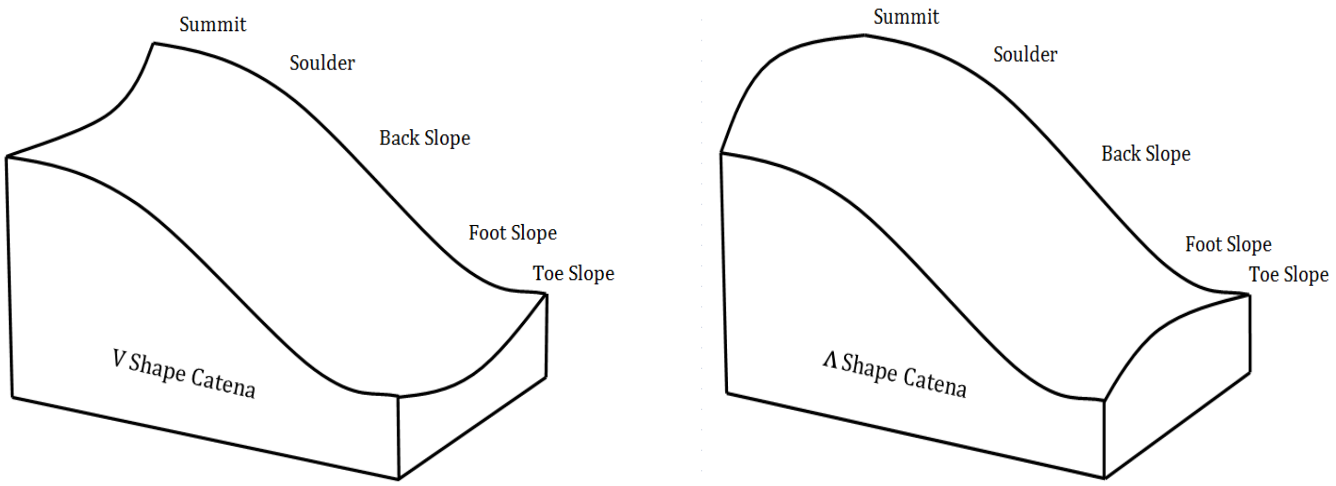

Fig 1. Description of two catenas and five positions.

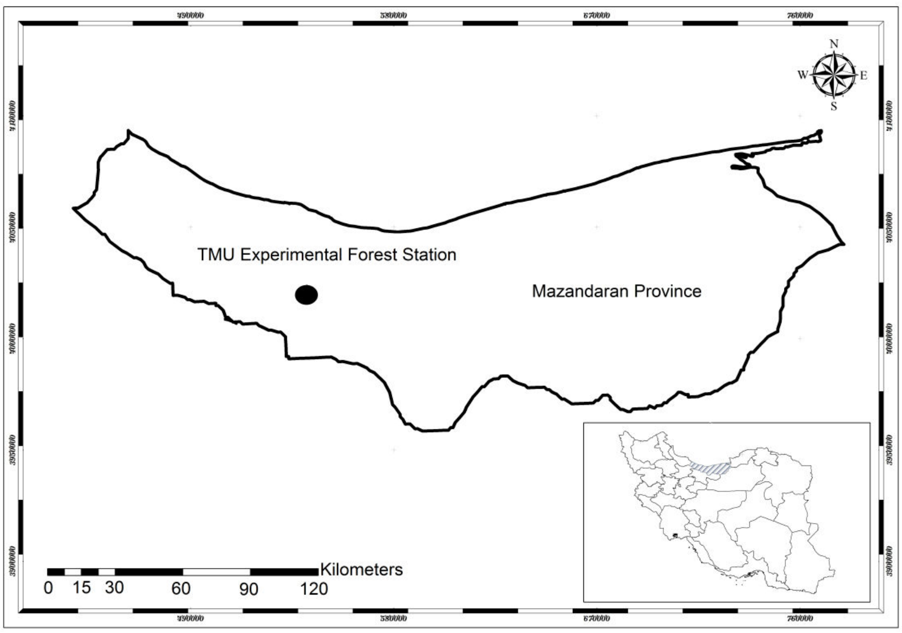

Fig 2. Location of the Experimental Forest Station of Tarbiat Modares University (TMU) in Mazandaran Province, Northern Iran.