EFFECTS OF SOIL DEPTH AND ALTITUDE ON SOIL TEXTURE AND SOIL QUALITY INDEX

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(Received 18th Apr 2023; accepted 30th Jun 2023)

Abstract. Healthy or good quality soils are essential for ecosystems to remain intact or recover from disturbances. Soil quality is soil- and site-specific and can vary according to controlling factors, such as inherent soil properties. The research proposal was conducted in 2015-2016 to study soil physio-chemical properties across seven elevations and the River Swat catchment area between Barikot and Topsin in Swat-district, Pakistan. The sampling date was March 11-12, 2016, to better evaluate soil classification. Soil samples were collected and analyzed for their physicochemical properties, including surface, sub-soil, and sub-strata. The data showed that silt content decreased, and clay content increased with altitude, while sand content showed inconsistent variation. Bulk density, lime content, electric conductivity, and pH decreased, while concentrations of nitrogen (N), phosphorus (P) and potassium (K), and micro-nutrients increased. Soil organic matter (SOM) content significantly increased ($P<0.05$) as the altitude increased. Soil samples were non-saline (EC<4 dSm^{-1}) and slightly calcareous (lime content 2.34% to 5.32%). Higher altitudes increase micro-nutrient content and water retention, while lower elevations decrease water retention. We found that crop available P in all selected sites along the altitude were deficient, classified as P deficient soil. All physicochemical properties were within the range of crop demands, so sustainable management practices are needed to build soil P levels that meet crop requirements.
Keywords: *soil physicochemical properties, soil quality, micronutrients, altitude, soil depth*

Introduction

District Swat is in a hilly mountainous area northwest of Khyber Pakhtunkhwa Pakistan at latitude 34° to 40° N, and longitude 720.7° to 740.6° E, having an area of 5337 km^2 containing about 18 million inhabitants. The region is substantially rough and mountainous. At short distances, there are altitudinal differences (Hussain and Sher, 2021). The area of the study has undulating, locally separated by ridges and low hills. Besides, residual and limestone colluviums, silica shists, amphibolite's, lemon loess, and refueling losses are parent materials. The possibility of erosion is from excessive to smooth drainage. Water erosion is the key to the depletion of soil and water nutrients (Bashir et al., 2017). The potential impacts of environmental shifts on climate system have drawn further attention towards high altitude soils (Gong et al., 2019). Rainfall

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2105_41354154

intensity, snowstorm, & alterations in temperature influence the degradation of organic matter (OM), which in turn drives OM accumulation at height (Dodds et al., 2019; Zhang et al., 2021). Environmental shifts can influence the physicochemical properties of soil in the proposed study area (Jing et al., 2020). Delineated altitudinal shifts have intimate direct correspondence with fertile soil properties such as O.M, EC, P, and pH. Cultivation and soil management vary with the soil type and the physicochemical characteristics (Aloo, 2021; Dar et al., 2022). Factors such as altitude, temperature, moisture, soil types, precipitation, and salinity influence soil proprieties (Okur and Örçen, 2020; Cheng et al., 2023).

The slope of the mountain is noticeable by varying temperatures and numerous records of precipitation. Different temperatures and humidity from the elevation and aspect gradients might have the same effect on the decomposition of organic matter (Pelletier et al., 2018; Ran et al., 2023). There have been large horizon compositions, variations including the texture of the soil, horizon depth, and temperature differences. Soil chemistry was associated with altitude (Tian et al., 2023). The influence of climate variables on the dynamics of SOC is also studied by using altitude (Zhang et al., 2023). The change in altitude gradients affects the SOM by regulating the balance of soil water (SW), soil erosion (SE), processing of geological deposition, species, and biomass of native vegetation and crops (Saeed et al., 2014; Xu et al., 2023). Changes were more complex in other soil properties, possibly because of weather differences, crop spin, soil types or long-time and organic soil management (Ramesh et al., 2019; Yang et al., 2023).

Trace elements and heavy metal ions in the crust of the earth's crust naturally and penetrate the soil with natural processes such as mineral weathering in parental materials and through other anthropogenic processes such as direct fertilization of P to the soil (Ali et al., 2020; Wang et al., 2022). The soil properties are the main factors that affect Fe, Mn, Cu, and Zn in cultivated soil distribution (Wu et al., 2021, 2022; Dhaliwal et al., 2022).

Such data will also be useful in determining future trend lines and estimating the stability of Quercus communities in the Hindukush Mountains' Swat area (Rahman et al., 2022). Keeping in view all the above-discussed parameters, this study was therefore designed to assess soil characteristics of the significant agricultural soils along cold-high-altitude gradients in the Swat district of KP, Pakistan. In parallel, the impact on soil physicochemical properties that will be useful for soil fertility restoration in the proposed study area was studied from the past SE.

Materials and methods

Study site

The present study has been carried out over 7 farmland significant soil types in district Swat, varying in altitude from Barikot to Topsin. The altitude ranged from 500 to 1700 m above sea level. Mingora series, Pirsabak, Nimogram, Makhnial, Gulibagh, Shangla alluvium, and Shangla cultivated were all part of this series. These series comprise the majority of the river Swat catchment area’s farmland, and the terrain is prone to SE. Depth of soil sampling were 0-15, 30-45, 45-60 (*Table 1*).

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DOI: http://dx.doi.org/10.15666/aeer/2105_41354154

Table 1. *Classification of soil series along the varying altitude in district Swat*

Altitude (m)	Soil series	Erosion Hazard	Series classification
500	Mingora	Slight to Moderate	Coarse silty, mixed, thermic type Eutrudepts
700	Pirsabak	Slight	Coarse silty, mixed, thermic type Eutrudepts
900	Nimogram	Moderate	Coarse silty, mixed, thermic type Eutrudepts
1100	Gulibagh	Moderate to severe	Coarse silty, mixed, thermic type Eutrudepts
1300	Makhnial	Moderate	Coarse silty, mixed, thermic type Eutrudepts
1500	Shangla Alluvium	Moderate to severe	Coarse silty, mixed, thermic type Eutrudepts
1700	Shangla cultivated	Moderate	Coarse silty, mixed, thermic type Eutrudepts

Site selection

For each location, specific areas were selected. At 500 m above sea level, the soil samples from the Mingora series have been collected on the Chakdara-Kabal road village Barikot. At 700 m above sea level, the Pirsabak series was sampled near village Jawand Kabal town, opposite to petrol pump. At 900 meters above sea level, a Nimogram series were collected on the Chakdara-Kabal road near Dawa khan farm, village Akhund Kaly. At an altitude of 1100 meters, the Gulibagh series was collected Matta town, village Baryam Village. At 1300 meters altitude, the Makhnial series was collected town Faizagot village Hayat Abad. At 1500 meters above sea level, Shangla Alluvium was sampled in town Alpurai, village Lilownai. At an altitude of 1700 meters, Shangla cultivated series has been collected from town Topsin, village Khyber khwazakhela besham road. Furthermore, *Fig. 1* depicts the average meteorological data of the experimental year of District swat and shangla at positions 500 to 1700 m above sea level.

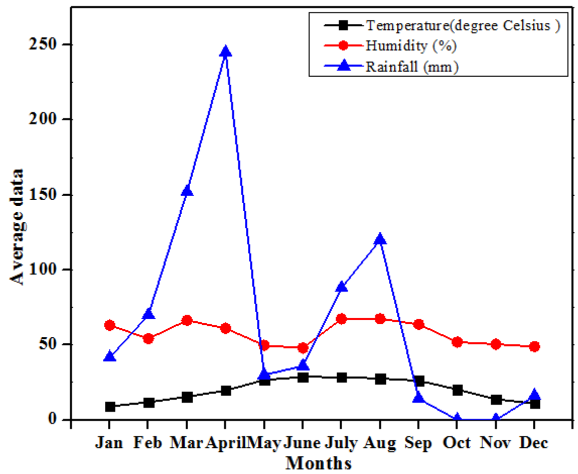

Figure 1. *Mean monthly rainfall, air temperature, and humidity of the experimental year averaged over 500 to 1700 m of district swat and Shangla sites*

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DOI: http://dx.doi.org/10.15666/aeer/2105_41354154

Profile study

Each series has been sampled separately along its differing altitude. For each location, the specific selected areas have been divided into three crosscuts randomly with the aim of replications. Every crosscut had a 1 m^2 pit dug for the detailed soil profile overview. The overview of soil profile was then described by the guidelines in soil taxonomy (Isbell, 2016). Soil horizons have been classified and described in terms of color, texture, consistency, calcareousness, and pH. Based on observations obtained during the profile analysis, soil series and phases were established (Tabor et al., 2017).

Soil sampling

Soil samples were taken separately with proper care from the selected series/areas at three different depths: 0-15, 30-45, and 45-60 cm. The collected soil samples were brought to the laboratory, made dry and clean, and store in plastic bags with proper labeling. Besides, core samples have also been collected in different depths for every pit in all the selected series along with the altitude. Soil samples were prepared and analyzed for selected physicochemical properties according to reported standard protocols.

Soil analysis

The soil samples prepared as described above well be analyzed for the following parameters.

Soil texture

The determination of soil texture was done by the hydrometer method (Gilliam et al., 1993). The soil was first dried and sieved through 2 mm mesh. Fifty g dried soil was taken and transferred to dispersion cup. Ten mL of 1N of Na_2CO_3 was added into dispersion cup and distilled water was added up to the groove. The SW suspension was dispersed for five mints through dispersion machine. Then, suspension was transferred to 1 L graduated cylinder, and it was made sure to transfer all soil particles (sand, silt, and clay) into graduated cylinder. The volume of graduated cylinder was made up to 1 L. Two readings (hydrometer and temperature) were taken within 40 S, which is called 40 S reading. The graduated cylinder was placed on table for two hours and some (hydrometer and temperature) were taken within after 2 hours which is called 2 hours reading. Calculation was done using 40 S and 2 hours reading. Standard temperature and correction factor were considered as 20 ºC and 0.3. The percentage of sand, silt and clay were decided by using texture triangle.

Bulk density (g/ cm^{-3})

The bulk density (BD) was determined by core method described by (Blake and Hartge, 1986). The core samplers (100 cm^3) were injected in the soil up to a certain depth as to fill the cylinder completely. The core was carefully pull and the surface of core was level by removing extra soil. The core was tightly closed with led. The obtained soil from core samplers was dried at 105ºC to a constant weight. BD was calculated as

$$P_b = \frac{Ms}{Vt} \quad \text{(Eq.1)}$$

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Saturation percentage

Saturation percentage (SP) will be determined by the following formula given by Gardner (1986) Core sampler will be used to find saturation (%). 100 cm^3 core sampler will be dig in the soil and very carefully recovered without disturbing the inner core soils. The saturated weight will be calculated and for finding dry weight the samples will be kept in the oven for a day at 105ºC. The saturation (%) shall be determined by the following formula.

$$\text{Saturation water percentage (sPw)} = \frac{\text{Mt}-\text{Ms}}{\text{Ms}}\ \text{x}100 \qquad \text{(Eq.2)}$$

Availability water holding capacity (%)

Availability water holding capacity (AWHC) was determined in soil samples by the procedure as mentioned by (Van Oeckel et al., 1999) Sample were taken in rubber rings arranged on pressure plates, soil saturated with water for 24 hours and kept in pressure membrane apparatus at different pressure such as 0.1, 0.3, 0.5 and 1 bar to determine SW contents. After determination of SW content at each pressure, a relationship was established between matric suction and water contents on mass bass's (gravimetric water) applying following expression.

Soil pH

The pH of sample was determined in 1:5 SW suspensions by pH meter (McLean, 1983). Ten g soil was taken in the shaking bottle. Fifty mL distilled water was added to the bottle and shacked for 30 mints on horizontal shaker. The pH reading was measured by pH meter.

Electrical conductivity (dS m^{-1})

Electrical conductivity (EC) of soil samples were determined in 1:5 SW suspensions by EC meter (Rhoades, 1993). Ten g soil was taken in the shaking bottle. Fifty mL distilled water was added to the bottle and shaken for 30 mints on horizontal shaker. The EC reading was measured by EC meter.

Soil organic matter (%)

SOM samples were determined by the Walkley-Black procedure as described by Nelson and Sommers (1996). In this method, 1 g soil sample was treated with 10 mL of 1 N $K_2Cr_2O_7$ and 20 mL of concentrated H_2SO_4. After adding 200 mL of distilled water upon cooling, the suspension was filtered, and the filtrate was titrated against 0.5 N $FeSO_4.7H_2O$ solution using ortho-phenolphthalein as indicator with the appearance of maroon color as an end point. A blank sample was also run at the same time to correct normality of $FeSO_4.7H_2O$. The amount of OM was calculated from the number of moles of $K_2Cr_2O_7$ utilized in the oxidation of organic C in soil by using the following equation.

$$\text{SOM \%} = \frac{[(\text{mL of K2Cr2O7 X N}) - (\text{mL of FeSO4 .7H2Ox N})]\ \text{x}\ 0.69}{\text{Weight of soil (g)}} \qquad \text{(Eq.3)}$$

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Lime content ($CaCO_3$)

Lime content of soil sample was determined by acid neutralization as the procedure described by Cruse et al. (1979). In this procedure 5-gram soil was transferred to 150 ml flask and mixed with 0.5 N 50 ml HCl. The suspension was boiled in fume hood for five min then cooled and filtered through Whatman No. 40 filter paper, then titrated against 0.25 N NaOH using phenolphthalein as indicator till pink color is obtained.

$$CaCO_3\,(\%) = \frac{(\text{ml of HCl x N of HCl}) - (\text{ml of NaOHxN of NaOH})\text{ x }5}{\text{Weight of soil sample}} \quad \text{(Eq.4)}$$

Soil AB-DTPA Extractable P and K, Zn, Cu, Fe, Mn (mg kg^{-1})

AB-DTPA extractable P and K in soil sample were determined by procedure described by Soltanpour and Schwab (1977). In this procedure, 10 g soil was taken with electric balance and added 20 mL AB-DTPA solution and shaking for 30 mints with horizontal shaker and then filtered. For P determination, 1 mL aliquot, 4 mL H_2O and 5 mL ascorbic acid mixed reagent was added, and 25 mL volume was made. Then it was placed in a dark place for 30 mints to developed dark color. Soil P was determined by spectrophotometer using 880 nm wavelengths.

For K determination, 20 mL AB-DTPA solution was added into 10 g soil and shaking for 30 mints with horizontal shaker and then filtered. K was determined by using a flame photometer.

Zn, Cu, Fe, Mn was determined through atomic absorption spectrophotometer.

Mineral N in soil

The total mineral N, NH_4-N and NO_3-N in soil samples were determined using the KCl extraction following distillation procedure as described in Mulvaney (1996). Briefly, 20 g soil sample was extracted with 200 ml of 1N KCL for one hour. After filtration, 20 ml extract was distilled with MgO for measuring NH_4-N and with MgO + Devarda's alloy for measuring NH_4-N and NO_3-N (total mineral N). Nitrate-N was determined by difference as follows: Total mineral N – NH_4-N = NO_3-N.

Statistical analysis

The data was analyzed statistically using the RCB design, and the means for each variable were determined. The LSD test was used to compare the treatment means (Raudonius, 2017). For some soil properties and altitude, a correlation analysis was also computed. Following that, the recorded data was divided into three categories: deficient, marginal, and adequate nutrient status of the region.

Results and Discussion

Physical properties of soil

Sand, silt and clay contents

The physical properties of Swat soil are influenced by the ratio of multiple soil characteristics. the data revealed that sand content varied non-significantly ($p<0.05$) along with altitudes (*Table 2*). The variation in sand content was inconsistent i.e., sand content

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increased from the altitude of 500 m to 1300 m. At 500 m it was 6.43%, while at 1300 m elevation it was accounted 40.93%. Beyond 1300 m the sand content was decreased, and it was reported 30.69% at 1700 m. The data regarding sand content showed a positive correlation with low altitude and negative correlation with high altitude. The reason of increasing sand content at low altitude may be due to the sand forming mineral of the parent material or as the altitude increase SE also increase, which erode fine particles and leaving behind coarse sandy particle (Schoonover and Crim, 2015). Another reason may be that from 500 m altitude the land slope in 1-2% and 1300 m elevation land slope is from 25-80%. This indicates that as slope increase erosion increase, and the soil becomes sandier. Beyond 1300 m to 1700 m elevation slope has decreased, and at this higher elevation land slope is 25-50%, which shows that erosion has decreased i.e., the sand content is low as bottom and mid elevation. In support of our results, it was stated that, high sand content in the lowest position and low sand content at the knoll and back slope (Hu et al., 2017; Das et al., 2021). Within the particle there was no effect of the soil depth on the sand contents and interaction of altitude and depth for sand content was also non-significant.

Table 2. *Mean values of sand, silt, and clay in soil depth along altitude of District Swat*

Altitude (A)	**Sand (%)**	**Silt (%)**	**Clay (%)**
500	6.34	74.40 a	19.00 a
700	16.70	64.32 b	19.42 ab
900	17.37	61.11 b	21.37 ab
1100	21.84	55.89 b	21.70 ab
1300	40.93	34.56 c	23.49 ab
1500	35.88	40.54 cd	23.83 b
1700	30.69	44.60 d	25.77 b
LSD	Ns	5.50	3.82
Soil depth (SD)			
0-15 cm	24.4	54.19	20.39 a
30-45 cm	23.6	53.92	21.28 b
45-60 cm	24.8	52.78	24.58 b
LSD	Ns	ns	1.53
LSD (A*SD)	Ns	5.83	Ns

Ns= non-significant. Values are means of three replicates (n=3). In each column, values with different letters are significantly different from each other at P<0.05

As compared to sand content, silt contents showed reversed trend with the altitude. Silt content decreased significantly ($p<0.05$) with the increase in altitude (*Table 2*). The correlation analysis showed that silt (%) was significantly and negatively correlated with the altitude. At altitude of 500 m silt contents was 74.40% while at higher altitude i.e., at 1700 m silt contents were 44.60%. Silt content was in reverse order indicating the dominance of sand forming minerals in parent materials. Climate and parent material profoundly influence soil characteristics (Kumar et al., 2022; Atwell et al., 2023). This may be due to the climate condition (low temperature, snowfall, availability and movement of water along the attitude). In surface soil (0-15 cm) silt was low (54.19%). In subsoil 30-45 cm silt content decreased significantly (53.92% silt content). At the depth from 45-60 cm silt decreased (52.78%). Leopold et al. (2020) found that silt content did

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DOI: http://dx.doi.org/10.15666/aeer/2105_41354154

not change but showed a trend inconsistent with increasing level of erosion, similar result is also reported by Sun et al. (2021). Interaction of altitude with soil depth for silt content was significant (p<0.05) (*Fig. 2*).

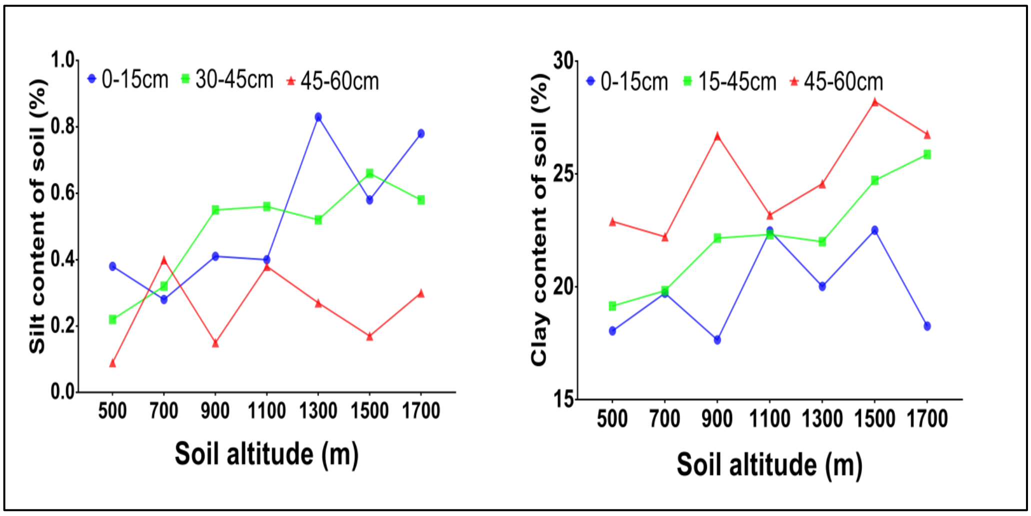

Figure 2. *Interactive effect of altitude and soil depth on silt and clay content of soil*

Variation in clay contents among different altitudes was significant (p<0.05) and showed increasing trend with increasing altitude. Clay contents showed positive correlation with increasing altitude (*Table 2*). At altitude of 1700 m clay contents were 25.77% while at lower altitude i.e., at 500 m clay contents were 19.00%. At high altitude the parent material, are residuum and colluviums and at lower altitude the parent materials are mainly compound of materials loses that may be the reason why clay content increased with increase in altitude. Clay content increased with depth indicating eluviation of clay. The result is supported by Kurniawan et al. (2019) who reported greater clay content in the subsoil than topsoil. This may be attributed to mixing of C-horizon with Ap and B horizon by tillage operation. Same results are taken from Azevedo et al. (2022) and Aguilera-Huertas et al. (2021). Interaction of altitude and soil depth was significant for clay content Minimum clay content of 20.39% was observed in 0-15 cm depth at altitude of 500 m and maximum clay content of 28.21% was observed in 45-60 cm depth at altitude of 1500 cm (*Fig. 2*).

Bulk density, saturation, and available water holding capacity

The significant variation (p<0.05) in BD of the area was negatively co-related with altitude. The BD of the bottom altitude was high (1.38 g cm^{-3}) as compared to the higher elevation i.e., 1.22g cm^{-3} (*Table 3*). The lower BD (1.22g cm^{-3}) of the higher elevation might be recognized to the existence of high OM accumulation and relatively lower OM buildup in the lower elevation. The overall B.D showed significant negative relation with soil OM. Thus, the soils with high OM accumulation are higher in percent pore space regardless of the content of soil particles and results in lower BD. Within the soil profile the BD (1.23 g cm^{-3}) was the lowest in Ap horizon (0-15 cm depth) followed B-horizon. i.e. (30-45 cm depth) and the highest BD (1.38 g cm^{-3}) was found in C-horizon i.e. (45-60 cm depth). The data revealed that average values of BD increased with increasing soil depth. This may be due to more OM in the soil as compared to the sub soil. The OM

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increases pore space and increases structural development which increase volume and decrease weigh per unit soil. Thus, the BD decreases with depth of the soil. The same results are reported by Shah et al. (2017) was represented that loose and poor topsoil, had low BD than compact sub soil. The interaction of altitude with soil depth for BD was no significant.

Table 3. *Mean values of bulk density, saturation % and AWHC in soil depth along altitude (m) of District Swat*

Altitude (A)	**Bulk density ($g\ cm^{-3}$)**	**Saturation (%)**	**AWHC (%)**
500	1.38 a	51.0 ab	15.6 f
700	1.36 a	50.7 ab	16.4 e
900	1.36 a	36.7 d	17.1 d
1100	1.29 ab	43.7 c	17.8 c
1300	1.29 ab	48.2 bc	17.8 c
1500	1.28 ab	56.5 a	19.9 a
1700	1.22 b	55.8 a	19.0 b
LSD	0.09	4.0	0.41
Soil depth (SD)			
0-15 cm	1.23 c	49.32 ab	18.42 a
30-45 cm	1.32 b	50.0 a	17.44 b
45-60 cm	1.38 a	47.51 b	17.09 c
LSD	0.3	1.58	0.30
LSD (A*SD)	Ns	4.1	0.8

ns= non-significant. Values are means of three replicates (n=3). In each column, values with different letters are significantly different from each other at $P<0.05$

The effect of altitude on SP was inconsistent (*Table 3*). SP was high (51.0%) at 500 m and (50.7%) at 700 m elevation. At elevation of 900 m SP decreased with a value of 36.7%. From altitude of 900 m to 1300 m SP was low and at 1500 m to 1700 m SP was highest. The inconsistent variation of SP may be due to difference in OM content or due to the difference in soil mineralogy. High SP of 56% at higher elevation from 1500 m to 1700 m may be attributed to high OM content which retains more water. Because OM improves aggregates formation, which consequently improves moisture retention in soil. With the profile SP decreased from Ap horizon (0-15 cm) to C-horizon (45-60 cm) (*Fig. 3*). The change in SP shows soil structure, soil texture and OM also change due to soil degradation. The results are supported by ("Soil aggregate stability and organic matter as affected by land-use change in central Iran: Archives of Agronomy and Soil Science: Vol 63, No 13," n.d.) who reported that soil having more OM form granular aggregates where those having more clay form blocky aggregates, which are less receptive to water as compared to granular aggregates. That is why the SP of surface soil is greater than sub surface and sub-strata. Interaction of altitude with soil depth for SP was significant.

The data pertaining to available water holding capacity (AWHC) was positively co-related with altitude (*Table 3*). Available water holding capacity increased significantly with increase in altitude. Minimum content of 15.6% AWHC was observed at altitude of 500 m while maximum of 19.0% was observed at 1700 m. Our results also confirmed the results produced by Howell et al. (2015), who reported that Available water holding

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capacity improved with altitude on both side south and north at 3500 m altitude. Within the profile (AWHC) was decreased from top to bottom. Maximum value of 18.42% AHWC was modified in topsoil (0-15 cm) and minimum of 17.09% was seen in the middle soil (45-60 cm) depth. Interaction of altitude with soil depth was significant for Available water holding capacity.

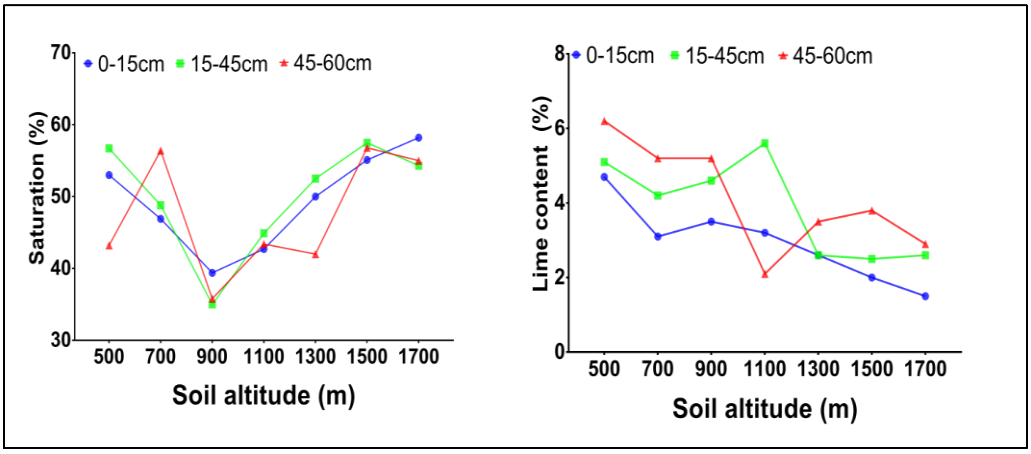

Figure 3. *Interactive effect of altitude and soil depth on saturation (%) and lime content (%) of soil*

Chemical properties

Soil pH, EC, organic matter, and lime content

There were minor differences in pH with elevation gradient. Soil pH showed decreasing trend as elevation increased (*Table 4*). For instance, high pH value 7.4 was observed at altitude of 500 m and low pH value of 6.3 was observed at high altitude of 1700 m. The mean soil pH value shows down from 700 m to 1700 m. The pH value increase and decrease due to sustain reason may be basic cation leaching at higher altitude shows greater SW contents (Seibert et al., 2007). Our results showed that soil from the low altitude was slightly alkaline and that from the high altitude was slightly acidic. Due to OM and salt reduction at high altitude results low pH. The findings are similar with the report of Ramesh et al. (2019). The average pH value was low in surface soil and increased from top (0-15 cm) to the bottom (45-60 cm). The decrease in pH from surface to sub-surface soil may be attributed to the leaching and accumulation of salts in the sub-soil and due to low OM in the subsoil as compared to the topsoil. The interaction of altitude with depth for soil pH was no significant.

Soil EC was high at 500 m and then decreased from 500 m elevation to 1700 m elevation. Variation in EC among different altitudes was consistent (*Table 4*). Generally, EC decreased with increase in altitude. There was significant change in EC which indicates no major difference in cumulative salt accumulation along the altitude. However, decreasing trend of EC from low altitude to high altitude shows that at lower altitude more salts accumulate rather than higher altitude sites. This may be due to the higher accumulation of base forming cations like Ca^{+2}, Mg^{+2}, K^2 and high accumulation of $CaCO_3$ (Dong et al., 2017; Ibrahim et al., 2022). Therefore, it is presumed that low EC at high altitude may be due to the non-available calcareous parent material (calcite mineral) throughout the soil profiles. The C-horizon (45-60 cm) had the lowest EC value

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of 0.37dS m^{-1}, whereas the Ap-horizon (0-15 cm) had the greatest EC value of 0.42 dS m^{-1}. The findings of Rhoades (1993) that SE alters the concentration of salts in the root zone confirm the same findings. The high EC of topsoil might be related to salt accumulating in the higher Ap horizon.

Table 4. *Mean values of chemical properties in Soil depth along altitude (m) of District Swat*

Altitude (A)	**pH -**	**E.C (dS m^{-1})**	**Organic matter (%)**	**Lime Content (%)**
500	7.4 a	0.68 a	0.79 d	5.3 a
700	7.4 a	0.45 b	0.93 d	4.2 abc
900	7.1 a	0.41 b	1.16 d	4.4 ab
1100	7.1 a	0.37 bc	1.25 cd	3.7 bcd
1300	7.1 a	0.31 bc	1.72 bc	2.9 cde
1500	6.8 ab	0.28 bc	2.12 ab	2.8 de
1700	6.3 b	0.21 c	2.28 a	2.3 e
LSD	0.41	0.12	0.32	0.81
Soil depth (SD)				
0-15	6.8 c	0.42	2.15 a	2.9 b
30-45	6.9 b	0.39	1.40 b	3.9 a
45-60	7.3 a	0.37	0.84 a	4.1 a
LSD	0.14	ns	0.18	0.39
LSD (A*SD)	Ns	ns	0.47	1.05

ns=non-significant. Values are means of three replicates (n=3). In each column, values with different letters are significantly different from each other at P<0.05

The present study revealed that SOM was positively co-related with altitude and OM content was increased significantly (P<0.05) with the increase in altitude (*Table 4*). Minimum value of 0.79% OM was observed at altitude of 500 m while maximum of 2.28% was observed at 1700 m elevation. That may be due to temperature as temperature decreases with altitude and OM decomposition slows down and there is more buildup of OM. Further, at higher elevation due to more plantation liter fall and more OM accumulates.

The accumulation of relatively high SOM in all the sites in general could be ascribed to the presence of high precipitation which promotes plant growth, cooler temperature and high soil acidity of the area which could decrease the rate of decomposition and mineralization of SOM (Ali et al., 2017; De la Cruz-Amo et al., 2020). Reports have also revealed that SOM increases with increasing precipitation and decrease with increasing temperature (Chen et al., 2022). Within the profile SOM was decreased from top to bottom. Maximum value of 2.15% was observed in surface soil (0-15 cm) and minimum of 0.84% was observed in the bottom soil (45-60 cm) depth. Parihar et al. (2019) also reported that subsoil exposed by removing top 30-45 cm of soil was extremely low in SOM. The same results were supported by Hobley et al. (2018) and Jakšić et al. (2021) who reported a decrease of SOM due to the effects of SE. Interaction of altitude and depth for SOM was significant.

Lime content was significantly (p<0.05) affected with increase in altitude (*Table 4*). Lime ($CaCO_3$) showed negatively correlation i.e., it decreased with increase in altitude. Maximum value of 5.3% at 500 m and minimum value of 2.3% at 1700 m elevation was observed. This means that $CaCO_3$ content was maximum at lower altitude as compared

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DOI: http://dx.doi.org/10.15666/aeer/2105_41354154

to higher altitude. This may be due to the types of parent material (calcite mineral in soil profile (Charan et al., 2013; Kramer et al., 2019) or due to decrease of water content and higher evaporation of soil and high soil mineralization which may result in higher accumulation of $CaCO_3$, as compared to higher altitude (Singh, 2018). Within the profile lime content increased from Ap horizon (0-15 cm) to C-horizon (45-60 cm) (*Fig. 2*). The major source of lime content in soil is the parent material (Arjumend and Abbasi, 2016) if the parent material contains more limestone, more $CaCO_3$ is expected in soil which leach down to C-horizon i.e., why lime content increased from surface (Ap horizon) to sub-surface C-horizon. Interaction of altitude with depth for $CaCO_3$ content was significant.

Available nitrogen, phosphorus, and potassium contents

Mineral nitrogen slightly increased from low altitude to higher altitude (*Table 5*). At low altitude of 500 m mineral nitrogen was 12.41 mg kg^{-1} and at higher altitude of 1700 m it was 13.53 mg kg^{-1}. Andreeva et al. (2022) found that soil mineral nitrogen transformation decreased with altitude in tropical rain forest. Their results indicate that reduced rates of N transformation occurred at high altitude because of higher SW content at high altitude. Lamprecht et al. (2018) and Bouchet et al. (2022) found the higher rates of soil net N transformation at intermediate altitude in forest soil. The content of SOM and total nitrogen increased by increasing altitude may be probably due to the greater SW content and lower soil temperature. High SW content and low temperature retard decomposition of litter and a decrease in soil N losses at higher than lower altitude (Berger et al., 2015; Kong et al., 2022). The effect of depth on mineral nitrogen was highly significant ($P<0.05$, *Fig. 4*). Mineral N at surface soil (0-15 cm) was 13.77 mg kg^{-1} while at depth of (45-60 cm) it was 11.93 mg kg^{-1}. The greater N availability in Ap horizon (0-15 cm) as compared to B and C horizon can be attributed to higher OM content in Ap horizon than B and C horizon. Interaction of altitude with depth for N content was highly significant (Silva et al., 2020).

Table 5. *Mean values of NPK in soil depth along altitude of District Swat*

Altitude (A)	**N %**	**P (mg kg^{-1})**	**K**
500	12.41 b	0.67 f	92.56 b
700	12.51 b	0.74 ef	92.20 b
900	12.74 ab	1.28 de	99.35 ab
1100	12.88 ab	1.64 cd	104.68 ab
1300	12.94 ab	2.17 bc	108.37 ab
1500	13.19 ab	2.54 ab	111.20 ab
1700	13.53 a	3.09 a	122.21 a
LSD	0.53	0.35	14.39
Soil depth (SD)			
0-15 cm	13.77 a	2.75 a	134.95 a
30-45 cm	12.96 b	1.58 b	97.55 b
45-60 cm	11.93 c	0.86 c	80.60 c
LSD	0.20	0.16	6.61
LSD (A*SD)	0.53	0.44	17.50

Values are means of three replicates (n=3). In each column, values with different letters are significantly different from each other at $P<0.05$

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DOI: http://dx.doi.org/10.15666/aeer/2105_41354154

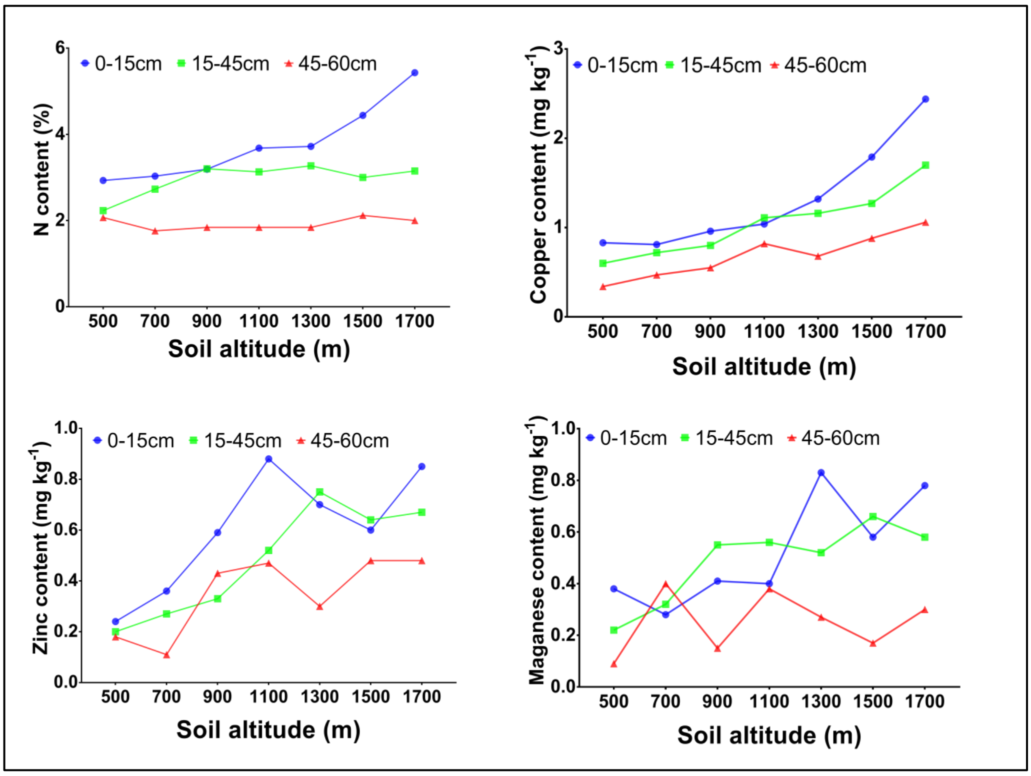

***Figure 4.** Interactive effect of altitude and soil depth on N, Cu, Zn and Mn content of soil*

Phosphorus content significantly increased with increasing altitude (*Table 5*). The lowest value of 0.67 mg kg^{-1} P was observed in 500 m altitudes, while the highest value of 3.09 mg kg^{-1} was observed at high altitude of 1700 m. Interaction of altitude with depth for P content was significant. The reason for high P content at higher altitude may be due to more OM at high altitude. These results are confirmed from of Malik and Haq (2022), who also reported greater P at high altitude. The available P content of the surface (0-15 cm) soil was high and then decreased with soil depth. The greater P availability extent in Ap horizon can also be attributed to higher OM content in Ap than B and C-horizons (Piotrowska-Długosz et al., 2021).

Potassium content significantly increased with increasing altitude (*Table 5*). The lowest value of 92.20 mg kg^{-1} K was observed in 700 m altitudes, while the highest value of 122.21 mg kg^{-1} was observed at high altitude of 1700 m. The reason for high K content at higher altitude may be due to more OM at high altitude. Same results are also supported by confirmed from Huynh et al. (2022) and Guha et al. (2017), who observed greater amount of K at high altitude. The available K content of the surface (0-15 cm) soil was high, and the available K decreased with soil depth. The greater K availability extent in Ap horizon can also be attributed to higher OM content in Ap than B and C-horizon. reported that SOM in the semi-arid region is the main factor controlling K uptake. Interaction of altitude with depth for K content was significant (Salimath et al., 2022; Yang et al., 2023).

Micronutrients (Fe, Cu, Zn, Mn) mg kg^{-1}

The present study revealed that Iron content was positively co-related with altitude (*Table 6*). Soil Fe content increased significantly with increase in altitude. Minimum

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DOI: http://dx.doi.org/10.15666/aeer/2105_41354154

content of 0.89 mg kg^{-1} iron content was observed at altitude of 500 m while maximum Fe content of 3.69 mg kg^{-1} was observed at 1700 m altitude. The reason of greater Fe content at high altitude may be due to low temperature as OM decomposition to more plantation and liter fall and more OM accumulates. Within the profile Iron content was decreased from top to bottom. Maximum value of 2.21 mg kg^{-1} Fe was observed in surface soil (0-15 cm) and minimum of 1.71 mg kg^{-1} was observed in the bottom soil (45-60 cm) depth. The trend of decreasing micronutrients with soil depth has been reported by Grantcharova and Fernández-Caliani (2021). It might be due to OM play important role in biochemical and geochemical cycles of nutrients and their reservoir in soil (Siles and Margesin, 2017; Yang et al., 2022). Interaction of altitude and depth for Iron content was non-significant.

Table 6. *Mean values of micronutrients in soil depth along altitude (m) of District Swat*

Altitude (A)	**Fe**	**Cu** (mg kg^{-1})	**Zn**	**Mn**
500	0.89 d	0.59 d	0.21 c	0.23 b
700	1.16 d	0.66 cd	0.25 c	0.33 ab
900	1.31 cd	0.77 cd	0.45 b	0.37 ab
1100	1.87 bcd	0.99 bcd	0.62 ab	0.44 ab
1300	2.37 bc	1.05 bc	0.58 ab	0.54 a
1500	2.50 b	1.31 ab	0.57 ab	0.47 a
1700	3.69 a	1.74 a	0.67 a	0.55 a
LSD	0.74	0.27	0.12	0.14
Soil depth (SD)				
0-15 cm	2.21 a	1.31 a	0.60 a	0.52 a
30-45 cm	2.00 ab	1.05 b	0.48 b	0.49 a
45-60 cm	1.71 b	0.69 c	0.35 c	0.25 b
LSD	0.30	0.11	0.06	0.07
LSD (A*SD)	Ns	0.30	0.17	0.18

ns=non-significant. Values are means of three replicates (n=3). In each column, values with different letters are significantly different from each other at P<0.05

Copper content significantly increased with increasing altitude. The lowest value 0.59 mg kg^{-1} Cu was observed in 500 m altitudes, while the highest value of 1.74 mg kg^{-1} was observed at high altitude of 1700 m. The reason for high Cu content at higher altitude may be due to more OM at high altitude. The available Cu content 1.31 mg kg^{-1} was observed in the surface (0-15 cm) soil while the lowest content value was 0.69 mg kg^{-1} was observed of (45-60 cm) depth (*Fig. 4*). The greater Cu content in Ap horizon can also be attributed to higher OM content in Ap than B and C-horizon. The high concentrations of Cu were observed in topsoil's, then declined with increasing depth to low values in the subsoil. OM (OM) play important role in bio and geo chemical cycles of micronutrients and their reservoirs in the soil (Beata et al., 2019; Iñigo et al., 2020; Yang et al., 2020). Interaction of altitude and depth for Copper content was significant.

The present study revealed that Zinc content was positively co-related with altitude (*Table 6*). Soil Zn content increased significantly with increase in altitude. Minimum content of 0.21 mg kg^{-1} Zinc was observed at altitude of 500 m while maximum of 0.67 mg kg^{-1} was observed at 1700 m elevation. That reason may be low temperature and more OM at high altitude. Further, at higher elevation due to more plantation and liter fall

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DOI: http://dx.doi.org/10.15666/aeer/2105_41354154

more OM accumulates. Within the profile Zinc content was decreased from top to bottom (*Fig. 4*). Maximum value of 2.21 mg kg^{-1} Zn was observed in surface soil (0-15 cm) and minimum content of 1.71 mg kg^{-1} Zn was observed in the bottom soil (45-60 cm) depth. The high concentrations were observed in the topsoils, and then declined with increasing depth to low values in the subsoil. Low value of micronutrient in the subsoil has also reported (Das et al., 2016; Choudhary et al., 2021; Miah et al., 2022). Interaction of altitude and depth for Zinc content was significant.

Manganese content significantly increased with increasing altitude (*Table 6*). The lowest value 0.23 mg kg^{-1} Mn was observed in 500 m altitudes, while the highest value of 0.55 mg kg^{-1} Mn was observed at high altitude of 1700 m. The reason for high Mn content at higher altitude may be due to more OM at high altitude. *Fig. 4* showed that the available Mn content 0.52 mg kg^{-1} was observed in the surface (0-15 cm) soil and then decreased with soil depth with the value of 0.25 mg kg^{-1} from 45-60 cm. The greater Mn content in Ap horizon can also be attributed to higher OM content in Ap than B and C-horizons (Langlois and James, 2015). The high concentration of Mn was observed in the topsoil's, and then declined with increasing depth to low values in the subsoil. Interaction of altitude and depth for Iron content was significant (Hamid et al., 2021; Menna, 2022).

Conclusions

Clay content increased and Silt content decreased, while sand content showed inconsistent variation along the altitude. B.D, Lime, EC and pH decreased with increase in altitude while these parameters increased within the profile from surface to sub surface soil. Nitrogen, Phosphorus, potassium, and micro-nutrients increased with increase in elevation. The reason may be more OM at high elevation due to accumulation of OM and low decomposition. All these parameters decreased from surface to sub surface soil. Water holding capacity and SP increased with increase in elevation, while decreased from surface to sub surface soil. The reason may be more OM and less BD is higher elevation. Based on the critical level of phosphorus all the selected site along the altitude were deficient in available P and was quite low than the crop requirements and so they will be classified as phosphorus deficient soils. Almost all the soils were non saline (EC<4 dS m$^{-1)}$ and were moderately calcareous (lime content 2.34% to 5.32%).

Acknowledgement. We extend our appreciation to the Researchers Supporting Project No. RSP2023R218, King Saud University, Riyadh, Saudi Arabia.

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