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Characteristics of soil profiles along the altitudinal gradients in Sikkilsdalen and Heimdalen mountains in Southeast Norway

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This thesis is worth 60 study points

Summary

This thesis examines and compares the characteristics of soil profiles along the altitudinal gradients in Sikkilsdalen and Heimdalen, situated in southeast Norway on the basis of primary data collected from the north facing and south facing slopes. To achieve the goal, content of plant available potassium (K), magnesium (Mg), calcium (Ca) and phosphorus (P) were quantified in soil profiles at an interval of 100 m from top to bottom of the mountains. Loss on ignition, pH, particle size and soil types were also examined and described.

Organic carbon (C) were determined by loss on ignition. The plant available nutrients were determined by extracting soil with AL-solution (0.1 M ammonium lactate and 0.4 M acetate). Soil pH of all samples were determined in a soil: water of 1:2.5 (volume based) with the help of pH meter. Dry sieving was performed to determine the particle size distribution (texture) of the soil. Unified soil classification technique was used to determine the soil type on the basis of uniformity coefficient and coefficient of curvature.

Overall, plant available nutrients K, Mg, Ca, organic C is found to be significantly unchanged with respect to the mountain, but, phosphate is significantly different. Soil type is not variate with altitude and slope. Particle sizes $D_{10,}$ D_{60} were found to be almost same in all profiles, but D_{30} Varies significantly. Also, pH is not changed too with respect to the mountain, horizon and soil type.

Soils were found acidic in all profiles. Organic C, K, Ca and Mg show negative correlations with pH and altitude. In contrast, phosphate is positive correlated with pH and altitude. Organic C is found to be skewed with respect to the mountains and depths. Its concentration is higher in sand than gravel, and it is declining downward as well. Average potassium contents were high in upper soil and poorly graded sand, and the average estimated content were 10 mg/100 g. Average Phosphate content was 1-2

mg/100 g in north face, and it was 0.5-1 mg/100 g in south face. The content was higher in gravel than sand.

Magnesium content was between 1.4 and 57.1 mg/100 gm, it was high in well graded sand, and not normally distributed. Ca varied between 10.4 and 279.6 mg/100 g and it was reducing with depth. Mg and Ca were also higher in sand than gravel.

Only GG (gap graded), GP (poorly graded gravel), GW (well graded gravel), SP (poorly graded sand) and SW (well graded sand) soil types were found in both mountains on the basis of unified soil classification.

pH shows almost uniform trends along the transects, however, regression lines for nutrients vary between mountains along the altitudinal gradients.

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Foreword

This master thesis entitled "Characteristics of soil profiles along the altitudinal gradients in Sikkilsdalen and Heimdalen mountains in Southeast Norway" would have been a dreary and obscure task without the support, help and supervision of different notable people.

I owe a lot of people a big gratitude for making it possible for me to complete this work. firstly, I would like to thank my Supervisor Associate Professor Live Semb Vestgarden and Co-Supervisor Professor Dr. Philos Arvid Odland for the guidance and encouragement. I want to thank them for comments that have considerably improved this thesis and for all their trust in what I am doing and upon me.

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< Bø i Telemark /15 May,2016>

<Md Jahangir Ali>

1 Introduction

1.1 Soil forming factors and processes at high altitudes

1.1.1Climate – precipitation and temperature

Characteristics of soil profiles can be understood by their physical and chemical properties that differs with the change of locations as temporal and spatial distribution of water is not uniform across the landscape (Nielsen et al., 1996). So, water and its different forms can be understood as the first vital climatic factor influencing the soil forming process at different sites. Precipitation and infiltration of water into the soil may be unique due to topography. As a result, soil structure in the soil is influenced (Blanco-Canqui et al., 2011). Intensive precipitation can increase the microbial activities in the soil; the rate of nutrients flow from soil to the plants, and the leaching and erosion processes (MatÍAs et al., 2011). Hence, nutrient deficiencies may be seen in the soil.

Rubinić et al. (2015) investigated pseudogley in Croatia and they claimed that excessive rainfall decreased the soil pH, base saturation and soil nutrient ratio's, but increased the concentration of organic C. Furthermore, they said that particle size distribution in a soil profile was also affected due to precipitation.

Temperature is another climatic factor that affects the characteristics of soil. Purton et al. (2015) studied the soil profiles of central Canada and argued that chemistry of soil, especially, soil organic matter (SOM) was poorly affected because of the influences of temperature along with rainfall and latitude, whereas, it varied noticeably with depth due to the pedogenic process.

Increased air temperature increases the upper soil temperature significantly, including different layers of a profile. It also enhances the rate of thawing of mountain soil (Bai et al., 2012). Mountain soil temperature increases due to the insulating effect of snow cover as well (Jungqvist et al., 2014). Short term summer radiation in alpine areas shows positive response on a frozen soil (Ridefelt et al., 2008). Hanson and Hoelzle (2005) argued that increased atmospheric temperature stimulated the permafrost which was formed on a bedrock. Change in surface characteristics is also important and should be considered while talking about the response of soil or frozen soil on temperature. Temperature is able to reduce the soil moisture and alter the hydrological process. And hence, a soil profile may change their physical and chemical behavior. So, temperature can be understood as the second important climatic factor that can affect the nature of soil profile.

Prolonged period of snow cover in a year also decreases the temperature and plant production, that is why, organic matter decreases in the soil, and hence characteristic of soil changes.

Felde et al. (2012) studied the shifting nature of plant species along the elevation in Sikkilsdalen and argued that plants species change their habitats throughout the elevational zone. Upward movement of species have been found more than the downward, normally, the species which are covered by the snow cover for a long time have been shifted upward than the species experience short term snow cover. High rainfall and temperature might have activated this phenomenon despite the changing pattern of snow cover.

1.1.2 Parent material

Soil formation process depends on bed rock quality. Generally, mountain soil is formed on boulders in alpine region. Soil may be coarse grain or fine grain. And, the availability of nutrients in deeper layer of coarse grain sand and clayey or upper horizon depends upon the early hydrothermal alternation of bedrock (Lemarchand et al., 2012).

Soil types may be different in different mountains. Generally, Acrisols and Alisols are found at low altitudes, podzols in montane and upper montane forest and Umrisols at high altitude in alkaline granite rock type of mountain (Podwojewski et al., 2011).

Allen (2005) conducted a research in Swedish Lapland and said that soils were poorly developed and structured, coarse textured, well drained and very low thickness (< 27 cm). Chemically, it is very acidic having soil pH ranges between 3.7 and 5.3, having minimum base saturation and cation exchange capacity and the extractable nutrients are found to be in an order of Na< K<Mg<Ca. In addition, organic carbon is also supposed to be in decreasing order with soil depth.

Nutrient storage and availability, water retention and soil erosion depend on the physical property of soil texture (Owji et al., 2012). So, soil texture should be described while discussing about the characteristics of soil profiles.

1.1.3Topography and altitudinal gradients

Soil nutrients may vary along the altitudinal gradients because they are moved from high to lowland by weathering, erosion and leaching activities. Normally, soluble ions of soil nutrients form the high land is transferred to the deep water table by the process of leaching. The content will be high in upper layer unless it is absorbed or stored by clayey B horizon. These ions may be accumulated on the closet surface of lowland water table from deep water table due to capillarity. Later, the lost nutrients are balanced by the soil forming parent martials (Anderson, 1988). Due to this phenomenon, the soil forming process and nutrient availability in soil horizons in mountain zones vary throughout the altitudinal gradients. Also, grazing activities may affect the levels of extractable calcium, magnesium, potassium and phosphorous in alpine soil (Binkley et al., 2003).

Phosphorous is an essential soil nutrient and its natural movement is supposed to be slow because of its low solubility and high conversion rate to insoluble forms, however, fertilizers can step up its limit value. After then, it is shifted to the downstream by soil erosion and surface run off and causes eutrophication (Smil, 2000).

Studies of Mt. Gongga by Zhou et al. (2016) showed that inorganic soil phosphorous was high in alpine areas, whereas, it is comparatively low in sub alpine and low altitude areas. They found a parabolic curve of phosphorous content along the slope, however, combined graph of Ca and inorganic P was not parabolic.

Soil erosion, shallow landslide, debris -flows etc. are the geological processes that causes soil loss in mountain areas, on the contrary, poorly crystalline and pedogenic oxides of iron in spodic and C horizons, including organic matter content in A horizon or top soil and other sub horizons play vital role for the soil stability (Stanchi et al., 2015).

1.1.4 Organic matter content and organisms

A study conducted in Tibetan Plateau along the altitudinal gradient between 4400 and 5300 m with the soil profile 0-30 cm and reported that soil organic carbon (SOC) increased up to 4950 m, however, it decreased in the nival zone at 5200-5300 m; it might happen due to the low vegetation cover and grazing effect (Ohtsuka et al., 2008).

Organic matter content in mountain soil might be exogenic input of vegetation and endogenic input of decaying roots. The process of organic carbon mineralization depend on temperature, oregano metallic complexes and pedogenetic process linked with variation in vegetation type with altitude (Podwojewski et al., 2011).

The concentration of soil organic carbon (SOC) was found higher in mountain top, conversely, it declined mountain slope. This might be happened due to the rise in temperature , fall in precipitation and increment in mineralization process which is activated by climatic factors (Martin et al., 2010).

Altitudinal gradient is an another factor that may change the concentration of SOC at different heights. For example, in alpine belts of Rondane, organic matter decreased with increase of height (Stützer, 1999). Also, organic matter can decline or variate at different locations and soil layers due to the mineralization rate of litter and its storage (Chen et al., 2002).

Soil carbon pool may differ in different ecosystem and climatic zone, for example, organic C decreases quickly with depth in tropical zone but it increases up to a depth of 24 cm, after then, it starts to decrease in temperate region (Bernal and Mitsch, 2008).

Soil microbes play vital roles in soil forming process because the rate of mineral weathering and reaction to produce the secondary minerals is accelerated by a group of bacteria formed of *Acidobacteria*, *Proteobacteria* and *Cyanobacteria*. As a result, rock is colonized and soil is formed in high mountain environments (Esposito et al., 2013). Usually, soil microbes and their residues are found to be positively associated with mountain soil pH, C/N ratio and substrate availability (Zhang et al., 2013).

1.2 Significance of the study

This study shows the first primary data for soil pH, Ca, Mg, K, P04, loss on ignition, particle size and soil types along transects of in North and South facing mountains, which will be applicable for further research and analysis. It also examines the chemical and physical properties of soil profiles and tests differences or similarities in two associated valleys; Sikkilsdalen and Heimdalen. This research will be helpful to analyze other Norwegian mountains and alpine belts in general. Thus, this study may be useful for analyzing the effect of present, past and future climate too.

1.3 Objectives

The main objective of this study was to examine and compare the variations in physical and chemical characteristics of soil profiles along the altitudinal gradients of two associated Norwegian mountain valleys; Sikkilsdalen and Heimdalen, on the basis of particle size distribution, soil pH, organic C and plant available P, Mg, Ca and K in the soil.

2 Materials and methods

2.1 Study Area

Sikkilsdalen and Heimdalen, both situated in southeast Norway, were chosen for this study. Samples were taken from soil profiles every 100 height meter along north and south facing transects in these valleys, from top of the mountains (1525 m.a.s.l for Sikkilsdalen and 1575 for Heimdalen) down to 1025 m.a.s.l. in Sikkilsdalen and 1150 m.a.s.l. in Heimdalen, as shown in Figure 2-1. It can be assumed that the soil forming process in Sikkilsdalen and Heimdalen could be started 9000 ^{14}C yr BP (Matthews and Caseldine, 1987).

Figure 2-1 All Transect Lines in Sikkilsdalen (right) and Heimdalen (left) (Høye, 2014).

2.1.1 Sikkilsdalen

Sikkilsdalen is situated in Oppland county in eastern Jotunheimen, central southeast Norway. The valley is located at 61^0 28' N and 09^0 00' E (longitude and latitude). Sikkilsdalen is a U shaped valley, extended up to 10 km and a constituent of Caledonian mountain chain. It is elevated from 992 to 1778 m.a.s.l. Normally, it covers with snow from October to May. Its soil is enriched with calcium and phosphates which is formed by the weathering of gneiss and quartzite dominated bed rocks (Felde et al., 2012). The average recorded temperature in January was -10.6^0 C and 8.8^0 C in July, whereas, the mean annual temperature was calculated as -0.2^0 C on the basis of database (1998-2008). And, the average precipitation recorded in January and July was 66.8 mm and 95 mm respectively. Reindeers, cows, sheep, goats and horses are found as the main grazing animals in this area (Felde et al., 2012).

On the basis of database 1961-1990, Sikkilsdalen receives the lowest precipitation i.e. 40 mm in April, 115 mm in October, average 79.16 mm and 950 mm of rainfall in a year. On the other hand, the temperature ranges between -10.2^0 C to 10.4^0 C. May, June, July, August, September and October avail positive temperature values and rest of the months are negative (Høye, 2014). It is also Adjoined by Sjodalen in north and Heimdalen in South. Some nutritious rocks like gabbro, amphibolite and norite are also found in Sikkilsdalen (Høye, 2014).The transect lines in south and north faces are shown in Figure 2-2 and Figure 2-3.

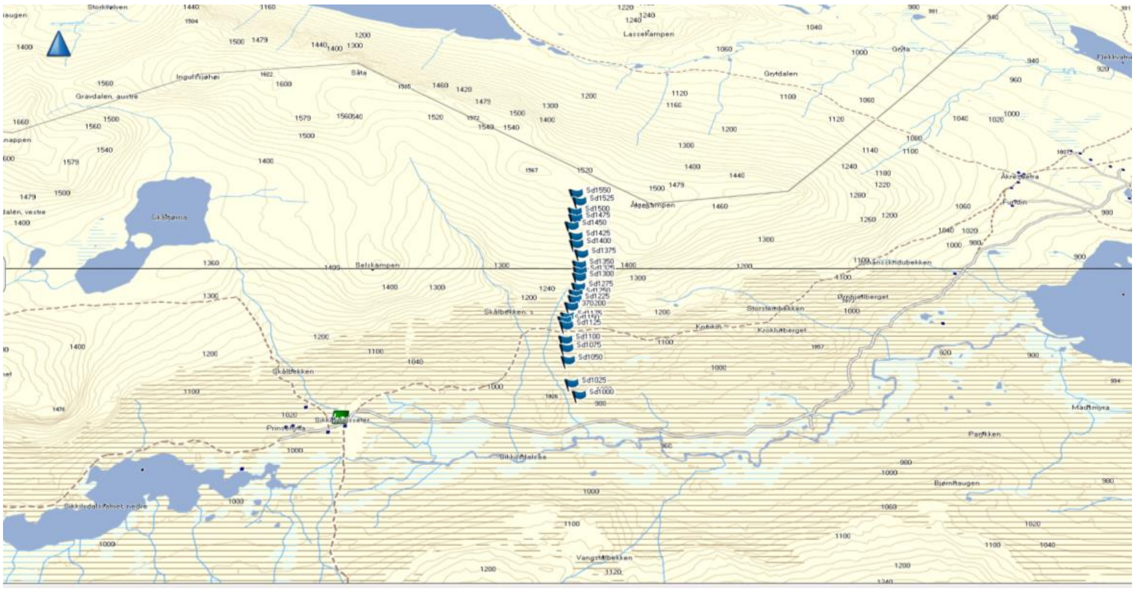

Figure 2-2 Transect line in Sikkilsdalen South Face (Høye, 2014)

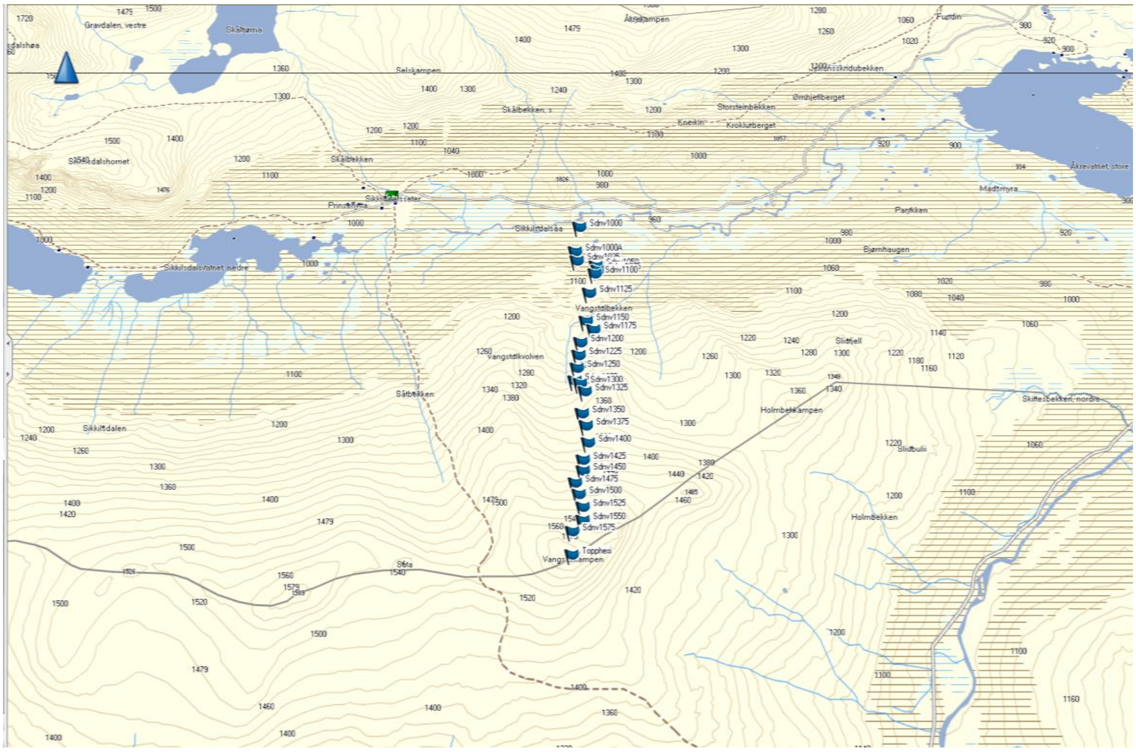

Figure 2-3 Transect Line in Sikkilsdalen North Face (Høye, 2014)

The major plant species identified in this mountain from bottom to top are *Empetrum nigrum, Vaccinium spp., Betula nana, salix spp., Antennaria spp., Omalotheca supina,* *Festuca ovina, Agrostis capillaris, Festuca rubra, Poa pratensis, Epilobium angustifolium, Alchemillia spp., Juncus trifidus, Luzula confusa, Harrimanella hypnoides* (Nordhagen et al., 1943,cited in,Felde et al., 2012).

2.1.2Heimdalen

Heimdalen is also situated in Oppland county and in Jotunheimen. The Valley is located at 61^0 26' N and 09^0 02' E (longitude and latitude). It is well known fishing and recreation. Bed rocks consists of alkaline rocks from Precambrian and it is also a part of Caledonian mountain chain. Gabbro, amphibolite and gneiss are main rocks (Høye, 2014).

Climatic condition varies along the altitudinal zones due to the terrain complexities. Air temperature, precipitation and air humidity are found high in summer in north side of the mountain than anywhere because of high intensity of solar radiation. Therefore, well vegetation pattern can be seen in this side (Johannessen, 1978). Some parts of this mountain has shown no vegetation at all, but in other parts, natural vegetation types are found. For examples birch forest, tall herb meadow, mire vegetation, bilberry heat, snowbed and chionophobous heath can be observed in Heimdalen (Østhagen and Egelie, 1978). Extreme rain water speeds up the rate of soil erosion and leaching activities, as a result, eroded materials are deposited in the lake which is situated at the bottom of the mountain (Grøterud and Kloster, 1978). The lake is clearly shown in Figure 2-4 and Figure 2-5 along with the transect lines.

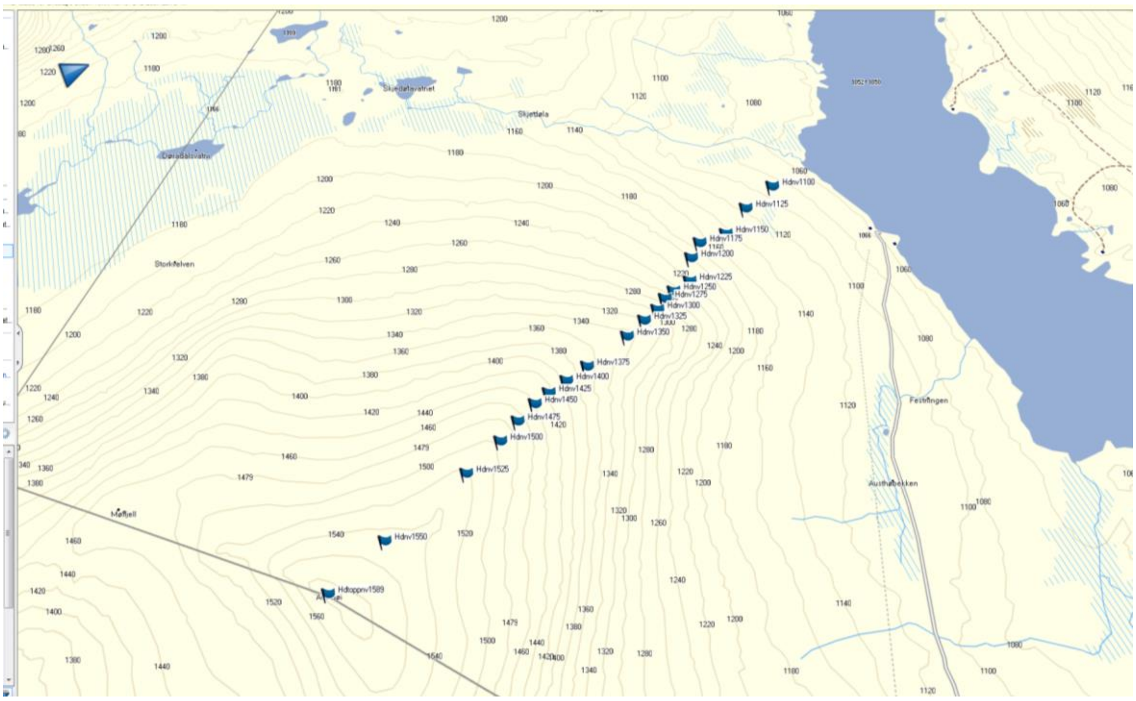

Figure 2-4 Transect line in Heimdalen North Face (Høye, 2014)

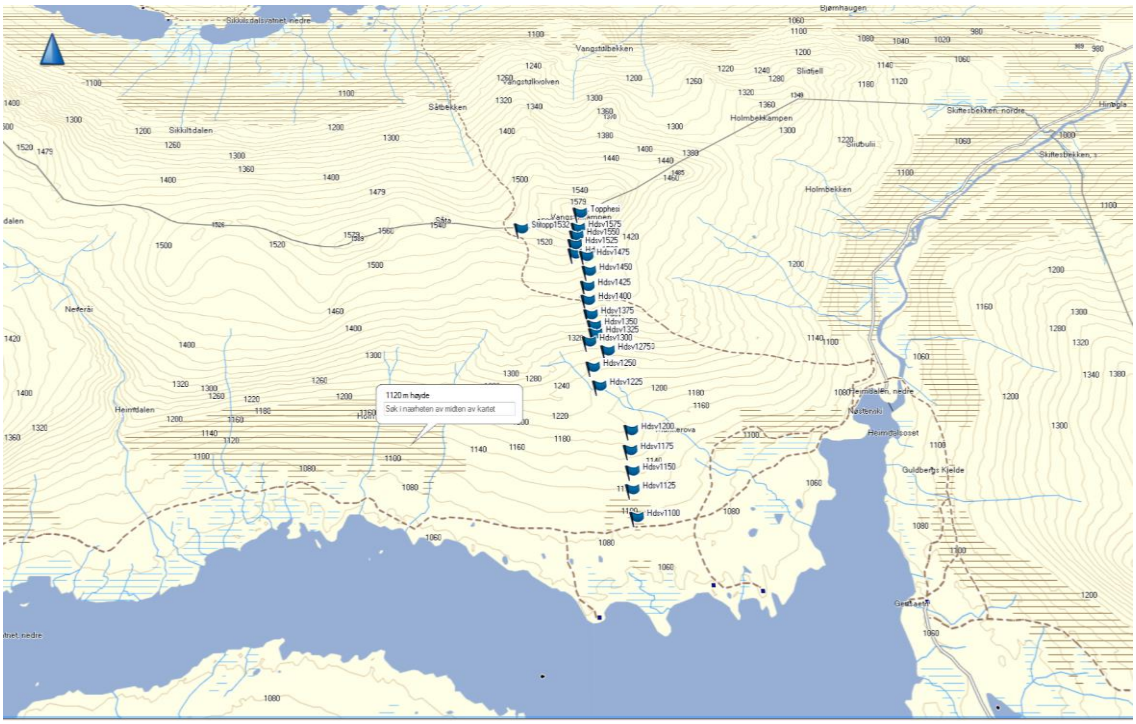

Figure 2-5 Transect line in Heimdalen South Face (Høye, 2014)

2.2 Soil Sampling and Field conditions

The mountains were identified in the field with the help of GPS along the transect lines in both the mountains. North and south facing soil samples were collected from both Sikkilsdalen and Heimdalen in an equal interval of 100 m from top to bottom. The soil samples were collected from 11 to 19 August, 2014 because it was assumed as the best time for field trip. It was summer month having no snow cover and long day length. Overall, the climatic condition during the field work was good in spite of rainfall and excessive wind. Very low temperature was experienced at the top of the mountains, whereas, temperature gradually decreased in lower altitudes. Pine tree, birch, aspen and other species of plant were observed at low altitudes, whereas, lichens and some other lower plants were observed in high altitudes.

Soil samples from A, B, BC and C horizons were collected from the side walls of ditches of depth 50-90 cm. Total number of soil profiles and samples were 22 and 63 respectively altogether in both mountains. During the field activities slope of the mountain and climatic conditions were also noted. The samples were kept in well labeled plastic bags and brought to the soil laboratory and kept in a cold room (4 ˚C). The sampling sites at different heights with slopes are shown below in Table 2-1:

Table 2-1 Sampling Sites with Altitudes and Slopes

S.N	PSDS/Slope	PSDN/Slope	PHDS/Slope	PHDN/Slope
1	$1525/7^0$	$1575/16^0$	$1575/15^0$	$1550/9^0$
2	$1425/2^0$	$1475/20^0$	$1475/20^0$	$1450/5^0$
3	$1325/5^0$	1375/	$1375/10^0$	$1350/5^0$
4	$1225/5^0$	1275/	$1275/5^0$	$1250/22^0$
5	$1125/20^0$	$1175/10^0$	$1175/5^0$	$1150/0^0$
6	$1025/5^0$	1075*/	-	-
Total	6	5	5	5
Total sampling sites			21	

*sampling not done because of steepness

2.3 Lab work

2.3.1 Texture analysis of soil

Dry sieving was performed for all soil samples of B, BC and C horizons to detect the particle size distribution and soil type on the basis of particle size. Sieves of 32 mm to 0.063 mm were used. The shaking was done up to 30 minutes, then weights of soil retained in all sieves were noted and semi log graphs were drawn in excel.

According to U.S.D.A, International modified Wentworth and Phi scale, soil particle size classes for fine earth were classified as clay (< 0.002 mm), silt (0.002 to 0.5 mm) and sand (0.05 to 2 mm) (Schaetzl and Anderson, 2005) .

The basic effective size (D_{10}), median (D_{50}), uniformity coefficient or coefficient of gradation (C_u) and coefficient of curvature (C_c) were estimated from particle size distribution curve, that was obtained by plotting particle size (mm) in x-axis and finer %

in y-axis in the semi log graph, with the help of Excel. The formulae used for the C_u and C_c (Briaud, 2013,Chapter 4,p.55) are given below:

Effective size

The diameter in the particle size distribution curve corresponding to 10% finer is defined as effective size or D_{10}

Uniformity Coefficient or (C_u):

The uniformity coefficient Cu is defined as the ratio of D_{60} by D_{10}

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

Coefficient of Curvature (Cc):

$$Cc = \frac{(D_{30})^2}{(D_{10} * D_{60})} \quad (2)$$

Where,

C_u=Uniformity Coefficient, D_{10}=grain diameter at 10% passing, D_{30}=grain diameter at 30% passing and D_{60}=grain diameter at 60% passing

Unified soil classification system (USCS) is used to classify the soil on the basis of criteria given in Table 2-2, the first letter used to say whether the soil is gravel (G), sand (S), silt

(M) and clay (C) whereas second letter W and P are used for well graded and poorly graded (Briaud, 2013,Chapter 2,p.55).

Table 2-2 Soil Criteria for Coarse Grained Soil (Briaud, 2013,Chapter 4,p.56)

S.N	Soil Criteria	Symbol	Soil Type
1	C_u>6 and 1< C_c<3	SW	Well graded sand
2	C_u<6 and C_c<1 or C_c>3	SP	Poorly graded sand
3	C_u>4 and 1< C_c<3	GW	Well graded gravel
4	C_u<4 and C_c<1 or C_c>3	GP	Poorly graded gravel

2.3.2 Loss on ignition (LOI)

Loss on ignition was determines by weighing 3- 5 g soil, drying it at 105^0C for 6 hours, before ignition at 550^0C for at least 3 hours. Organic matter is supposed to be oxidized on ignition (Koide et al., 2011). Salehi et al. (2011) said that organic C can be roughly estimated by the method of LOI. And hence, organic C is used as term here instead of organic matter. The following Formulas were used to calculate the dry matter and loss on ignition (Krogstad, 1992):

$$\% \, Dry \; Matter = \frac{m3 - m4}{m2} \times 100 \qquad (3)$$

$$\% \, Loss \; on \; Ignition = \frac{m3 - m4}{m3 - m1} \times 100 \qquad (4)$$

Where,

m_1= Weight of cup

m_2 = Weight of soil sample before drying

m_3 = Weight of cup and soil sample after drying

m_4 = Weight of cup and soil sample after ignition

2.3.3 Plant available nutrients and pH estimation

Plant available Potassium (K), Phosphorous (P), Magnesium (Mg) and Calcium (Ca) were determined by extracting with AL-solution (0.1 M ammonium lactate and 0.4 M acetate). This method is described by Egner et al 1960, cited in Krogstad (1992). Soil pH of all samples were determined in a soil: water of 1:2.5 (volume based) by the help of pH meter connected with glass electrode. All the chemical analysis was done in the laboratory of University College of Southeast Norway in Bø, Telemark.

2.3.4 Statistical analysis

The null hypothesis states that there is no significant difference within and between the nutrients and particle size distribution in Sikkilsdalen and Heimdalen mountains in both faces. To test this hypothesis, a non-parametric, Kruskal-Wallis rank sum test was applied because data were not distributed normally along the altitudes in both the mountains. The data were inserted in Excel and loaded in R Commander and p-values were obtained. Also, Pearson's product moment correlation test is preformed and p-values and correlation coefficients were estimated. And, decision about whether the null hypothesis is rejected or accepted is made on the basis of p-values and correlation coefficients.

Some box plots were drawn in R Commander to analyze and compare the trends of average values of nutrients and particle size in both mountains along the altitudes. Trend lines of soil nutrients and pH were drawn along the transect lines of all four mountains with the help of Excel. Regression equations were determined by keeping altitude as an input, and nutrients as an output. Also, R square, p values, intercept and coefficients of altitude were estimated. Same analysis was done for pH as well.

3 Results

3.1 Characteristics of Soil Profiles

3.1.1 Profile Characteristics of Sikkilsdalen South Face (SSF)

 Profile 3-1 at 1525 m	 *Profile 3-2 at 1425 m*	 *Profile 3-3 at 1325 m*
 *Profile 3-4 at 1225 m*	 *Profile 3-5 at 1125 m*	 *Profile 3-6 at 1025 m*

Figure Profile Photos in SSF

Table 3-1 Chemical Data of Soil Profiles in SSF

Depth(cm)	Horizon	C_{org}	pH	Po_4	Ca	Mg	K
		Profile 1 at 1525 m					
50-35=15	A	11.68	5.15	0.80	12.00	2.70	1.50
35-5=30	B	3.91	5.12	1.64	20.70	1.40	0.30
5-rest =5	C	1.85	5.45	1.90	30.20	2.40	0.00
		Profile 2 at 1425m					
50-31=19	A	21.41	5.04	0.48	46.60	6.40	5.30
31-20=11	B	4.81	5.37	0.31	18.90	2.20	0.20
11-rest=11	BC	2.81	5.54	0.30	19.40	1.80	0.10
		Profile 3 at 1325 m					
50-45=5	A	40.25	4.90	2.03	279.60	57.10	19.90
45-30=15	B	7.04	5.30	1.26	49.50	6.70	1.30
15-rest=15	BC	5	5.59	0.33	39.10	4.40	0.60
		Profile 4 at 1225 m					
50-45=5	A	16.09	4.74	0.45	72.70	16.10	12.30
45-0=45	B1(up)	6.12	5.25	0.48	37.40	4.40	1.30
45-Bed rock=45	B2(down)	6.12	5.28	0.37	35.60	3.60	0.60
		Profile 5 at 1125 m					
66-47=19	A	14.25	4.86	0.76	41.60	7.20	11.50
47-12=35	B1(up)	5.41	5.33	0.34	22.20	1.70	0.60
12-rest=12	B2(down)	6.73	5.31	0.30	28.10	2.30	0.60
		Profile 6 at 1025 m					
60-45=15	A	6.57	5.38	0.34	55.20	40.60	4.50
45-rest=45	B	6.34	5.52	0.39	32.90	11.50	1.60
	C	6.05	4.89	34.40	30.70	NA	

Table 3-2 Physical Data for Soil Profiles in SSF

Depth(cm)	Horizon	D10	D30	D60	Cu	Cc	Median	Soil Type
Profile 1 at 1525 m								
50-35=15	A							
35-05=30	B							
5-rest =5	C	0.1	0.1	0.2	4.23	0.87	0.16	GP
Profile 2 at 1425m								
50-31=19	A							
31-20=11	B	0.1	0.1	0.2	2.95	0.58	0.17	Gap Graded
11-rest=11	BC	0.1	0.1	0.3	6.4	1.23	0.22	SP
Profile 3 at 1325 m								
50-45=5	A							
45-30=15	B	0.2	0.3	2	13.3	0.28	0.85	SP
15-rest=15	BC	0.1	0.2	0.3	4.43	1.18	0.22	SW
Profile 4 at 1225 m								
50-45=5	A							
45-0=45	B1(up)	0.1	0.1	1	16.1	0.27	0.46	SP
45-Bed rock=45	B2(down)	0.1	0.1	0.2	3.77	0.55	0.14	Gap Graded
Profile 5 at 1125 m								
66-47=19	A							
47-12=35	B1(up)	0.1	0.2	0.4	4.2	0.77	0.28	GP
12-rest=12	B2(down)	0.1	0	0.5	7.26	0.01	0.31	SW
Profile 6 at 1025 m								
60-45=15	A							
45-rest=45	B	0.3	8	22	84.6	11.2	4.6	SP

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3.1.2Profile Characteristics of Sikkilsdalen North Face

		
Profile 3-7 at 1575 m (SNF)	*Profile 3-8 at 1475 m (SNF)*	*Profile 3-9 at 1375 m (SNF)*

	
Profile 3-10 at 1275 m (SNF)	*Profile 3-11 at 1175 m (SNF)*

Figure 3-1 Profile Photos in SNF

Table 3-3 Chemical Data of Soil Profiles (SNF)

Depth(cm)	Horizon	C_{org}	pH	PO_4	Ca	Mg	K
		Profile 7 at 1575 m					
68-59=9	A	6.63	4.80	0.54	14.80	2.20	1.60
59-32=27	B	4.65	5.06	0.39	21.70	1.60	0.00
32-rest =32	C	2.36	5.20	3.54	19.10	1.60	0.10
		Profile 8 at 1475 m					
60-51=9	A	16.76	4.74	1.84	55.20	9.30	8.40
51-rest=51	B	2.24	5.29	1.39	23.80	2.60	0.60
	R (Bedrock)						
		Profile 9 at 1375 m					
61-46=15	A	20.41	4.67	0.95	199.20	25.30	11.10
46-20=26	B1(up)	5.59	5.42	1.21	44.30	3.90	1.30
20-rest=20	B2(down)						
		Profile 10 at 1275 m					
80-69=11	A	10.79	4.54	0.44	20.90	6.50	4.60
69-35=34	B1(up)	4.88	5.22	0.30	24.00	2.10	0.60
35-rest=45	B2(down)	3.66	5.47	2.29	29.50	2.10	0.70
		Profile 11 at 1175 m					
60-50=10	A	18.75	5.17	0.40	131.90	14.10	9.50
50-16=36	B1(up)	4.47	5.36	1.24	38.20	3.20	1.80
36-rest=36	B2(down)	2.35	5.41	1.02	32.70	2.60	1.30

Table 3-4 Physical Data of Soil Profiles (SNF)

Depth(cm)	Horizon	D10	D30	D60	Cu	Cc	Median	Soil Type
				Profile 7 at 1575 m				
68-59=9	A							
59-32=27	B	0.04	0.11	0.325	8.13	0.93	0.22	SP
32-rest =32	C	0.061	0.12	0.29	4.75	0.81	0.9	SP
				Profile 8 at 1475 m				
60-51=9	A							
51-rest=51	B	0.072	0.28	2.2	30.5	0.49	1.25	SP
	R (Bedrock)							
				Profile 9 at 1375 m				
61-46=15	A							
46-20=26	B1(up)	0.089	0.19	0.69	7.75	0.59	0.39	SP
20-rest=20	B2(down)							
				Profile 10 at 1275 m				
80-69=11	A							
69-35=34	B1(up)	0.089	0.21	2.2	24.7	0.23	1	SP
35-rest=45	B2(down)	0.052	0.1	0.5	9.62	0.38	0.24	SP
				Profile 11 at 1175 m				
60-50=10	A							
50-16=36	B1(up)	0.09	0.19	8	88.89	0.05	1	SP
36-rest=36	B2(down)	0.072	0.16	0.95	13.19	0.37	0.36	SP

1.1.1Profile Characteristics of Heimdalen South Face (HSF)

 *Profile 3-12 at 1575 m*	 *Profile 3-13 at 1475 m*	 *Profile 3-14 at 1375 m*
 *Profile 3-15 at 1275 m*	 *Profile 3-16 at 1175 m*	

Figure 3-2 Profile Photos in HSF

Table 3-5 Chemical data of Heimdalen Southface

Depth(cm)	Horizon	C_{org}	pH	Po_4	Ca	Mg	K
		Profile 12 at 1575 m					
68-56=12	A	25.69	4.64	0.32	20.00	4.00	8.00
56-30=26	B	8.07	5.04	0.33	22.20	2.60	0.40
30-rest=30	C	1.57	5.36	2.57	21.60	1.90	0.20
		Profile 13 at 1475 m					
64-46=18	A	13.9	5.03	0.32	13.30	2.90	1.50
46-30=16	B	3.5	5.17	0.90	10.90	1.60	0.30
30-rest=30	C	13.9	5.10	2.36	31.00	3.50	2.10
		Profile 14 at 1375 m					
73-60=13	A	10.67	4.46	0.37	10.40	3.90	2.70
60-rest=60	B	15.19	5.02	0.43	35.90	5.20	0.80
		Profile 15 at 1275 m					
57-44 =13	A	14.25	5.08	0.30	36.70	8.50	3.60
44 -rest=44	B Up	6.88	5.43	4.74	30.50	2.90	0.30
44-rest=44	B Down	7.25	5.32	0.49	29.80	3.20	0.50
		Profile 16 at 1175 m					
64-41=23	A	25.93	4.36	1.44	52.80	11.30	17.30
41-21=20	B	11.16	5.17	0.30	48.20	6.80	1.80
24-rest=24	C	3.1	5.49	0.99	31.40	2.40	0.30

Table 3-6 Physical Data of Heimdalen South Face

Depth(cm)	Horizon	D10	D30	D60	Cu	Cc	Soil Type	Median
				Profile 12 at 1575 m				
68-56=12	A							
56-30=26	B	0.061	0.19	0.49	8.03	1.21	SP	0.35
30-rest=30	C	0.061	0.15	0.44	7.21	0.84	SP	0.29
				Profile 13 at 1475				
64-46=18	A							
46-30=16	B							
30-rest=30	C	0.084	0.28	0.98	11.67	0.95	SP	0.58
				Profile 14 at 1375 m				
73-60=13	A							
60-rest=60	B	0.061	0.22	0.95	15.57	0.84	SP	0.48
				Profile 15 at 1275 m				
57-44=13	A							
44 -rest=44	B Up	0.085	0.21	1.7	20.00	0.31	SP	0.59
44-rest=44	B Down	0.062	0.15	0.44	7.10	0.82	SP	0.3
				Profile 16 at 1175 m				
64-41=23	A							
41-21=20	B	0.062	0.15	0.45	7.26	0.81	SP	0.34
24-rest=24	C	0.061	0.24	1.4	22.95	0.67	SP	0.71

3.1.3 Characteristics of Soil Profile in Heimdalen North Face (HNF)

Profile 3-17 at 1550 m

.Profile 3-18 at 1550 m

Profile 3-19 at 1350 m

Profile 3-20 at 1250 m

Profile 3-21 at 1150 m

Figure 3-3 Profile Photos of Heimdalen North face

Table 3-7 Chemical Data of Heimdalen North Face

Depth(cm)	Horizon	C_{org}	pH	PO4	Ca	Mg	K
		Profile 17 at 1550 m					
55-48 =7	A	30.99	4.46	1.16	85.4	15.4	22.8
48-24 =24	B	2.61					
24-0 =24	C	1.76	5.69	3.78	29.1	1.8	0.4
		Profile 18 at 1450 m					
57-49=8	A	8.43	4.84	0.98	13.3	3.4	3.6
49-36=13	B	3.61					
36-0=36	C	1.46	5.17	5.63	28.6	1.9	0.7
		Profile 19 at 1350 m					
57-50=7	A	9.79					
50-36=14	B	5.79	5.08	0.51	17.5	1.8	0.5
36-rest=36	C	1.20					
		Profile 20 at 1250 m					
68-52=16	A	15.70					
52-38=14	B	7.72	4.78	0.41	17.1	1.9	0.8
38-rest=38	C	4.64	5.17	1.42	28.4	2.5	0.9
		Profile 21 at 1150 m					
68-59=9	A	55.40	4.33	6.49	182.9	29.3	47
59-6=53	B	7.27	4.96	0.73	52	5.5	1.5
6-rest =6	C	4.30	5.41	2.14	38.1	3.6	1.8

Table 3-8 Physical Data of Soil Profiles in Heimdalen North Face

Depth	Horizon	D10	D30	D60	Cu	Cc	Median	Soil Type
				Profile 17 at 1550 m				
55-48 cm	A							
48-24 cm	B	0.12	0.21	0.95	7.92	0.39	0.45	SP
24-0 cm	C	0.12	0.17	0.22	1.83	1.09	0.21	GW
				Profile 18 at 1450 m				
57-49	A							
49-36	B	0.05	0.20	1.40	25.93	0.53	0.56	SP
36-0	C	0.10	0.18	0.62	6.20	0.52	0.26	SP
				Profile 19 at 1350 m				
57-50	A							
50-36	B	0.06	0.13	0.39	6.09	0.68	0.26	SP
36-1	C	0.07	0.26	1.50	21.13	0.63	0.82	SP
				Profile 20 at 1250 m				
68-52	A							
52-38	B	0.12	0.38	1.60	13.33	0.75	0.85	SP
38-rest	C	0.12	0.24	1.60	13.33	0.30	0.76	SP
				Profile 21 at 1150 m				
68-59	A							
59-6	B	0.08	0.18	0.48	6.40	0.90	0.28	SP
6-rest	C	0.07	0.21	0.77	11.16	0.83	0.35	SP

3.2 Average pH and nutrients

Error! Reference source not found. sows that both mountains have acidic soils since pH ranges from 4.69 to 5.75. Lower mean values of Ca, Mg and K are seen in upper soil layer in Heimdalen South face.

Table 3-9 Mean pH and nutrients values

Horizon	PH	PO4	Ca	Mg	K	Corg(%)
Sikkilsdalen South Face						
A	5.01	0.81	84.62	21.68	9.17	18.37
B	5.34	0.49	32.09	4.63	0.89	6.08
BC	5.42	0.76	26.4	2.53	0.33	3.91
C	5.75	3.4	32.3	16.55	0	1.85
Sikkilsdalen North Face						
A	4.78	0.83	84.4	11.48	7.04	14.67
B	5.29	0.93	30.78	2.67	0.93	4.03
C	5.34	2.92	24.3	1.85	0.4	3.01
Heimdalen South Face						
A	4.71	0.55	26.64	6.12	6.62	18.09
B	5.19	1.2	29.58	3.72	0.68	8.68
C	5.32	1.97	28	2.6	0.87	6.19
Heimdalen North Face						
A	4.69	1.85	62.22	11.6	15.7	24.06
B	5.08	0.5	27.34	2.64	0.84	5.4
C	5.39	2.87	30.28	2.3	0.8	2.67

3.2.1Organic carbon content

Figure 3-4 shows that contents of average organic C are between 1.19 and 55.39 mg/100 g in all four mountains except Heimdalen south facing site. The data is skewed negatively in Sikkilsdalen whereas it is positively skewed in Heimdalen south face. Organic C is high in A horizon and reduces in B, BC and C horizons, normal trends are seen A, B, BC however it is negatively skewed in C(Figure 3-5). It is higher in sand than gravel (Figure 3-6).

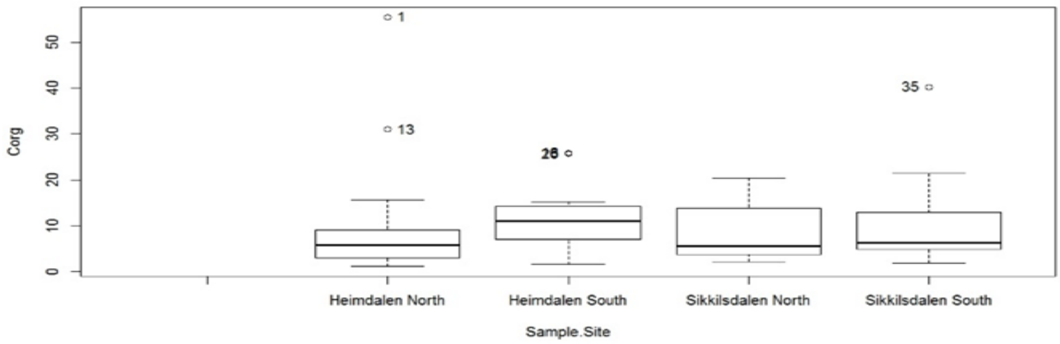


Figure 3-4 Organic Carbon by Mountain(mountain)

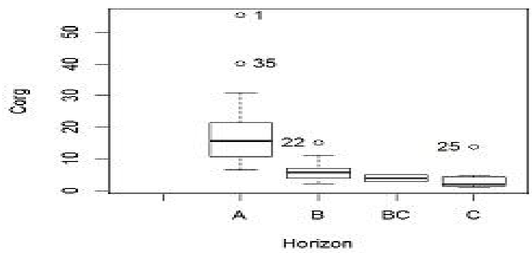


Figure 3-5 Organic Carbon Horizon

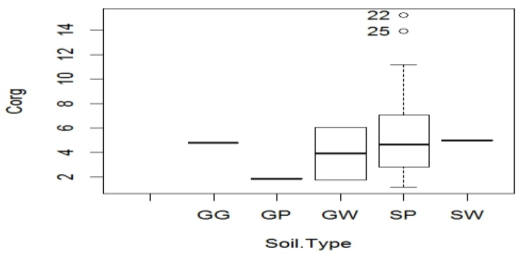


Figure 3-6 Organic carbon by Soil Type

3.2.2pH

The soil was acidic and the average pH was higher in Sikkilsdalen than Heimdalen; North faces having low average pH in both mountains (Figure 3-7). The average pH values increases with depths and are skewed positively in B and C horizons (Figure 3-8). The average pH is found to be low in poorly graded sand (Figure 3-9).

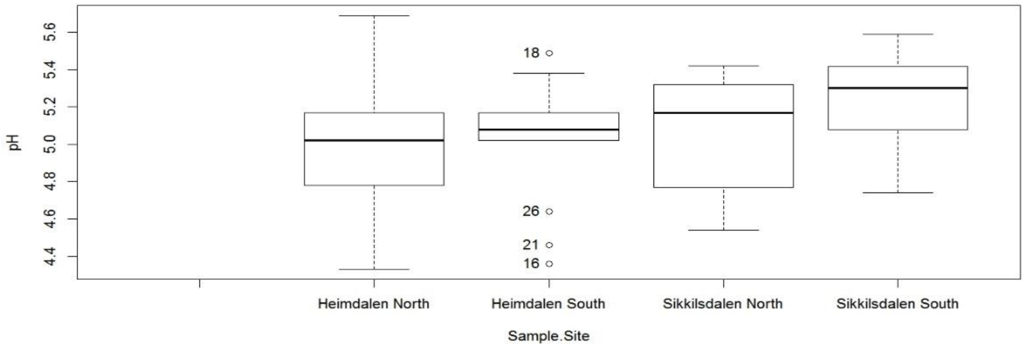


Figure 3-7 pH by Mountain

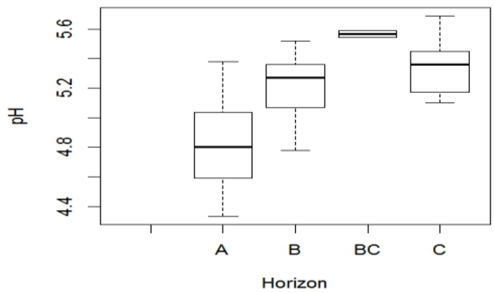


Figure 3-8 pH by Horizon

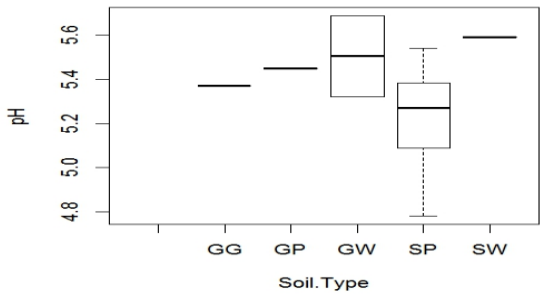


Figure 3-9 pH by soil Type

3.2.3Potassium content

Outliers are seen in all the mountains except Sikkilsdalen North face, it means that some estimated K are out of expected range, it might happen by chance. The average values of K in all samples are between 0 and 47 mg/100 gm and the data are found to be negatively skewed in all site except Heimdalen South Face (Figure 3-10). The average values of K is found to be high in A horizon and comparatively very low in B, C and BC horizons (Figure 3-11). The highest average values are found in poorly graded sand (Figure 3-12).

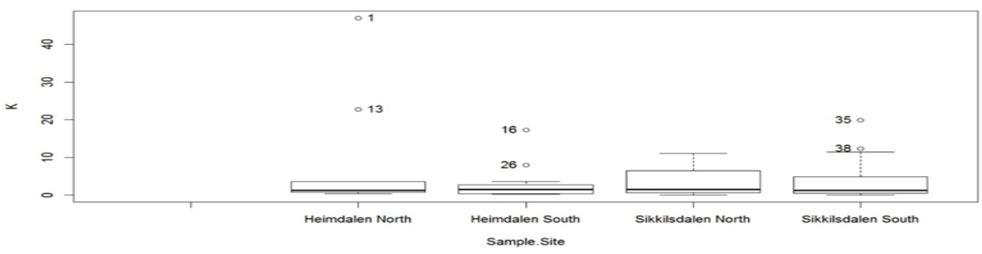


Figure 3-10 K by Mountain

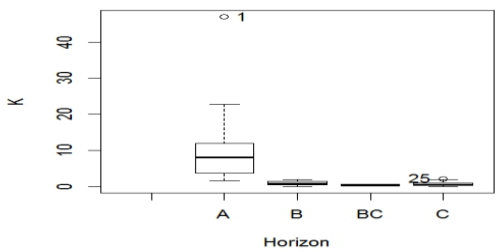


Figure 3-11 K by Horizon

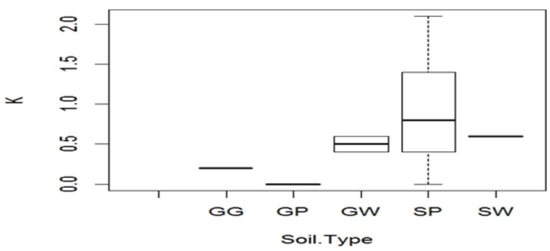


Figure 3-12 K by Soil Type

3.2.4Phosphate content

The average phosphates ranges between 1 and 2 mg/100 gm in north facing mountains, whereas, the values lowered in south facing mountains (Figure 3-13). And, the average phosphate is seen high (>2 mg/100 gm) in C horizon but the vales are less than 1mg/100 gm in A, B and BC horizons (Figure 3-14).The concentration of phosphates are comparatively higher in gravel than sand (Figure 3-15).

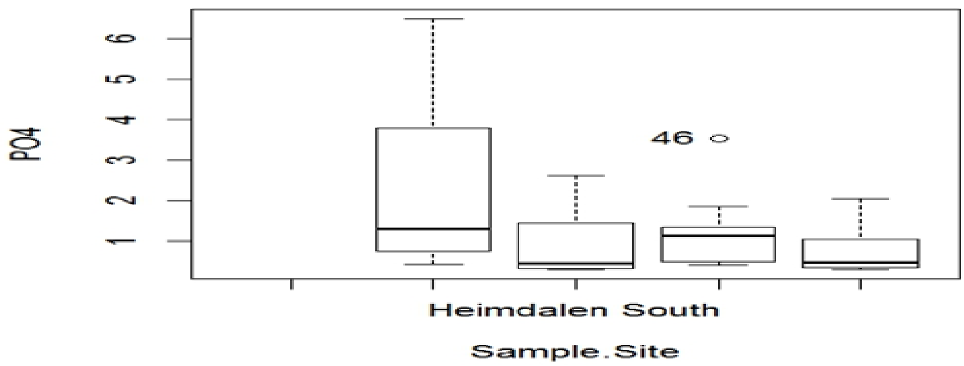
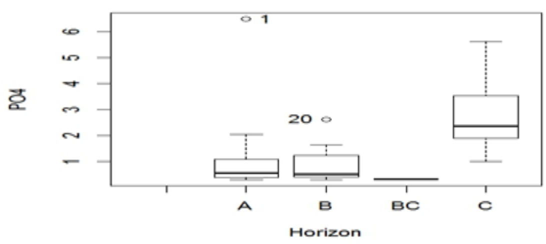


Figure 3-13 Phpsphate by Mountain



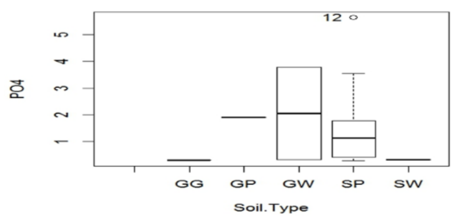


Figure 3-15 Phosphate by Soil Type

Figure 3-14Phosphate by Horizon

3.2.5Magnesium content

The average magnesium is found between 1.4 and 57.1 mg/100 gm in all sites despite the fact that all mountains have outliers above the range. The data is skewed negatively in Sikkilsdalen (Figure 3-16). A horizon has the higher concentration of Mg is found to be accumulated high in upper layer of all the soil profiles (Figure 3-17) . And, well graded sand holds higher magnesium than poorly graded sand and gravels (Figure 3-18).

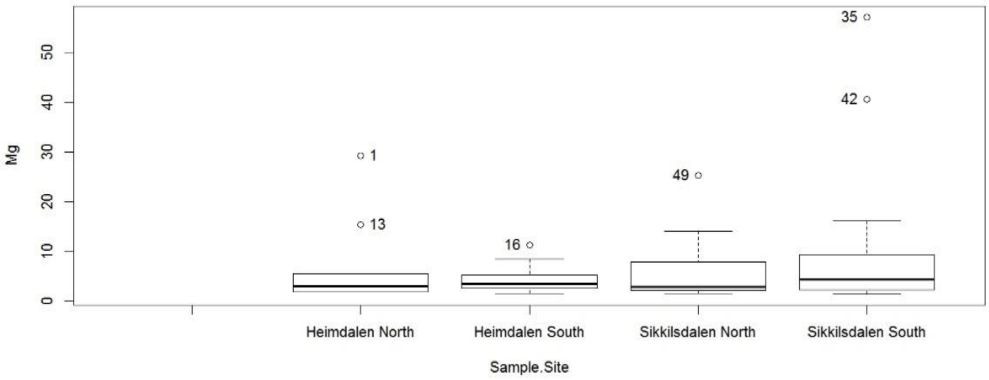


Figure 3-16 Magnesium by Mountain

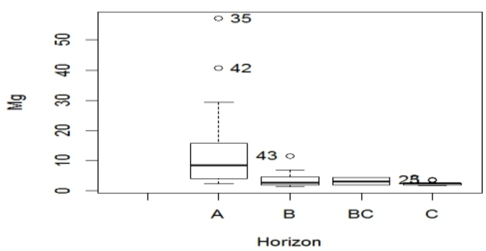


Figure 3-17 Mg by horizon

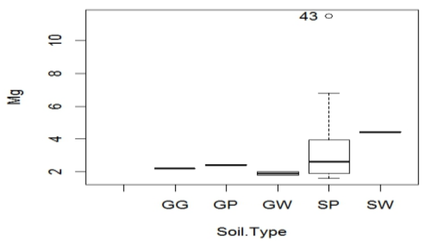


Figure 3-18 Mg by soil type

3.2.6Calcium content

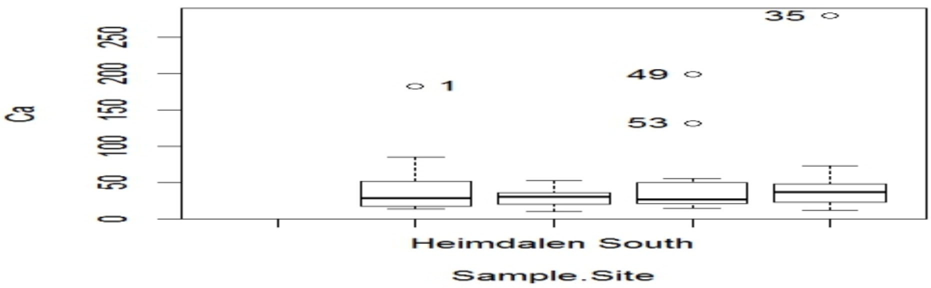


Figure 3-19 Ca by Mountain

The average Calcium values are found to be less than 50 mg/100 gm in all sites, some values are found to be out of range

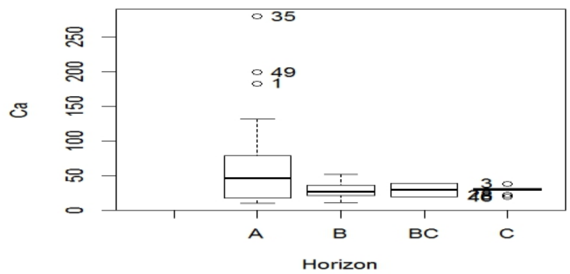


Figure 3-20Ca by Horizon

Average Ca decreases with depth

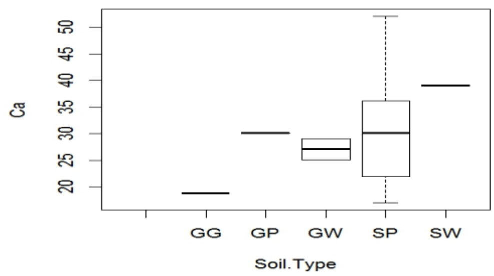


Figure 3-21 Ca by Soil Type

Ca is high in sand than gravel

3.3 Physical Analysis

3.3.1Determination of Soil Type

Table 3-10 is formed on the basis of uniformity coefficients and coefficient of curvature. The majorities of well graded gravel (GW) and poorly graded sand were found in B and C horizons respectively.

Table 3-10 Estimated Soil Types

Horizon	GG	GP	GW	SP	SW	Total
B	1	0	17	0	0	18
BC	0	0	0	1	1	2
C	0	1	1	8	0	10
Total	1	1	18	9	1	30
%	3.33	3.33	60.00	30.00	3.33	100.00

3.3.2 Particle size

3.3.2.1 D10

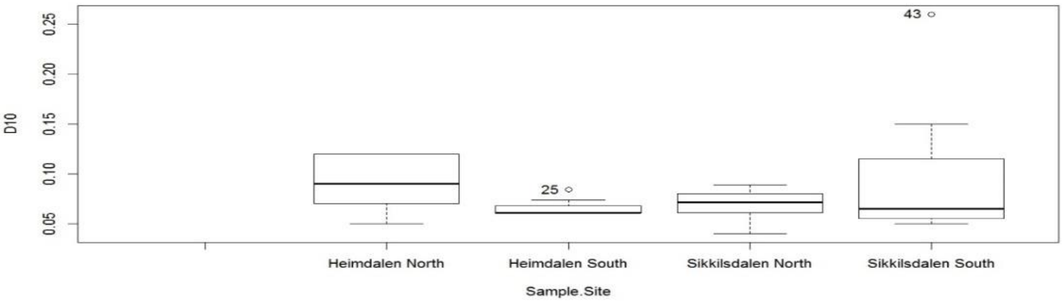


Figure 3-22 D10 by mountain

10 % soil passes through average sieve size of range between 0.05 and 1 mm. Average D_{10} is higher in north facing mountain than south facing.

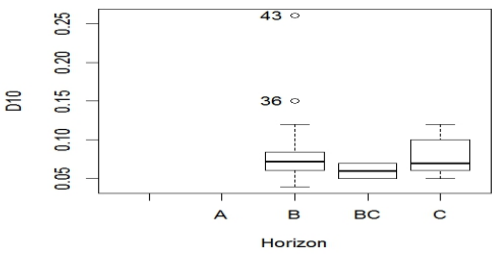


Figure 3-23 D10 by Horizon

Average D10 is almost same in A and C

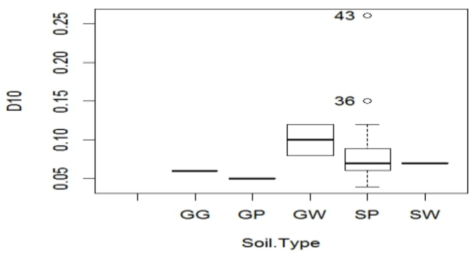


Figure 3-24 D10 by soil type

D10 is higher in well graded gravel than sand

3.3.2.2 D_{30}

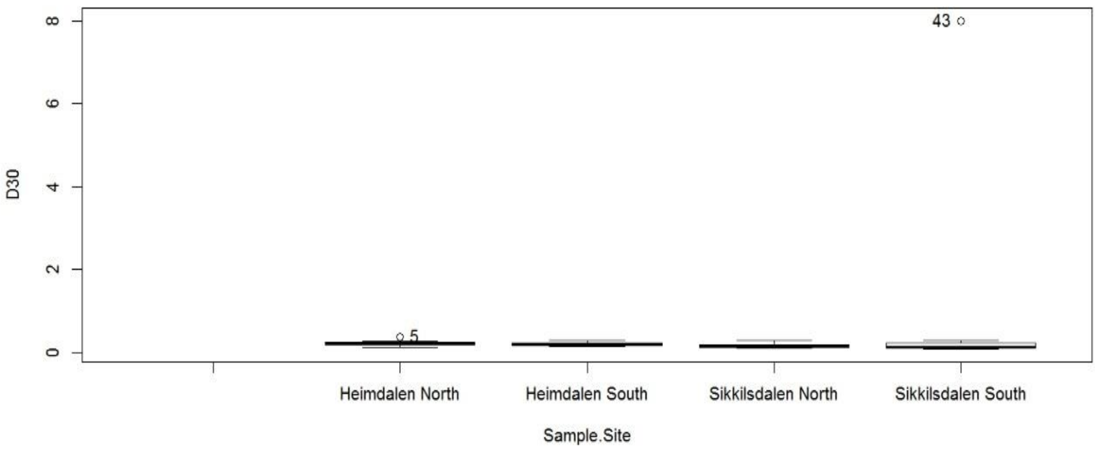


Figure 3-25D$_{30}$ by Mountain

D_{30} is less than 0.5 mm in all sites

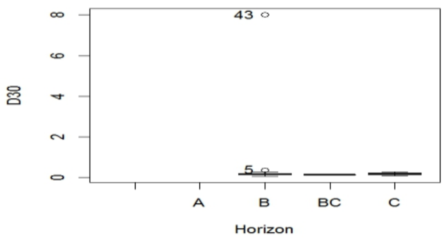


Figure 3-26 D30 by Horizon

D_{30} does not vary with depth

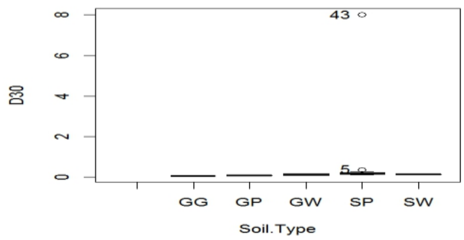


Figure 3-27 D30 by Soil Type

D_{30} does not vary with soil type as well

3.3.2.3 D60

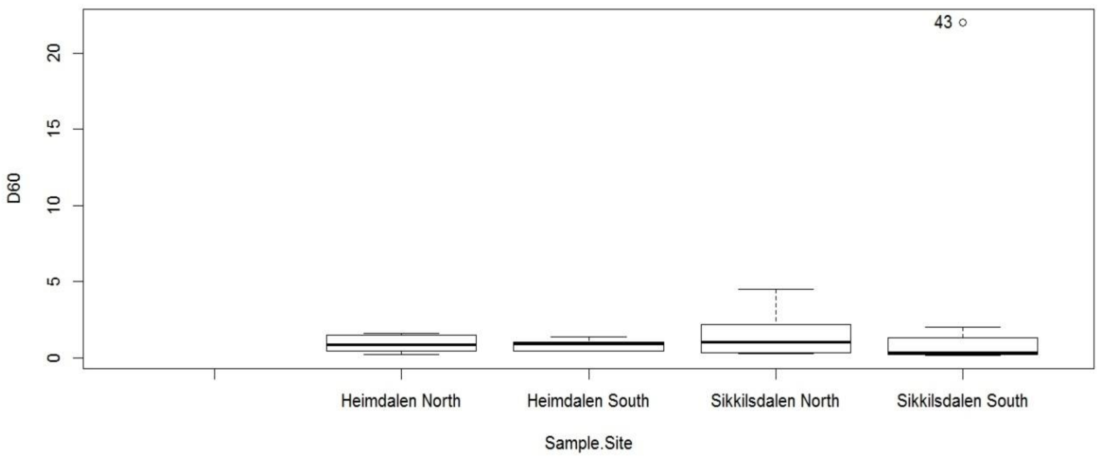


Figure 3-28 D60 by Mountain

60% soil passes through 2mm sieve (Approximately). And, average D_{60} is slightly higher in Sikkilsdalen North Face than others.

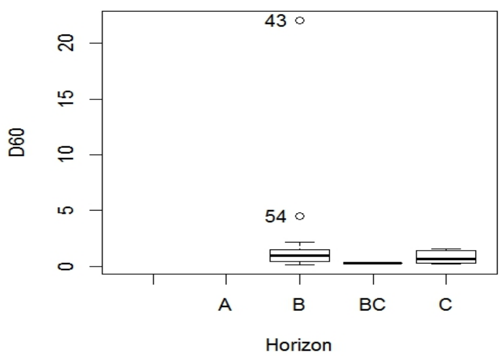


Figure 3-29 D60 by Horizon

Outliers seen in B layer

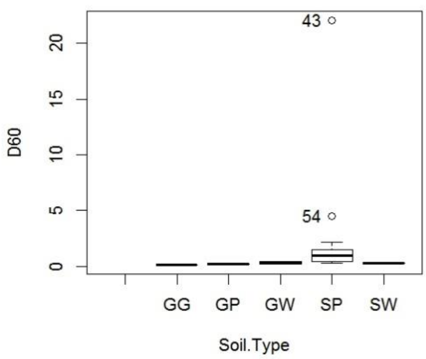


Figure 3-30 D60 by Soil Type

Outliers seen in poorly graded sand

3.4 Hypothesis Testing

Table 3-11 ***Kruskal-Wallis Rank Sum Test***

S.N	Variables	Kruskal-Wallis chi-squared value	df	p-value
1	Altitude by soil type	1.3037	4	0.8607
2	Ca by horizon	2.6287	3	0.4525
3	Ca by mountain	1.8565	3	0.6027
4	Ca by soil type	3.5256	4	0.474
5	Cc by horizon	5.6685	2	0.05876
6	Cc by mountain	3.4839	3	0.3228
7	Corg by mountain	2.1953	3	0.5329
8	Cu by mountain	3.454	3	0.3268
9	D_{10} by mountain	2.3086	3	0.5109
10	D_{30} by mountain	4.3643	3	0.2247
11	D_{60} by mountain	1.9714	3	0.5784
12	depth by horizon	19.143	3	0.000255
13	depth by soil type	7.4058	4	0.1159
14	K by horizon	31.508	3	6.65E-07
15	K by mountain	0.42626	3	0.9348
16	K by soil type	4.7056	4	0.3189
17	Mg by horizon	19.61	3	0.000204
18	Mg by mountain	1.1283	3	0.7702
19	Mg by soil type	3.3181	4	0.5061
20	pH by horizon	26.148	3	8.88E-06
21	pH by mountain	4.1845	3	0.2422
22	pH by soil type	5.9651	4	0.2018
23	PO4 by horizon	17.694	3	0.000509
24	PO4 by mountain	7.2673	3	0.06385
25	PO4 by soil type	3.9022	4	0.4194
26	Slope by soil type	3.3416	4	0.5024

Table 3-11 Shows that Plant available nutrients K, Mg, Ca, Corg are not significantly different ($p > 0.05$), but Phosphate is significantly different ($p < 0.05$) with respect to the mountains. Similarly, types of soil are not also found to be different ($p > 0.05$) with respect to the altitude and slopes. And, D10 and D60 are almost similar ($p > 0.05$) with respect to the mountains whereas D30 ($p < 0.05$) is significantly different. pH and nutrients does not vary significantly ($p < 0.05$) with the mountains, horizons, soil types.

Also, uniformity coefficient and coefficient of gradation are not found to be significantly different ($p < 0.05$) with respect to the mountain and horizon.

3.5 Correlation Analysis

Table 3-12Pearson's product-moment correlation at 95 % confidence limit

S.N	Correlation between	t value	df	p-value	Cor
1	Corg and pH	-6.5739	47	3.63E-08	-0.69212
2	K and pH	-5.7517	47	6.38E-07	-0.64273
3	Altitude and Cu	-2.834	29	0.00828	-0.46571
4	Altitude and D60	-2.6582	29	0.01265	-0.44262
5	Altitude and D30	-2.2881	29	0.02961	-0.39105
6	Altitude and D10	-2.1275	29	0.04201	-0.36743
7	Altitude and Mg	-2.4092	47	0.01996	-0.33154
8	Altitude and Cc	-1.8867	29	0.06925	-0.33065
9	Ca and pH	-2.2983	47	0.02604	-0.31786
10	Mg and pH	-2.0929	47	0.04179	-0.29197
11	Altitude and Ca	-1.6483	47	0.106	-0.2337
12	Altitude and K	-1.4508	47	0.1535	-0.20704
13	Altitude and Corg	-1.0934	52	0.2792	-0.14992
14	Altitude and pH	-0.36374	47	0.7177	-0.05298
15	pH and PO4	-0.21559	47	0.8302	-0.03143
16	Altitude and PO4	0.86775	47	0.3899	0.125572
17	Mg and PO4	0.90435	47	0.3704	0.13078
18	Ca and PO4	1.8404	47	0.07202	0.259274
19	Ca and K	6.851	47	1.38E-08	0.706864
20	Corg and Mg	6.0454	47	2.30E-07	0.661391
21	Corg and PO4	1.6884	47	0.09795	0.239138
22	Corg and K	16.052	47	2.20E-16	0.919635
23	Corg and PO4	1.6884	47	0.09795	0.239138

Table 3-12shows that organic Carbon, K, Ca, PO4, Mg are negatively correlated with soil pH and altitudes. And, all the plant available nutrients except PO4. The particle sizes and soil pH are also negatively correlated with altitude. However, nutrients are positively correlated with each other. Since p-value < 0.05 in all relationship, it can be understood that nutrients are significantly different with respect to altitude and pH.

3.6 Regression Analysis

Table 3-13 Nutrients and pH Analysis along altitudes in SSF

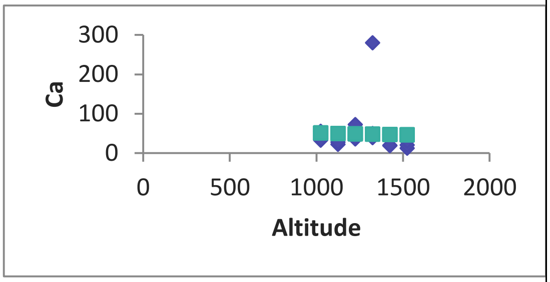


Figure 3-31 Ca by Alt. in SSF
Ca=60.39-0.00919*Alt.,
R^2= 0.07 %, p=0.91

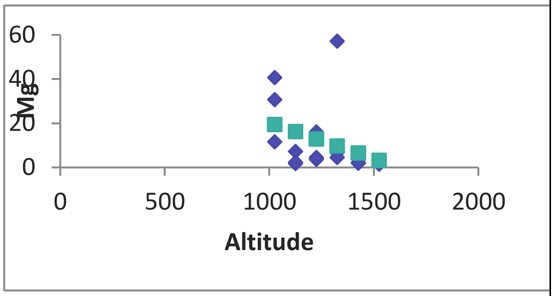


Figure 3-32 Mg by Alt. in SSF
Mg=52.55-0.03236*Alt.,
R^2= 13.19 %, p=0.13

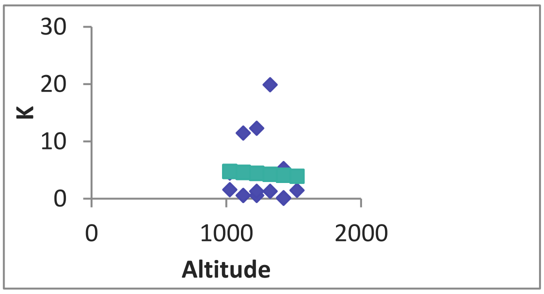


Figure 3-33 K by Alt. in SSF
K=6.482-0.00168*Alt.,
R^2= 0.20 %, p=0.8801

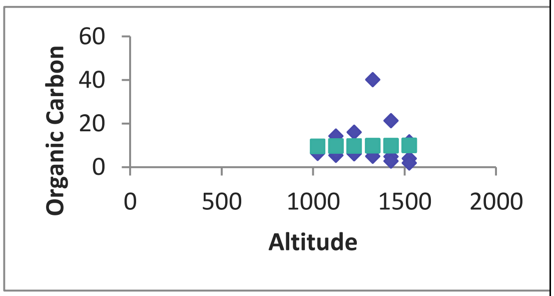


Figure 3-34 OC by Alt. in SSF
OC=8.9972-0.000613*Alt.,
R^2= 0.01 %, p=0.966

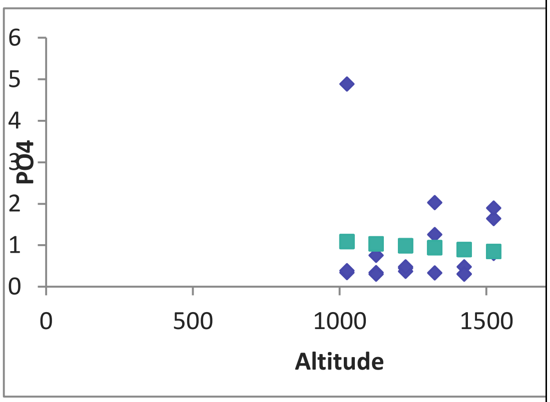


Figure 3-35 PO4 by Alt. in SSF
PO4=1.573-0.00048*Alt.,

R^2= 0.54%, p=0.77

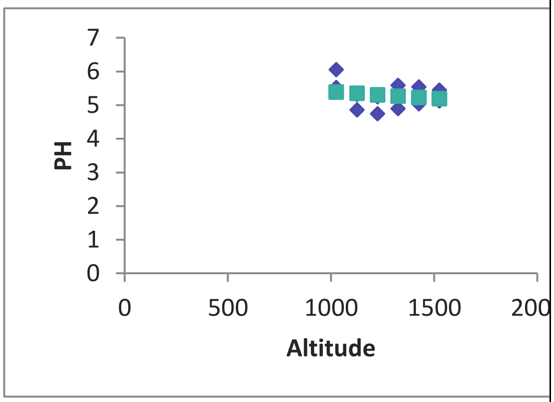


Figure 3-36 pH by Alt. in SSF
pH=5.807-0.00041*Alt.,

R^2= 0.055%, p=0.34

Table 3-14 Nutrients and pH Analysis along Altitudes in SNF

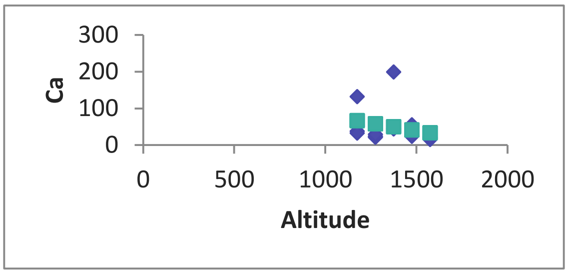


Figure 3-37 Ca by Alt. in SNF
Ca=163.57-0.08277*Alt.,

R^2= 5.65 %, p=0.434

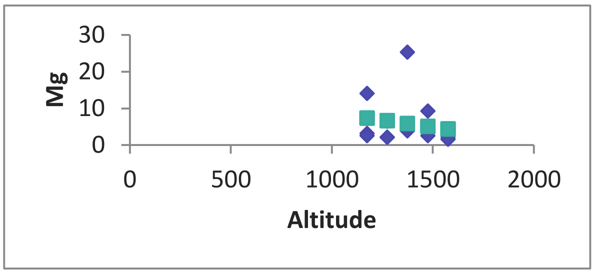


Figure 3-38 Mg by Alt.in SNF
Mg=16.26-0.00756*Alt.,
R^2= 2.91 %, p=0.5773

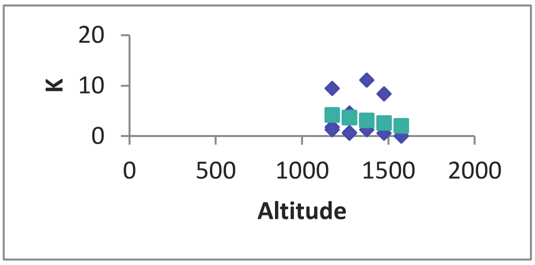


Figure 3-39 K by Alt. in SNF
K=10.52746-0.00536*Alt.,
R^2= 04.55 %, p=0.4839

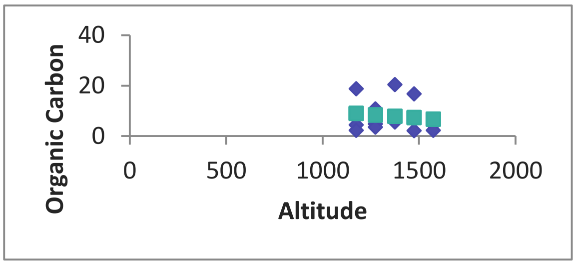


Figure 3-40 OC by Alt. in SNF
OC=15.65-0.00562*Alt.,
R^2= 1.79 %, p=0.66

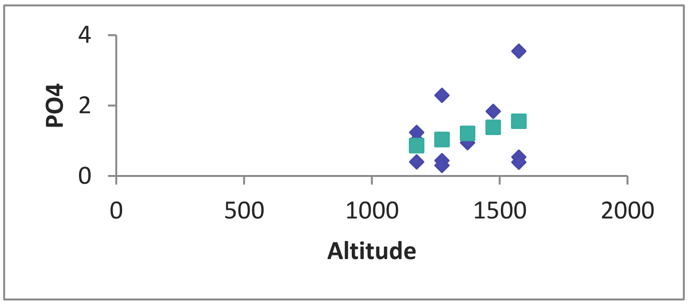


Figure 3-41 PO4 by Altitude in SNF
PO4=-1.17518+0.001734*Alt.,
R^2= 08.42%, p=0.3360

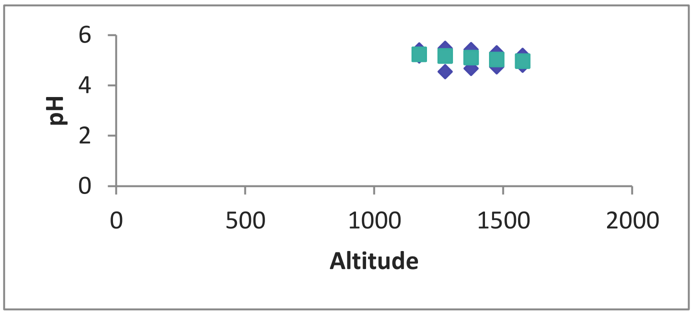


Figure 3-42 pH by Alt. in SNF
pH=5.98+0.00064*Alt.,
R^2= 10.03%, p=0.2918

Table 3-15 Nutrients and pH analysis along the altitudes in HSF

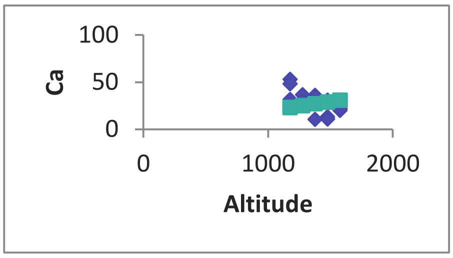


Figure 3-43 Ca by Alt. in HSF
Ca=110.2345-0.05967*Alt.,
R^2= 49.73 %, p=0.004844

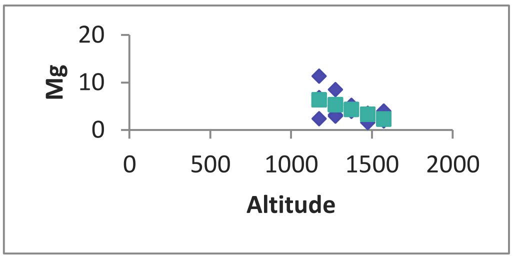


Figure 3-44 Mg by Alt. in HSF
Mg=18.36071-0.0102*Alt.,
R^2= 31.44 %, p=0.036966

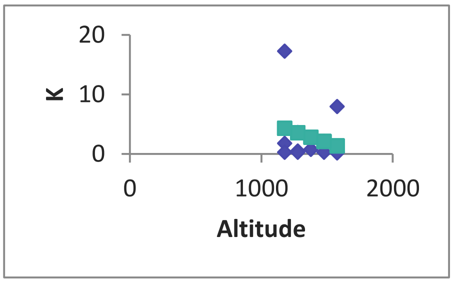


Figure 3-45 K by Alt. in HSF
k=12.97-0.00737*Alt.,
R^2= 5.78 %, p=0.4076

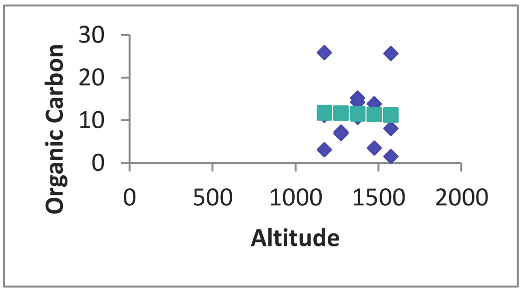


Figure 3-46 Organic Carbon by Alt. in HSF
OC=13.43-0.0014*Alt.,
R^2= 0.08 %, p=0.924

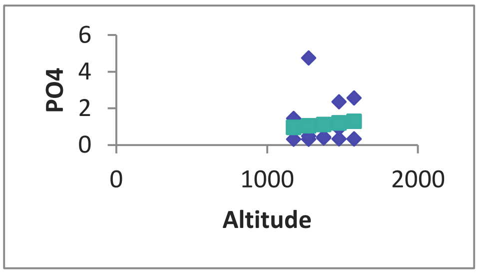


Figure 3-47 PO4 by Alt. in HSF
PO4=1.57-0.00032*Alt.,
R^2= 0.15 %, p=0.897

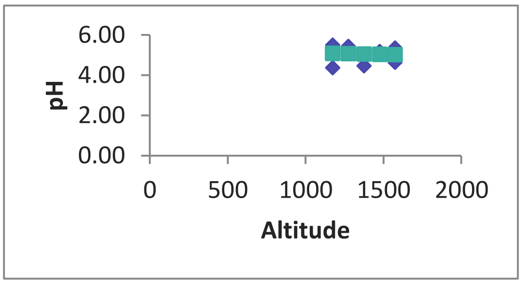


Figure 3-48 pH by Alt. in HSF
pH=5.27-0.00016*Alt.,
R^2= 0.52%, p=0.806086

Table 3-16 Nutrients and pH along the altitudinal gradients in Heimdalen Northface

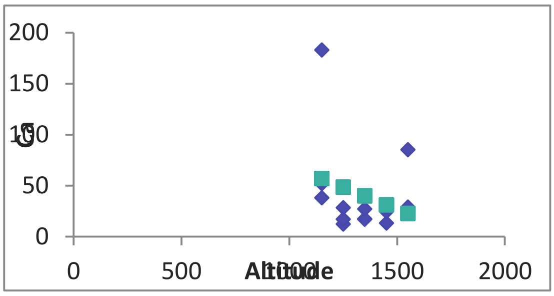


Figure 3-49 Ca by Altitude in HNF
Ca=155.77-0.0858*Alt.,
R^2= 8.29 %, p=0.298

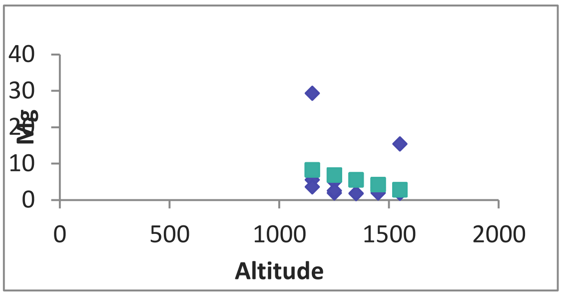


Figure 3-50 Mg by Altitude in HNF
Mg=23.73-0.0135*Alt.,
R^2= 7.06 %, p=0.33845

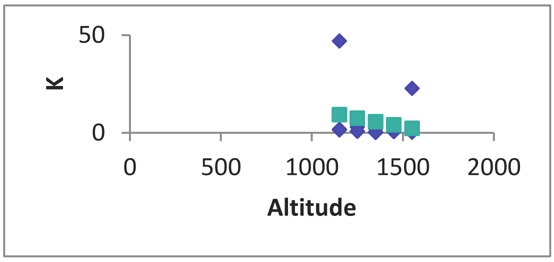


Figure 3-51 K by Altitudein HNF
K=29.36-0.01747*Alt.,
R^2= 4.04 %, p=0.472

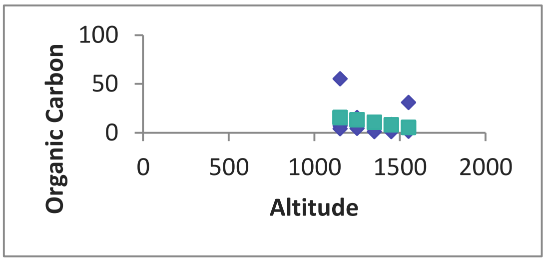


Figure 3-52 Organic Carbon by Altitude in HNF
OC=45.69-0.02592*Alt.,
R^2= 6.87 %, p=0.345

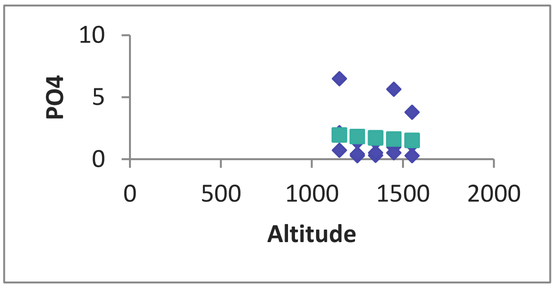


Figure 3-53 PO4 by Altitude in HNF
PO4=3.19-0.00108*Alt.,
R^2= 0.63 %, p=0.7783

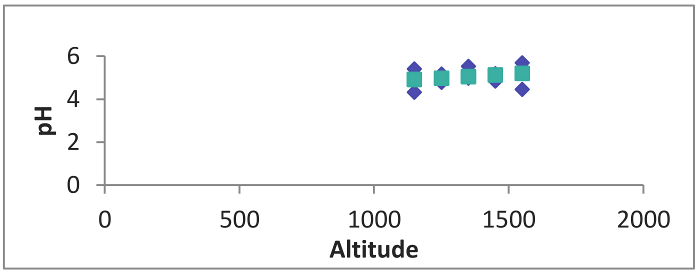


Figure 3-54 pH by Altitude in HNF
pH=4.093-0.000713*Alt.,
R^2= 7.66 %, p=0.3180

4 Discussion

4.1 Variations along the transects – the effect of altitude

Ca

On the basis of trend (regression line), It can be said that calcium content decreased with increase of height in SNF and HNF, however, it increased in HSF, but, it is steady in SSF (regression line is parallel to altitude). P-values were found > 0.05 in SSF, SNF, HNF, whereas, it was <0.05 in HSF. These findings indicate that Ca is not significantly different with respect to the altitudes in SSF, SNF and HNF. But, it is significantly different along the transects in HSF.

Mg

The null hypothesis is accepted in case of Mg along the altitudes in SSF, SNF and HNF. It means that Mg content is not significantly different in these mountains. But –value was lower than 0.05 in HSF, so, Mg content is changing with the change of height. Also, Mg content decreased with the increase of height in all four mountains.

K

Potassium was not significantly different along the transects in all mountains as p-values were greater than 0.05. A decreased trend line was observed in in all the mountains except SSF. it may be possible due to the smooth distribution of plant species in SSF along the transects than other mountains.

OC

In case of organic carbon, p- values were higher than 0.05 in all four mountains, so, it can be understood that there is no any significant difference between the mountains different along the transect lines. The regression lines were parallel to X-axis in SSF and HSF, it clears that organic carbon is not almost same along the transects whereas. A declined trend lines were seen in SNF and HNF. From these results, it can be known that south facing mountains have well and regular vegetation patterns than north facing mountains along the transect lines.

3Phosphate

Phosphate contents were similar($p>0.05$) in all the mountains along the transects. Furthermore, they were increasing in HSF and SNF, in contrary, it was decreasing in HNF, but, it was observed almost same in SSF along the transect lines.

Soil pH

Soil pH in the samples taken from all the mountains was same ($p>0.05$) along the transect lines. Almost in all mountains the trend was seemed parallel to heights and it says that pH was not changing along the transects.

The trends described above for soil nutrients and pH along the Sikkilsdalen and Heimdalen may not predict the same or exact trends in other mountains due to several biotic and abiotic factors. For example,xe et al. (1997,Table 4) examined the nutrients and altitudes below 1000 m altitudes did not notice any rising or falling trend.

4.2 Effects of soil depth

Organic carbon, K and Mg decreases with depth whereas pH increases and, the percentage of gravel is found to be higher than sand These findings are similar to the results obtained from the study of soil profile of Vestre Memurubreen, Jotunheimen, Norway by Mellor (1984), cited in, Matthews and Caseldine (1987). It indicates that the study area consists lots of boulders and soil is forming on it, at the same time, boulders might be disintegrated to sand and deposited in the dipper layers.

According to (Allen, 2005,Table 2), pH values increases with depth in the most of the Karkevagge boulder-top soil samples and shows the soils are acidic, however, organic carbon , Ca, Mg and K decreases with depth. These findings are also support the results of this paper. But, pH in upper layer of soils at altitudes 1100 m, 1260 m and 1600 m in

Rondane (Norway) shows increasing trend whereas organic carbon decreases (Stützer, 1999,Table 2)

Reinhardt et al. (2013,Table 3) also showed positive correlation between pH and the altitudes which contradicts the result of this paper. Also, they found negative correlation between nutrients (organic carbon, Phosphorous, Magnesium and potassium) and altitudes, however, Ca is positively correlated.

The results obtained above could be different if the samples size would increase. the samples were taken at a difference of equal interval of 100 m. Sample size would be increased if the altitude differences were reduced. Reduction in equal interval might increase the sample size and the result might be different.

The differences in nutrients values at different altitudes in different mountains might be seen due to the differences in vegetation patterns and geological processes. Highest values of organic carbon indicate that well developed pattern of vegetation in that site.

The highest Magnesium is seen in clayey layer (A horizon) because B and C layers consist of coarse sand and these particles shows negative correlation with Magnesium (Lemarchand et al., 2012).

Average concentration of phosphates is high in C layer indicates that leaching activity is higher rather than erosion. Also, High Phosphates in north facing mountains than south facing mountains indicates that erosion rate is slow (Smil, 2000) in North face. It can be assumed that intensity of rainfall is low in North face than south face.

D_{10}, D_{30} and D_{60} below top layer all shows that the soil is sandy as its size ranges between 0.5 to 2 mm (marginal differences are excluded). It might have possible because soil has been formed on same rocks.

Only altitude, depth and soil type were chosen to check the variations in nutrient in all the four sites. Precipitation, temperature and vegetation data were not included in this research despite the fact that these factors are very important that can change the characteristics of soil profiles. This paper shows that soil nutrients do not vary significantly with altitude. It cannot be assumed true in other mountains also because they are dependent on climatic conditions, vegetation cover, grazing activities, landscape, bedrock quality, weathering, leaching and many more. Some of values of this result slightly differ from the other researchers because of the nutrient cycles might have change with respect to the time.

5 Conclusion

Average Plant available nutrients K, Mg, Ca and organic carbon is found similar with respect to the mountains, but, phosphate is significantly different. Particle sizes D_{10}, D_{60} are found to be almost same in all sites, however, D_{30} varies significantly. Moreover, nutrients K, Ca, Mg and organic carbon shows anti correlation with pH and altitude, however, phosphates show positive correlation with them. Average Nutrients and pH also not changed with respect to the mountain, horizon and soil type.

Trends of pH are seen uniform in almost all mountains along the transect lines, but regression lines for plant available nutrients K, PO4, Mg, Ca and organic carbon shows mixed trends at north and south facing mountains along the altitudes because of unequal vegetation pattern.

Average characteristics of soil profiles shown in this paper is understood as almost same between or within Heimdalen and Sikkilsdalen along the altitudinal gradients, however, nutrients are slightly fluctuating in individual sites from top to bottom due to the effect of altitude and depth. Moreover, it might be varied due to the climatic factors, vegetation, landscape, particle size and many more. To get more detail characteristics of soil profile in alpine zones, further research works are needed including more parameters like Temperature, precipitation, vegetation and other inorganic minerals.

6 References/bibliography

Soil gradation.

Allen, C.E., 2005. Physical and Chemical Characteristics of Soils Forming on Boulder Tops,Karkevagge,Sweden. Soil Science Society of America.

Anderson, D., 1988. The effect of parent material and soil development on nutrient cycling in temperate ecosystems. Biogeochemistry 5, 71-97.

Bai, W., et al., 2012. Effects of elevated air temperatures on soil thermal and hydrologic processes in the active layer in an alpine meadow ecosystem of the Qinghai-Tibet Plateau. Journal of Mountain Science 9, 243-255.

Bernal, B., Mitsch, W.J., 2008. A comparison of soil carbon pools and profiles in wetlands in Costa Rica and Ohio. Ecological Engineering 34, 311-323.

Binkley, D., et al., 2003. Influence of elk grazing on soil properties in Rocky Mountain National Park. Forest Ecology and Management 185, 239-247.

Blanco-Canqui, H., et al., 2011. Soil-profile distribution of carbon and associated properties in no-till along a precipitation gradient in the central Great Plains. Agriculture, Ecosystems & Environment 144, 107-116.

Briaud, J.L., 2013. Soil Classification. Hoboken, NJ, USA: John Wiley & Sons, Inc., Hoboken, NJ, USA.

Chen, Q., et al., 2002. Organic matter turnover rates and CO2 flux from organic matter decomposition of mountain soil profiles in the subtropical area, south China. CATENA 49, 217.

Egner H., R., and Domingo, W.R., 1960. Untersuchungen uber die chemische Boden-Analyse als Grundlage fur die Beurteilung des Nahrstoffzustandes der Boden. 26: 199-215

Esposito, A., et al., 2013. A Three-Scale Analysis of Bacterial Communities Involved in Rocks Colonization and Soil Formation in High Mountain Environments. Current Microbiology 67, 472-479.

Felde, V.A., et al., 2012. Upward shift in elevational plant species ranges in Sikkilsdalen, central Norway. Ecography 35, 922-932.

Grøterud, O., Kloster, A.E., 1978. Hypsography, Meteorology and Hydrology of the Øvre Heimdalen Catchment. Holarctic Ecology 1, 111-116.

Hanson, S., Hoelzle, M., 2005. Installation of a shallow borehole network and monitoring of the ground thermal regime of a high alpine discontinuous permafrost environment, Eastern Swiss Alps. Norsk Geografisk Tidsskrift - Norwegian Journal of Geography 59, 84-93.

Høye, T.I., 2014. Variasjon i utbredelse av karplanter i sørvendte og nordvendte dalsider, T.I.Høye, Bø i Telemark.

Johannessen, T.W., 1978. The Local Climate of the Øvre Heimdalen Valley. Holarctic Ecology 1, 93-102.

Jungqvist, G., et al., 2014. Effect of Climate Change on Soil Temperature in Swedish Boreal Forests. PLoS ONE 9, e93957.

Koide, R.T., et al., 2011. Quantitative analysis of biochar in field soil. Soil Biology and Biochemistry 43, 1563-1568.

Krogstad, T., 1992. Metoder For Jordanalyser, ISSN 0803-1304, Jordfag.

Lemarchand, D., et al., 2012. Boron isotopes in different grain size fractions: Exploring past and present water–rock interactions from two soil profiles (Strengbach, Vosges Mountains). Geochimica et Cosmochimica Acta 98, 78-93.

Martin, D., et al., 2010. Soil organic carbon storage changes with climate change, landform and land use conditions in Garhwal hills of the Indian Himalayan mountains. Agriculture, Ecosystems & Environment 138, 64-73.

MatÍAs, L., et al., 2011. Soil-nutrient availability under a global-change scenario in a Mediterranean mountain ecosystem. Global Change Biology 17, 1646-1657.

Matthews, J.A., Caseldine, C.J., 1987. Arctic-alpine brown soils as a source of palaeoenvironmental information: Further 14C dating and palynological evidence from Vestre Memurubreen, Jotunheimen, Norway. Journal of Quaternary Science 2, 59-71.

Mellor, A., 1984.

An investigation of pedogenesis on selected neoglacial moraine ridge sequences, Jostedalsbreen and Jotunheimen, southern Norway Hull.

Nielsen, D.R., et al., 1996. Surface soil water content regimes: opportunities in soil science. Journal of Hydrology 184, 35-55.

Nordhagen, R., et al., 1943. Sikilsdalen og Norges fjellbeiter : en plantesosiologisk monografi. s.n., Bergen.

Ohtsuka, T., et al., 2008. Soil organic carbon pools in alpine to nival zones along an altitudinal gradient (4400–5300 m) on the Tibetan Plateau. Polar Science 2, 277-285.

Østhagen, H., Egelie, K., 1978. The Vegetation of the Øvre Heimdalen Valley. Holarctic Ecology 1, 103-106.

Owji, A., et al., 2012. The effects of hydrometer reading times on the spatial variability of soil textures in southeast Iran. Arabian Journal of Geosciences 7, 1491-1499.

Podwojewski, P., et al., 2011. Climate and vegetation determine soil organic matter status in an alpine inner-tropical soil catena in the Fan Si Pan Mountain, Vietnam. CATENA 87, 226-239.

Purton, K., et al., 2015. Will changes in climate and land use affect soil organic matter composition? Evidence from an ecotonal climosequence. Geoderma 253-254, 48-60.

Reinhardt, S., et al., 2013. Calciphile alpine vegetation in Southern Norway: importance of snow and possible effects of climate change. Phytocoenologia 43, 207-223.

Ridefelt, H., et al., 2008. Statistic-empirical modelling of mountain permafrost distribution in the Abisko region, sub-Arctic northern Sweden. Norsk Geografisk Tidsskrift - Norwegian Journal of Geography 62, 278-289.

Rubinić, V., et al., 2015. Climate and relief influence on particle size distribution and chemical properties of Pseudogley soils in Croatia. CATENA 127, 340-348.

Salehi, M.H., et al., 2011. Refining Soil Organic Matter Determination by Loss-on-Ignition. Pedosphere 21, 473-482.

Schaetzl, R., Anderson, S., 2005. Soils : Genesis and Geomorphology. Cambridge University Press, Cambridge.

Smil, V., 2000. PHOSPHORUS IN THE ENVIRONMENT: Natural Flows and Human Interferences, Annu. Rev. Energy Environ., pp. 53-88.

Stanchi, S., et al., 2015. Liquid and plastic limits of mountain soils as a function of the soil and horizon type. CATENA 135, 114-121.

Stützer, A., 1999. Podzolisation as a soil forming process in the alpine belt of Rondane, Norway. Geoderma 91, 237-248.

xe, et al., 1997. Shifts in Mycorrhiza and Microbial Activity along an Oroarctic Altitudinal Gradient in Northern Fennoscandia. Arctic and Alpine Research 29, 93-104.

Zhang, B., et al., 2013. Variations in Soil Microbial Communities and Residues Along an Altitude Gradient on the Northern Slope of Changbai Mountain, China. PLoS One 8.

Zhou, J., et al., 2016. Variations in soil phosphorus biogeochemistry across six vegetation types along an altitudinal gradient in SW China. CATENA 142, 102-111.

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