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Original Article

Variations in soil physico-chemical properties, soil stocks, and soil stoichiometry under different soil layers, the major forest region Liupan Mountains of Northwest China

Variações nas propriedades físico-químicas do solo, estoques e estequiometria do solo sob diferentes camadas de solo, a principal região florestal das montanhas Liupan do noroeste da China

M. Rahman[a,b], K. Zhang[a*], Y. Wang[b*], B. Ahmad[a,b,c], A. Ahmad[d], Z. Zhang[a,b], D. Khan[a], D. Muhammad[e] and A. Ali[f]

[a]Beijing Forestry University, School of Soil and Water Conservation, Beijing, China
[b]Chinese Academy of Forestry, Institute of Forest Ecology, Environment and Nature Conservation, Beijing, China
[c]University of Swat, Institute of Agriculture Sciences and Forestry, Swat, Pakistan
[d]Shaheed Benazir Bhutto University, Department of Forestry, Khyber Pakhtunkhwa, Pakistan
[e]The University of Agriculture, Faculty of Crop Productions, Department of Soil and Environmental Sciences, Peshawar, Pakistan
[f]Karakoram International University, Department of Forestry, Range and Wildlife Management, Gilgit Baltistan, Pakistan

Abstract

Liupan Mountains are an important region in China in the context of forest cover and vegetation due to huge afforestation and plantation practices, which brought changes in soil physio-chemical properties, soil stocks, and soil stoichiometries are rarely been understood. The study aims to explore the distribution of soil nutrients at 1-m soil depth in the plantation forest region. The soil samples at five depth increments (0-20, 20-40, 40-60, 60-80, and 80-100 cm) were collected and analyzed for different soil physio-chemical characteristics. The results showed a significant variation in soil bulk density (BD), soil porosity, pH, cation exchange capacity (CEC), and electric conductivity (EC) values. More soil BD (1.41 g cm^{-3}) and pH (6.97) were noticed in the deep soil layer (80-100 cm), while the highest values of porosity (60.6%), EC (0.09 mS cm^{-1}), and CEC (32.9 c mol kg^{-1}) were reflected in the uppermost soil layer (0-20 cm). Similarly, the highest contents of soil organic carbon (SOC), total phosphorus (TP), available phosphorus (AP), total nitrogen (TN), and available potassium (AK) were calculated in the surface soil layer (0-20 cm). With increasing soil depth increment a decreasing trend in the SOC and other nutrient concentration were found, whereas the soil total potassium (TK) produced a negative correlation with soil layer depth. The entire results produced the distribution of SOCs and TNs (stocks) at various soil depths in forestland patterns were 0→20cm > 20→40cm > 40→60cm ≥ 60→80cm ≥ 80→100 cm. Furthermore, the stoichiometric ratios of C, N, and P, the C/P, and N/P ratios showed maximum values (66.49 and 5.46) in 0-20 cm and lowest values (23.78 and 1.91) in 80-100 cm soil layer depth. Though the C/N ratio was statistically similar across the whole soil profile (0-100 cm). These results highlighted that the soil depth increments might largely be attributed to fluctuations in soil physio-chemical properties, soil stocks, and soil stoichiometries. Further study is needed to draw more conclusions on nutrient dynamics, soil stocks, and soil stoichiometry in these forests.

Keywords: forest soil, physico-chemical properties, soil stocks, soil depth, Liupan Mountain.

Resumo

As montanhas de Liupan são uma região importante na China no contexto de cobertura florestal e vegetação devido às enormes práticas de florestamento e plantação, que trouxeram mudanças nas propriedades físico-químicas do solo, e estoques e estequiometrias do solo raramente são compreendidos. O estudo visa explorar a distribuição de nutrientes do solo a 1 m de profundidade do solo na região da floresta plantada. As amostras de solo em cinco incrementos de profundidade (0-20, 20-40, 40-60, 60-80 e 80-100 cm) foram coletadas e analisadas para diferentes características físico-químicas do solo. Os resultados mostraram uma variação significativa nos valores de densidade do solo (BD), porosidade do solo, pH, capacidade de troca catiônica (CEC) e condutividade elétrica (CE). Mais DB do solo (1,41 g cm-3) e pH (6,97) do solo foram observados na camada profunda do solo (80-100 cm), enquanto os maiores valores de porosidade (60,6%), CE (0,09 mS cm-1) e CEC (32,9 c mol kg-1) foram refletidos na camada superior do solo (0-20 cm). Da mesma forma, os maiores teores de carbono orgânico do solo (SOC), fósforo total (TP), fósforo disponível (AP), nitrogênio total (TN) e potássio disponível (AK) foram

*e-mail: ctccd@126.com; wangyh@caf.ac.cn
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calculados na camada superficial do solo (0-20 cm). Com o aumento do incremento da profundidade do solo, uma tendência decrescente no SOC e na concentração de outros nutrientes foi encontrada, enquanto o potássio total do solo (TK) produziu uma correlação negativa com a profundidade da camada do solo. Todos os resultados produziram a distribuição de SOCs e TNs (estoques) em várias profundidades de solo em padrões de floresta 0 → 20cm> 20 → 40cm> 40 → 60cm ≥ 60 → 80cm ≥ 80 → 100 cm. Além disso, as relações estequiométricas de C, N e P, as relações C / P e N / P, apresentaram valores máximos (66,49 e 5,46) em 0-20 cm, e valores mais baixos (23,78 e 1,91) em solo de 80-100 cm profundidade da camada. Embora a relação C / N fosse estatisticamente semelhante em todo o perfil do solo (0-100 cm). Esses resultados destacaram que os incrementos de profundidade do solo podem ser amplamente atribuídos a flutuações nas propriedades físico-químicas do solo, estoques e estequiometrias do solo. Mais estudos são necessários para tirar conclusões adicionais sobre a dinâmica dos nutrientes, estoques de solo e estequiometria do solo nessas florestas.

Palavras-chave: solo florestal, propriedades físico-químicas, estoque do solo, profundidade do solo, Liupanshan.

1. Introduction

Soil plays a significant role in the biosphere by facilitating plant production, through soil organic matter (SOC) decomposition (Zhang et al., 2015) and mineral nutrients recycling (Haileslassie et al., 2005). The frequent ecological research reported one of the major drivers' soil fertility for different ecological processes and researchers which are important to investigate their various aspects (Wigley et al., 2013). The knowledge of soil physio-chemical properties is required (Osman, 2013), to assess the productive capacity of a site for the support of forest vegetations. Recently, the evaluation of soil physio-chemical properties increased due to the growing interest in the assessment of management practices, consequences on the quality of soil, sustainability of forest ecosystem functions, and addition to plant production (Schoenholtz et al., 2000). These physio-chemical properties are related to soil fertility and soil productivity including, soil bulk density (BD), porosity, total nitrogen (TN), total phosphorus (TP) and total potassium (TK), available phosphorus (AP), and available potassium (AK), exchangeable cations capacity (CEC), electric conductivity (EC), soil pH, and organic carbon contents (SOC), (Zhang et al., 2018).

The SOC, TN, TP, and TK are varying among forest ecosystems (Toriyama et al., 2007), due to variation in topography (Griffiths et al., 2009), vegetation types, climate, weathering, ground cover, elevation, soil depth and stand structural attributes (Xu et al., 2011). Vegetation help in the soil formation process i.e., plant biomass (above and below ground), the main sources of soil organic matter, which influence soil physio-chemical properties such as pH, texture, bulk density, and nutrient availability. Therefore, understanding the relationship between forest vegetation and soil nutrient dynamics (Hoogmoed et al., 2014; Zhou et al., 2006) is crucial for effective soil management (Li et al., 2013). Furthermore, the soil is usually affected by the land management practices such as cultivation, harvesting, plantation, and deforestation (Li et al., 2013). The effect of these management activities, changes in soil physio-chemical properties, and their stoichiometries require detailed investigation (Li et al., 2016b).

Since China has diverse kinds of soils that are built under various climatic conditions and derived from different parent matter in a variety of geographical surroundings. Therefore, the C, N, and P association studies in Chinese soil are expected to generate tremendous contributions to the knowledge regarding the global N, C, and P relationship. In this regard, the forest's value can never be ignored. Plantation forests are very important, and a major proportion of forest cover in China as well as worldwide, which play a dynamic role in the renovation and restoration of vegetation, soil resources, and economic expansion (Bull et al., 2006; Hoogmoed et al., 2014). Accelerating natural resource cultivation and improving forest coverage in China is important to properly alleviate the increasing atmospheric carbon.

Ningxia a typical region of China, the Liupan Mountains are the main distribution areas of forest resources. The forests located in the south of Ningxia, play a major role in the regulation of climate, maintenance of ecological balance as well as health stability of forest vegetation and water conservation in the Loess Plateau. Based on soil fertility and vegetation growth some fundamental indices exist which are applied to assess forest growth and expected production. The limiting factor of soil fertility can affect community diversity, forest distribution, forest succession, human disturbance, and forest management. Therefore, forest soil needs a detailed investigation of soil's physio-chemical properties.

The Liupan forest soils have been rarely investigated for soil physio-chemical properties at various soil layer depths. So, the information of soil nutrients and their fertility status might help to manage the Liupan Mountains forests. Thus, the present study was conducted first to identify the basic characteristics of the sampling site, forest structure, stand types, species community, and forest vegetations, while the main research objectives were I) to characterize the fundamental physio-chemical properties of forest soils under different soil depth increments, II) dynamics of soil carbon, nitrogen, and phosphorus across the soil layer depth, III) evaluate the soil C, N, and P stocks and soil C, N, and P stoichiometries in the selected soil profiles. Furthermore, the study provides a deep understanding of soil physio-chemical properties of the study area and baseline information for further research investigation.

2. Materials and Methods

2.1. Study area

The study was conducted at the Xixia forest farm (35°29'53.52" N, 106°19'50.16" E), Jingyuan County, Hui Autonomous region Ningxia, which is located in the east slope of the south section of Liupan main mountains core area (Figure 1). Covering an area of 95.2 km^2 with an altitude of 2263-2524 m bordering with Gansu Province to the east and southwest. The temperature is warm (average 5.18 °C), the climate is semi-arid to semi-humid, with an average annual rainfall of 600-820 mm, mostly concentrated in June-August, and annual evaporation is recorded 1214-1426 mm. The main forest vegetation includes *Larix principis rupprechtii, Pinus tabulaeformis, Betula platyphylla, Pinus armandi, populus davidiana, Tilia aucicostata, and Quercus liaotungensis.* The dominant species of trees, shrubs, and herbs are *Larix principis rupprechtii*, *Cotoneaster acutifolius,* and *Oriental snakeberry* respectively. The area has no natural forests with only fewer natural plantations. The parent rocks are gneiss with slope deposits parent materials and mainly water erosion occurs in the area with mild erosion intensity.

2.2. Site characteristics and forest vegetation surveys

The soil horizons (soil layers) consisted of O, A, A/B, B, B/C, and C (horizon types). The degree of downward transition was mostly indeterminate (indistinct/vague) with a smooth downward transition pattern. Compaction of soil ranged from moderate to strongly loose, while the soil structure was wet granular to agglomerates (crumby soil structure). The forest type was *Larix principis rupprechtii* (origin belonged to planted forest) with community structures trees, shrubs, and grasses with one distinct age (31 years old) and size class of forest. The dominant species of *Larix principis rupprechtii*, C*otoneaster acutifolius,* and *Oriental snakeberry* belongs to trees, shrubs, and herbs respectively.

The artificial interference was mostly found in tending. The canopy closure, tree layer density and average tree height, plant community structure, and health status were surveyed for the trees in each sample plot (30 m × 30 m), when soil samples were collected (Table 1).

2.3. Soil sampling and experimental set-up

Forestland sampling was operated, and composite soil samples were taken from experimental plots with a single plot size of 30 x 30 m^2 within the Xixia forest farm. A pit of 1-m^2 was dug out at the forest floor and soil samples were taken at five individual soil layers (0-20, 20-40, 40-60, 60-80, and 80-100 cm) from the soil profile. The ground litter, debris, insects, roots, waste, and gravel were removed during sampling. Each soil sample was broken along the planes of weakness into smaller aggregates, dried at room temperature, and sieved through a 2 mm screen according to the National Standard Method. The stored soil samples were then subjected to many different standardized tests to assess the basic physio-chemical characteristics. For soil BD samples were taken with a ring tube method in all soil depth increments then dried for 48 h at 104°C in an oven.

2.3.1. Soil samples analysis

The soil bulk density (BD) was measured by the oven drying method. pH was measured with a pH meter (soil-water suspension-1:5), (McLean, 1982) and electric

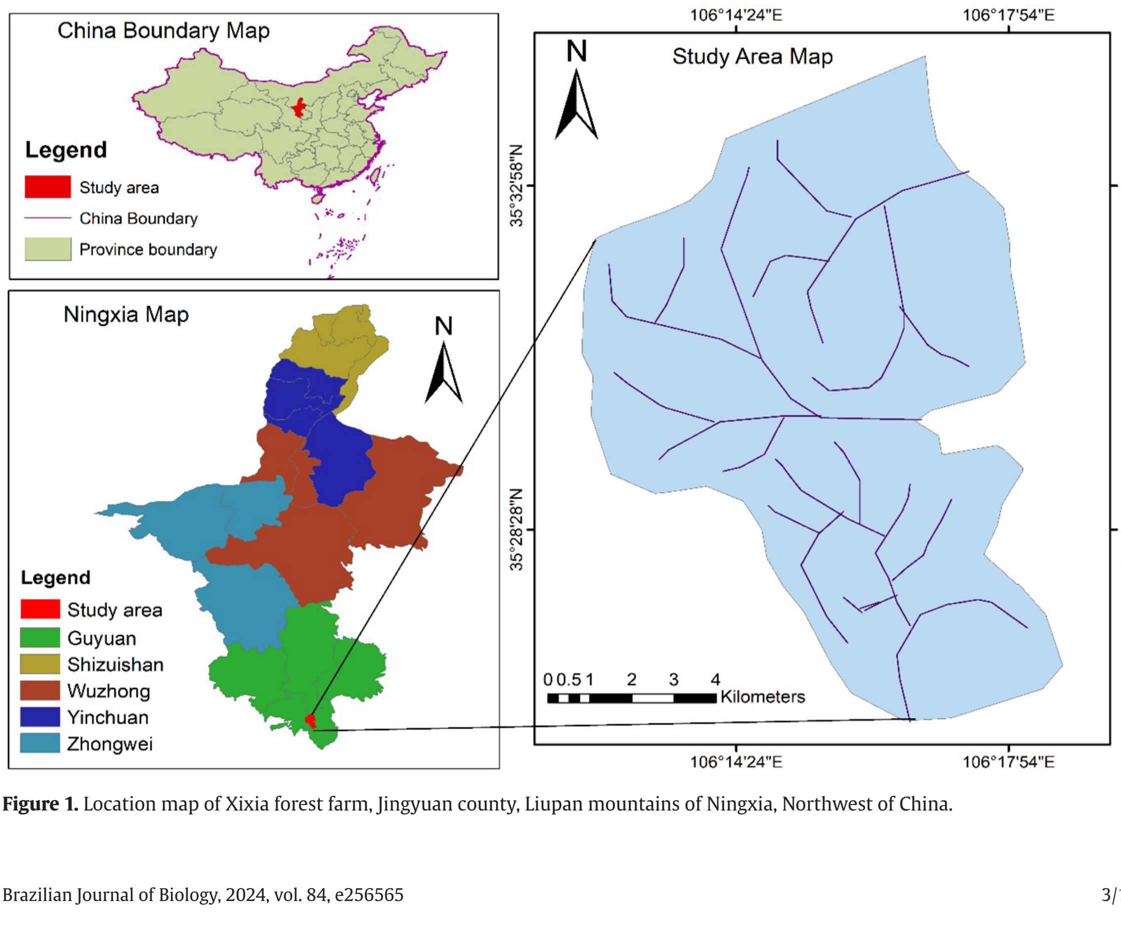

Figure 1. Location map of Xixia forest farm, Jingyuan county, Liupan mountains of Ningxia, Northwest of China.

Table 1. Overview of the 24 samples plots with ground vegetation characteristics data of the study area.

Sample Plot	longitude	latitude	Altitude (m)	Slope Aspect	Canopy Density (%)	Tree Density (trees/ha)	Avg Tree Height (m)
Jing-01	106.222350	35.516560	2276.6	Southeast	0.75	907	16.19
Jing -02	106.223250	35.513820	2294.7	Southeast	0.72	955	15.97
Jing-03	106.223250	35.513830	2312.6	Southeast	0.74	1035	16.57
Jing-04	106.223250	35.513840	2330.4	Southeast	0.8	786	18.07
Jing-05	106.223250	35.513850	2348.4	Southeast	0.71	770	17.04
Jing-06	106.223250	35.513860	2362.9	Southeast	0.68	572	17.75
Jing-07	106.223250	35.513870	2376.7	Southeast	0.62	674	18.24
Jing-08	106.223250	35.513880	2394.2	Southeast	0.74	815	17.87
Jing-09	106.223250	35.513890	2411.4	Southeast	0.81	933	17.12
Jing-10	106.223250	35.513900	2429.0	Southeast	0.76	719	17.94
Jing-11	106.223250	35.513910	2447.1	Southeast	0.71	831	15.72
Jing-12	106.223670	35.513760	2460.4	Southeast	0.78	746	17.54
Jing-13	106.223950	35.513920	2474.1	Southeast	0.75	870	17.4
Jing-14	106.224170	35.513990	2489.7	Southeast	0.72	854	17.04
Jing-15	106.224240	35.514840	2506.9	Southeast	0.76	749	17.04
Jing-16	106.224280	35.516770	2524.5	Southeast	0.74	942	16.71
Jing-17	106.224430	35.514850	2308.5	Southwest	0.75	/	/
Jing-18	106.224460	35.516230	2323.1	Northeast	0.76	/	/
Jing-19	106.224570	35.515960	2281.0	Northwest	0.85	725	18.3
Jing-20	106.224590	35.514120	2352.0	Northwest	0.45	462	16.1
Jing-21	106.224640	35.514590	2349.0	Northwest	0.49	876	20.1
Jing-22	106.224740	35.513920	2263.0	Northwest	0.85	675	12.2
Jing-23	106.225030	35.513870	2335.0	Southwest	0.75	954	18.9
Jing-24	106.226480	35.514130	2277.0	Southwest	0.78	1221	19.9

conductivity (EC) with a conductometer (soil-water suspension-1:1). The soil TN was calculated using a fully automated Kjeldahl analyzer method (dissolved by sulfuric acid plus catalyst). Soil TP (Bremmer et al., 1996), soil TK (Gomez and Gomez, 1984; Grewal and Kanwar, 1966), and AN (Subbaiah, 1956) were measured using an automatic discontinuous analyzer (Clever chem200, Germany) by dissolved nitric acid, perchloric acid, and hydrofluoric acid method. The soil AP and AK were assessed with an ultraviolet spectral photometer (UV-1780, Shimadu, Tokyo, Japan), and flame photometer (FP640, Shanghai, China) respectively (Jackson, 1973). The organic matter (OM) was determined according to the $K_2Cr_2O_4$ volumetric method (Walkley, 1947), with analytical instrument oil bath-$K_2Cr_2O_7$ titration.

2.4. Data processing and statistical analysis

The following formula was used to calculate soil organic carbon (SOC_s), nitrogen (TN_s), and phosphorus stocks (TP_s) (Liu et al., 2011) (Equation 1),

$$\text{SOCs} = \sum_{i}^{n}[\,D_i \times SOC_i \times SBD_i \times (1 - G_i)/100]/100 \qquad (1)$$

Where, the SOCs are the SOC stocks (Mg ha^{-1}), *n* indicated the number of soil layers, *i* is the ith soil layer, SBD*i*, G*i*, and D*i* are the bulk density of soil (g cm^{-3}), the proportions of course (%) particles (> 2 mm), and sampling thickness in the ith layer respectively. The SOC content is denoted by SOC*i* (g kg^{-1}).In the same way, as described in Equation (1), we calculated the TNs and TPs for the soil thickness of 100 cm with five layers (0-20, 20-40, 40-60, 60-80, and 80-100 cm).The statistical tests were conducted by using SAS, ver.8.1, and Excel 2019 software programs. All data were checked for one-way analysis of variance (ANOVA) and LSD test subsequently followed by the analysis of means with identical soil layer depths, and presented in means ± standard deviation (SD values). The ANOVA was followed to investigate the response of soil layer depth on the SOC, TN, TP concentration, soil stocks, soil stoichiometries, and soil physio-chemical parameters. The statistical differences were evaluated at a 5% significance level. When significance was observed at the $P < 0.05$ level, the test was used to carry out the mean comparisons. Pearson linear correlation coefficients analysis was used to evaluate the relationships between the stocks and stoichiometry of SOC, TN, and TP. Finally, Origin Software (2018) was used to plot the data for linear regression models.

3. Results

3.1. Variations in soil BD, porosity, pH, EC, and CEC

Diverse variations were observed in soil bulk density, porosity, pH, EC, and CEC with increased soil depths from 0 to 100 cm (Figures 2A-2D). In the whole forest land pattern, the highest bulk density was recorded in the deeper soil layer (80-100 cm), with the value of 1.41 g cm^{-3}, while the lowest BD (0.88 g cm^{-3}) was noticed in the surface soil layer (0-20 cm), indicated that more porous soil included in the surface soil layer as reflecting from the soil porosity measurement. The maximum porosity was reported in the top layer with a value of 60.68%, while the minimum porosity (43.56%) was seen in the deeper soil profile layer (80-100 cm).

For soil pH, the higher pH value (6.97) was recorded in the deeper soil profile layer, which is found statically similar with a soil depth of 60-80 cm, while the lower pH value (6.35) was observed in the upper soil layer (0-20 cm), which showed slightly significant results along with soil depth from 0-100 cm. In this way, the soil depth significantly affected ($p \leq 0.05$) soil EC and CEC values. The highest EC and CEC values were found in the surface soil layer (0-20 cm), i.e., 0.85 mS cm^{-1} and 32.90 c mol kg^{-1} respectively, while the lowest EC and CEC were noted at deep soil layers of 60-80 and 80-100 cm. The soil porosity, EC, and CEC were significantly decreased with increasing soil depth, while the soil BD and soil pH remained increased with increasing soil depth. The above soil properties showed a different trend in the middle soil layers of 20-40, 40-60, and 60-80 cm. Moreover, the soil BD, soil porosity and soil CEC showed significant variation throughout the soil profile, at the same time soil pH and soil EC trends had shown an approximately similar effect to their consecutive soil depths (40-100 cm), and the only significant differences were assessed from top to deep soil layers and vice versa (Table 2).

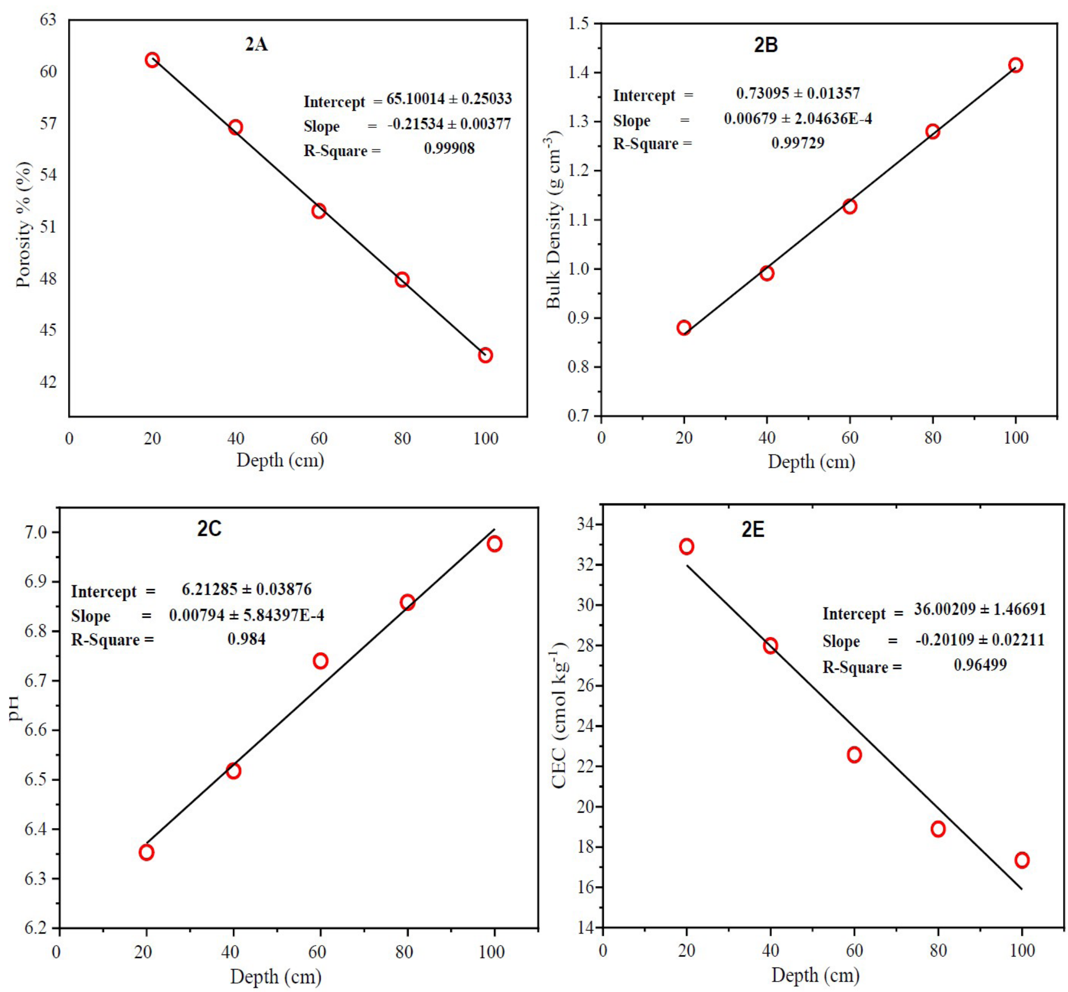

Figure 2. Distributions of soil bulk density, porosity, electrical conductivity, pH values, cation exchange capacity among the different soil depths increment through linear regression.

Table 2. The variation in soil physio-chemical properties in the study area under various soil layer depth increments.

Depth (cm)	BD (g cm^{-3})	Porosity (%)	pH	EC (mS cm^{-1})	CEC (c mol kg^{-1})
0-20	0.88 ± 0.09^{e}	60.68 ± 2.41^{a}	6.35 ± 0.40^{c}	0.85 ± 0.23^{a}	32.90 ± 8.04^{a}
20-40	0.99 ± 0.08^{d}	56.78 ± 2.06^{b}	6.51 ± 0.48^{bc}	0.65 ± 0.10^{b}	27.98 ± 4.20^{b}
40-60	1.12 ± 0.12^{c}	51.92 ± 4.32^{c}	6.74 ± 0.51^{ab}	0.55 ± 0.12^{c}	22.57 ± 4.40^{c}
60-80	1.28 ± 0.12^{b}	47.94 ± 4.96^{d}	6.85 ± 0.58^{a}	0.48 ± 0.011^{c}	18.88 ± 4.55^{d}
80-100	1.41 ± 0.16^{a}	43.56 ± 5.96^{e}	6.97 ± 0.62^{a}	0.52 ± 0.10^{c}	17.34 ± 3.94^{d}
Mean	1.14 ± 0.12	52.18 ± 3.95	6.69 ± 0.52	0.62 ± 0.14	23.94 ± 5.03

BD-Bulk Density, EC-Electric Conductivity, pH-pH values, CEC-Cation Exchange Capacity. The values are means ± standard deviations, and the lower-case letters (superscript) within the column indicate the significant statistical differences at P ≤ 0.05 level among different soil depths.

Table 3. The dynamics of soil organic carbon and nutrient concentration in the given forest sloping land under different soil depths increment.

Depth (cm)	SOC (g kg^{-1})	TN (g kg^{-1})	TP (g kg^{-1})	TK (g kg^{-1})	AP (mg kg^{-1})	AK (mg kg^{-1})
0-20	54.72 ± 11.12^{a}	4.66 ± 1.32^{a}	0.85 ± 0.183^{a}	19.98 ± 1.94^{b}	11.4 ± 4.27^{a}	227.3 ± 51.06^{a}
20-40	41.48 ± 9.86^{b}	3.58 ± 0.84^{b}	0.81 ± 0.157^{ab}	20.51 ± 1.71^{ab}	5.22 ± 1.38^{b}	120.4 ± 36.56^{b}
40-60	26.75 ± 11.28^{c}	2.41 ± 0.84^{c}	0.72 ± 0.198^{bc}	20.62 ± 1.74^{ab}	2.91 ± 0.95^{c}	72.03 ± 18.05^{c}
60-80	18.23 ± 9.21^{d}	1.49 ± 0.78^{d}	0.62 ± 0.199^{cd}	21.00 ± 1.98^{ab}	2.28 ± 1.27^{c}	64.90 ± 12.68^{c}
80-100	14.75 ± 7.52^{d}	1.18 ± 0.64^{d}	0.60 ± 0.174^{d}	21.18 ± 2.27^{a}	2.04 ± 1.28^{c}	64.99 ± 14.07^{c}
Mean	31.19 ± 10.40	2.58 ± 0.97	0.73 ± 0.18	20.66 ± 1.93	4.78 ± 1.83	109.9 ± 26.49

SOC-Soil organic C, TN-total N, TP-Total P, TK-Total K, AP-Available P, AK-Available K. The values are means ± standard deviations, and the lower-case letters in the superscript indicate the significant differences at probability level 0.05 (P < 0.05) amid the different soil layers depth.

3.2. Changes in soil SOC and nutrient concentration

The soil depth significantly affected (P ≤ 0.05) the SOC and soil nutrient concentration in the mentioned forest farm of Liupan mountains (Figure 3). The one-way ANOVA analysis showed a statistical variation in SOC, TN, TP, AP, and AK concentrations along with different soil depth increments (Table 3). The significant contents of SOC, TN, TP, AP, and AK were detected in the surface soil layer (0-20 cm), with maximum values of 54.72 g kg^{-1}, 4.66 g kg^{-1}, 0.85 g kg^{-1}, 11.4 mg $kg^{-1,}$ and 227.3 mg kg^{-1} respectively, while the minimum concentration was noted in the deeper soil profile layer (80-100 cm).

The soil TK had revealed an increasing tendency with increasing soil depths from 0-100 cm. The statistical differences were found similar throughout the whole soil profile layers, with maximum concentration (21.18 g kg^{-1}) recorded in the deeper soil layer (80-100 cm), that only could produce a significant result (19.98 g kg^{-1}) when compared with topsoil layer (0-20). The relation of middle soil layers (20-40, 40-60, and 60-80 cm) excluding from SOC, TN, the soil TP, TK, AP, and AK showed non-significant results at (P ≤ 0.05), while AP and AK at soil profile layers 0-20 and 20-40 cm showed significant differences, indicating that the concentration of AP and AK were only significantly higher at the depth between 0 to 40 cm while did not significantly different from the soil depth 60 to 100 cm (Table 3).

3.3. Changes in soil stocks (SOCs, TNs, and TPs)

The SOC and TN stocks significantly varied in the planted forest land of the study area with increasing soil depth increments (Figure 4). The highest values of SOCs and TNs were recorded in the topsoil layer (0-20 cm), which accounted for 95.95 and 8.20 Mg ha^{-1} at probability level ≤ 0.05, while the lowest SOC and TN stocks were computed 39.85 and 3.18 Mg ha^{-1} in the deeper soil profile layer (80-100 cm). The TPs showed non-significant values along with the whole soil profile depth (0-100 cm), which produced statistically similar results, with maximum stocks of 1.67 Mg ha^{-1} in the deeper soil profile layer (80-100 cm). The entire results showed the distribution of SOCs and TNs at different soil depths in forest land patterns were built 0→20 cm > 20→40 cm > 40→60 cm ≥ 60→80cm ≥ 80→100 cm excluding TPs (Table 4). In all soil profile layers, the highest percentage of SCOs and TNs were noticed at soil profile depth of 0-20 cm, while for TPs at deeper soil layer of 80-100 cm, accounting for 30.41%, 30.99%, and 20.90% respectively (Figure 5A). While these percentages were significantly greater than other soil layers at (P ≤ 0.05).

The results showed the deeper SOCs, TNs and TPs can be calculated from the topsoil layer (0-10 cm or 0-20 cm). The overall distributions of SOCs, TNs, and TPs with average values were reported 64.7 Mg ha^{-1}, 5.30 Mg $ha^{-1,}$ and 1.60 Mg ha^{-1} from 0-100 cm soil depth, while the total SOCs, TNs, and TPs were calculated 327.5 Mg ha^{-1}, 26.5 Mg $ha^{-1,}$ and 8.0 Mg ha^{-1} respectively. Thus, the one-way ANOVA analysis showed that soil profile depth had significantly affected the soil SOCs, TNs, and TPs distribution in the study area.

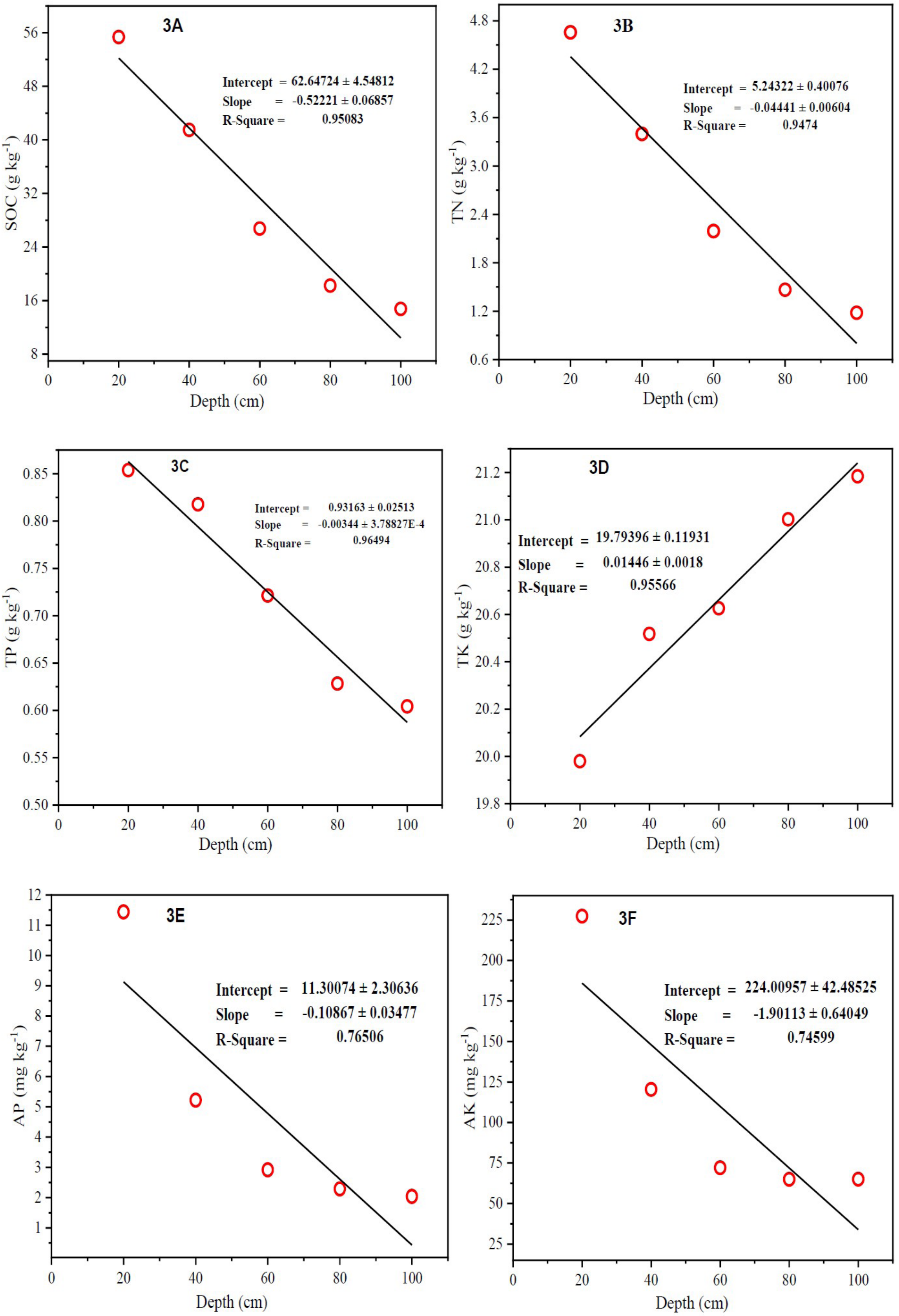

Figure 3. Linear regression analysis graph of soil SOC, and nutrient concentration among the different soil depths increment.

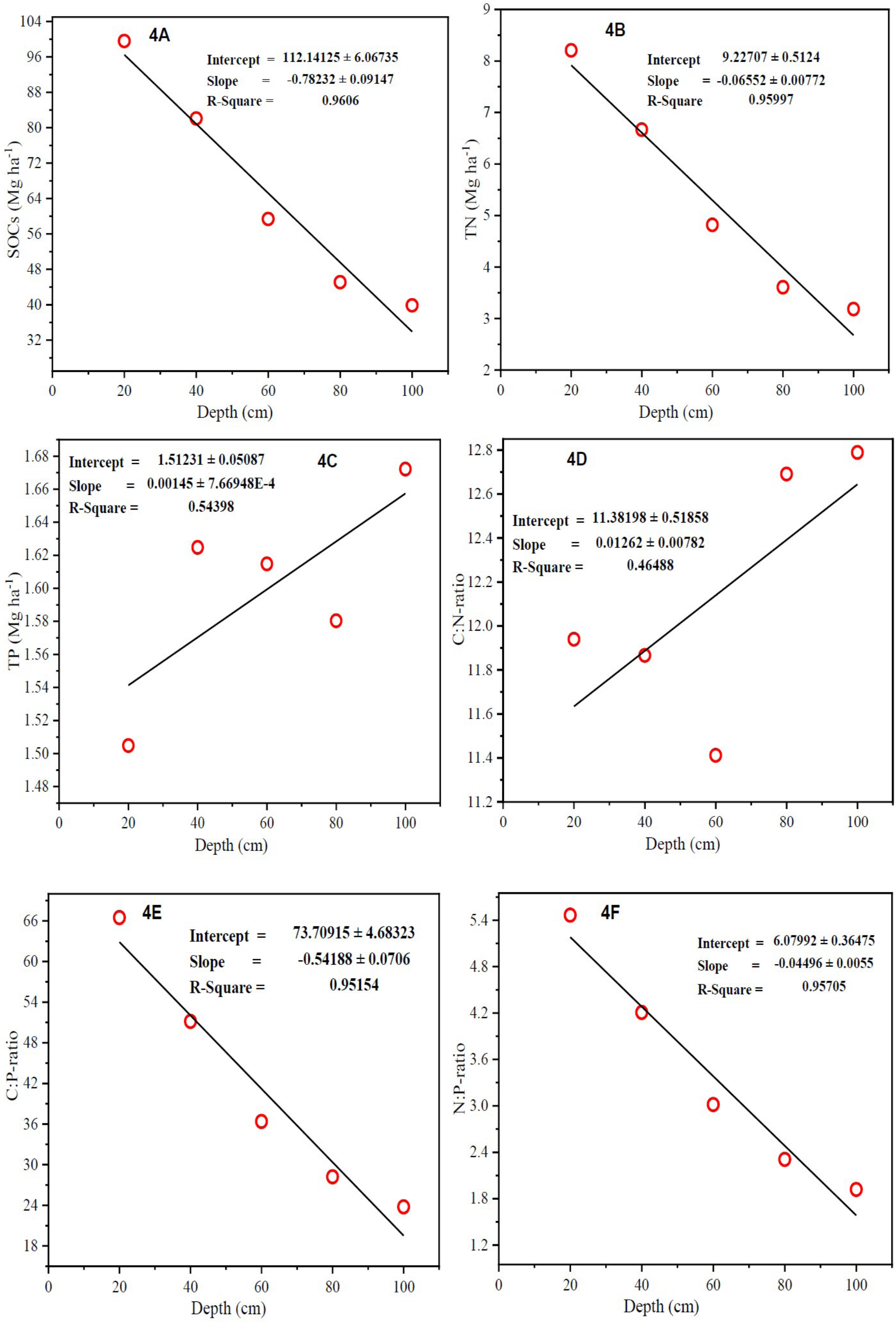

Figure 4. Distributions of soil stocks and soil stoichiometry among the different soil depths.

Table 4. Distribution of the SOC, TN, and TP stocks under different soil layer depths.

Depth (cm)	SOCs (Mg ha^{-1})	TNs (Mg ha^{-1})	TPs (Mg ha^{-1})
0-20	95.95 ± 25.77[a]	8.20 ± 2.65[a]	1.50 ± 0.38[a]
20-40	83.60 ± 21.32[b]	6.66 ± 2.19[b]	1.62 ± 0.38[a]
40-60	59.37 ± 24.72[c]	4.82 ± 2.16[c]	1.61 ± 0.46[a]
60-80	45.09 ± 20.12[cd]	3.60 ± 1.75[d]	1.58 ± 0.45[a]
80-100	39.85 ± 16.83[d]	3.18 ± 1.41[d]	1.67 ± 0.39[a]
Mean	64.77 ± 21.76	5.30 ± 2.03	1.60 ± 0.41

SOCs-Total carbon stocks, TNs-total nitrogen stocks, TPs-Total phosphorus stocks. The different values are mean ± standard deviation. The lowercase superscript letters indicate the significance level among the different soil depths at probability level 0.05 ($P < 0.05$), under Liupanshan, planted forest.

Table 5. The changes in the distribution pattern of C:N, C:P, and N:P stoichiometries under different soil layer depths.

Depth (cm)	C:N-ratios	C:P-ratios	N:P-ratios
0-20	11.86 ± 0.83[a]	66.48 ± 15.39[a]	5.46 ± 0.96[a]
20-40	11.87 ± 1.00[a]	51.15 ± 10.20[b]	4.20 ± 1.14[b]
40-60	11.41 ± 4.65[a]	36.37 ± 12.43[c]	3.01 ± 1.11[c]
60-80	12.69 ± 4.58[a]	28.20 ± 9.96[d]	2.30 ± 0.94[d]
80-100	12.79 ± 2.98[a]	23.78 ± 9.31[d]	1.91 ± 0.81[d]
Mean	12.12 ± 2.81	41.20 ± 11.46	3.38 ± 0.99

The different values are means ± standard deviation. The superscript letters indicate the significant variations amid the different soil depths at probability level 0.05 ($P < 0.05$), under the Liupanshan, planted forest.

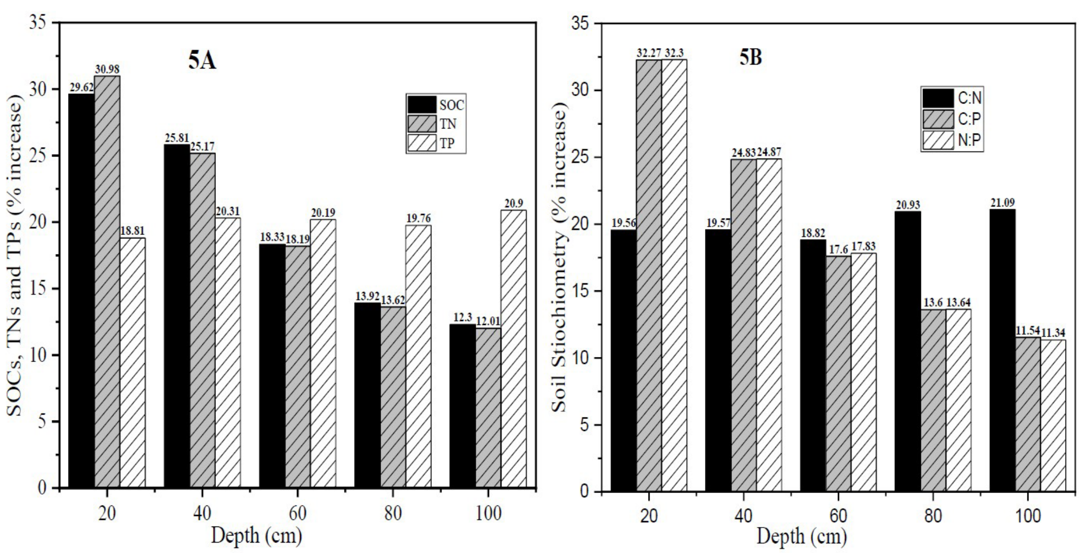

Figure 5. Percent increase in soil stocks and soil stoichiometries under various soil depths increments.

3.4. Changes in soil stoichiometries (C:N:P)

The soil profile layers had a different effect on the soil stoichiometries of C:N:P ratios (Figure 4). The C:N ratios were found statistically similar across the whole soil profile layer (0-100 cm), with the highest value of 12.79 noted in the deeper soil profile layer (80-100 cm), while the C:P ratios showed a significant difference among the different soil layers (Table 5). The highest value of 66.49 was recorded in the upper soil layer (0-20 cm), with the lowest value of 23.78 in the deeper soil profile layer (80-100 cm), which is found statistically similar to that of 28.20 in the middle soil layer of (60-80 cm). Similarly, the N:P also produced significant results ($P \leq 0.05$), with the highest N:P value of 5.46 in the topsoil layer of 0-20 cm, while the lowest value of 1.91 was observed in the deeper soil profile layer (80-100 cm), which is found statistically similar to the middle soil layer of (60-80 cm). The *Larix principis rupprechtii* response to the soil stoichiometries

Table 6. Pearson correlations analysis among the soil organic C, TN, TP concentration grouped with TK, AK, and AP under different soil layers (0-100 cm).

Depth	Component	SOC	TN	TP	TK	AP
0-20 cm	TN	0.95**	1			
	TP	0.72**	0.76**	1		
	TK	-0.70**	-0.60**	-0.44*	1	
	AP	0.78**	0.75**	.34	-0.64**	1
	AK	0.372	0.38	0.32	-0.029	0.173
20-40 cm	TN	0.95**	1			
	TP	0.57**	0.60**	1		
	TK	-0.28	-0.26	-0.11	1	
	AP	0.62**	0.54**	0.11	-0.01	1
	AK	0.22	0.08	0.44*	0.32	0.08
40-60 cm	TN	0.71**	1			
	TP	0.75**	0.54**	1		
	TK	-0.24	-0.17	-0.02	1	
	AP	0.71**	0.53**	0.43*	0.10	1
	AK	0.48*	0.22	0.62**	0.37	0.52**
60-80 cm	TN	0.88**	1			
	TP	0.77**	0.62**	1		
	TK	0.03	-0.08	0.16	1	
	AP	0.56**	0.59**	0.46*	0.39	1
	AK	0.40	0.31	0.47*	0.63**	0.58**
80-100 cm	TN	0.93**	1			
	TP	0.68**	.59**	1		
	TK	-0.02	-.12	0.27	1	
	AP	0.50*	0.37	0.51*	0.18	1
	AK	0.29	0.13	0.42*	0.65**	0.66**

**Correlation was evaluated at significance level 0.01 ($P < 0.01$). *. The correlation was tested at a significance level of 0.05 ($P \leq 0.05$).

showed a significant percent increase in C:P and N:P, while C:N ratios were characterized as minuscule. Compared to deeper soil layer (80-100 cm) the C:P and N:P ratios (11.54% and 11.34%), were significantly higher in the topsoil layer (0-20 cm) by 32.28% and 32.31% (Figure 5B) respectively at ($P \leq 0.05$). In the whole forest land, the soil C:P and N:P ratios were first dropped abruptly at a soil depth of 20-40 cm, and then gently decreased from 40-60 cm, 60-80 cm, and 80-100 cm soil depth, except for C:N ratios (Table 5). Thus, the one-way ANOVA analysis indicated that soil layer depth significantly affected the soil stoichiometries.

3.5. Relationship among SOC, nutrient concentrations, soil stocks, and soil stoichiometry

The relationship between the SOC and nutrient concentration was illustrated differently with each nutrient concentration. A strong positive correlation was reflected between SOC and TN (Table 6) throughout the whole soil profile. Similarly, the SOC was positively correlated with soil TP, AP, AK and negatively correlated with soil TK over whole soil depth increments apart from TK at soil depth (60-80 cm), which produced a slightly positive correlation. While the rest of all nutrient concentrations were positively correlated with each other except for total potassium. The correlation between soil stocks and soil stoichiometry of TN, TP, and SOC among various soil layers was measured (Table 7). A strong positive correlation existed amid the SOC and soil TN at all soil profile depths 0-100 cm. The SOCs and TNs were also significantly correlated with C:P, N:P ratios in all soil layers. While the C:N ratio was found non-significant throughout the soil profile with N:P and C:P ratios. Similarly, the soil TP stocks produced a negative and uncertain correlation with soil stoichiometries at all soil depth increments except for the C:N ratio at 40-60 and 80-100 cm soil depth (Table 7).

4. Discussion

4.1. Description and distribution of forest soil physio-chemicals properties

The experimental soil physio-chemical properties had changing behavior with increasing soil depth throughout the soil layers, which is consistent with the previous results of (Olorunfemi et al., 2018), that increasing soil depth has significant change on the soil properties (Ali et al., 2019). An increase in soil depth significantly affected the soil BD, porosity, pH, EC, and CEC values (Table 2), indicating that soil layer depth was the important influencing factor for soil nutrient distribution and diversification. Bulk density typically increased with soil depth from 0 to 100 cm, due to change in soil structure, soil texture, gravel content (Landsberg, 2003), high organic matter, and vegetation

Table 7. Pearson correlations coefficient (r) analysis between the soil SOC, TN, TP stocks, and soil C:N:P ratios under different soil profile layers.

Depth	Component	SOCs	TNs	TPs	C:N	C:P
0-20 cm	TNs	0.95**	1			
	TPs	0.74**	0.79**	1		
	C:N	-0.41*	-0.64**	-0.68**	1	
	C:P	0.50*	0.52**	-0.08	-0.14	1
	N:P	0.54**	0.54**	-0.05	-0.13	0.96**
20-40 cm	TNs	0.56**	1			
	TPs	0.63**	0.22	1		
	C:N	0.22	-0.62**	0.10	1	
	C:P	0.53**	0.44*	-0.29	0.18	1
	N:P	0.20	0.75**	-0.43*	-0.51*	0.73**
40-60 cm	TNs	0.66**	1			
	TPs	0.72**	0.35	1		
	C:N	0.62**	-0.08	0.57**	1	
	C:P	0.75**	0.62**	0.11	0.39	1
	N:P	0.46*	0.84**	-0.10	-0.16	0.79**
60-80 cm	TNs	0.89**	1			
	TPs	0.53**	0.39	1		
	C:N	0.24	-0.20	0.36	1	
	C:P	0.84**	0.81**	0.03	0.04	1
	N:P	0.72**	0.86**	-0.08	-0.32	0.92**
80-100 cm	TNs	0.71**	1			
	TPs	0.71**	0.33	1		
	C:N	0.36	-0.38	0.50*	1	
	C:P	0.78**	0.72**	0.12	0.05	1
	N:P	0.53**	0.86**	-0.09	-0.45*	0.85**

**. Correlation was evaluated at significance level 0.01 ($P < 0.01$). *. The correlation was tested at a significance level of 0.05 ($P \leq 0.05$).

residues down the soil profile (Doerr et al., 2000). In our study, significant improvement in soil physics was observed (the estimated soil porosity inversely related to soil bulk density (Figure 2A) over the whole soil profile from 0 to 100 cm soil depth (Olorunfemi and Fasinmirin, 2012; Vogelmann et al., 2010; Wu et al., 2019). Soil life is directly affected by soil pH and the availability of essential nutrients for plant growth (Olorunfemi et al., 2018). In all soil samples, there was no certain sequence of distribution in their degree of acidity and alkalinity, however, the pH values of soil were under the acceptable limit for maximum utilization of nutrients (Burt, 2009), showing some slight acidification in the surface soil compared with deep soil layer. (Martínez et al., 2016). Some inherent factors affected soil pH such as mineral content, soil texture, and climate. The CEC of all sampled soils (measurement of its ability to hold or bind exchangeable cations) showed a significant change from the top to the deeper soil layer. The high organic carbon and clay content increased the CEC values and showed a strong correlation between soil organic carbon and CEC values which displays that organic carbon is the major source of electrostatic sites (Bayer and Bertol, 1999; Vogelmann et al., 2010). The simple linear regression plots reflected different soil depth increments have a strong association (R^2-values) with the soil physio-chemical variables in the investigated forest land, indicating that the regression predictions were perfectly suitable for predicting the significant relationship of soil profile depth and soil physio-chemical properties (Figures 2A-2D).

4.2. Distribution patterns of SOC and nutrient concentration under different soil layers

In this study, the C contents in the soils significantly decreased with an increase in soil depth over the soil profile (Table 3). The concentration of nitrogen in the soil profile also decreased significantly with soil depth (Bing et al., 2016; Li et al., 2016a). The more C content was observed in the surface soil due to the direct environmental effect on the exposed litter and dead roots over the forest floor turned to more plant nutrients (Deng et al., 2016). The nutrient might also get transported in windblown dust particles when deposit on the surface and reach soil solution, enhancing the concentration of the essential nutrient (TP, TN, TK, and SOC), which in turn improve soil fertility and vegetation growth (Zhang et al., 2006). About 60 to 70% SOC, TN, and TP are stored in the subsoil to deep soil layer (20-100 cm). These percentages were showed close affirmation to the results reported by Batjes (2014) and Jobbágy and Jackson (2000), that more than 50% of the soil organic carbon stored in the subsoil suggests that the subsoil soil layer is very crucial for soil nutrient accumulation assessment. Furthermore, forests have deeper and larger roots system than herbaceous plants which produced more SOC and TN contents in the soil (Laganiere et al., 2010), as well as fine roots, which may contribute to SOC and TN changes in deep soil (Paul et al., 2002). The SOC, N, P, and K concentrations in soil are affected by bulk density, soil pH, and human activities. We further found that the AP and AK decreased as soil depth increased (0-40 cm), but the decreasing trend was non-significant for the deeper soil layers (40-100 cm), possibly due to differences in nutrient infiltration, absorption (Bell et al., 2012; Martínez et al., 2016), variation in the forest surface litters, and residues left and understory vegetation (An et al., 2010). Another reason for low available P could be the fixation on clay particles (Yeshaneh, 2015). Availability of phosphorus is maximum when pH is between 5.5 to 7.5, which is the ideal pH range for optimal nutrients availability (SOC, N, AK) to plant. Moist and warm conditions are suitable while soil pH values between 7.5 to 8.5 and below 5.5 restrict the P-availability to plants due to fixation problems with aluminum, iron, and calcium, which may often associate with soil parent material (Burt, 2009). From the simple linear regression plots it has been concluded that the SOC and nutrient concentration have high values of R^2, which showed strong negative correlations of soil depth with SOC and other nutrient concentration, except for soil TK which exist positive association with soil depth (Figures 3A-3F).

4.3. Effect of soil depth increments on the soil stocks and soil stoichiometry

Our results presented that forest enhanced the SOC, TN stocks (Table 4), and soil stoichiometry whereas non-significant change was found in the case of soil TP stocks (Table 5). Recently it was reported that the sampling depth is an important factor for the measurements of change in SOC (VandenBygaart et al., 2011) and TN stocks (Zhang et al., 2013). The soil TP is mainly influenced by soil parent materials and the biogeochemical process of soil. The parent materials were similar for all vegetation and the rate of soil TP was not obvious like SOC and TN (Cheng et al., 2016; Xu et al., 2019). The study demonstrated that soil depth had a significant negative effect on the SOC and TN stocks (Figures 4A-4B), reflecting that the soil depth was the key factor influencing SOCs and TNs stocks distribution (Gao et al., 2020). In this study, the established forest showed higher SOCs and TNs throughout the soil profile from 0-100 cm depth when compared with the conclusions of (Han et al., 2019).

Stoichiometry not only bring change in the elemental balance in ecological interaction and process but also on a global scale provides nutrient framework linkage to the biogeochemical pattern (Sterner and Elser, 2002). Results of the present study showed that the C:P and N:P ratios of the forest were significantly negatively affected by soil depth (Figures 4E-4F) but no change was observed in C:N ratios (Liu et al., 2017). The same findings were reported by (Deng et al., 2013) in the loess plateau of China that C:N ratios remained unchanged, therefore it is important to conduct further research on C:N ratios to enhance the understanding of soil stoichiometry in forest development (Deng and Shangguan, 2017). Usually, the C:N ratio is negatively associated with the rate of soil organic matter decomposition and a lower C/N ratio led to a quicker mineralization process, and it is often constant (10:1) estimating global soil carbon storage (Stevenson and Cole, 1999). The soil N:P ratio can be used to indicate the P and N saturation and to calculate the threshold nutrient limitation. Limited N:P ratio would affect the rate of soil organic carbon decomposition, quantity, and quality of litters (McGroddy et al., 2004). The evidence from the simple linear regression plots (R^2- values) of soil depth significantly affected the SOCs, TNs stocks, and soil stoichiometry (Figures 4A-4C).

5. Conclusions

This research assessed and characterized changes in soil physio-chemical properties, soil stocks, and soil stoichiometries. Our results revealed that the soil depth increments significantly affected the soil BD, porosity, pH, EC, and CEC values ($p < 0.05$), wherever the soil BD and pH showed a negative correlation with soil depth. The SOC and nutrient concentration were significantly decreased with increasing soil depth increments. The study also found great variation in soil stocks, C, N, and P stoichiometries across the whole soil profile. The key findings of this study include a decline in all SOC and nutrient contents, soil stocks, and soil stoichiometries within each interval of soil depth. The results confirm that the SOC, nutrients contents, soil stocks, and stoichiometry in the 0-60 soil layers accounted for more than 50% in comparison with the whole soil profile. To completely understand the model dynamics of many soil properties and depth-dependent soil processes, soils must be studied more deeply and their association with the environment. Further studies should be conducted to demonstrate the impact of soil depth increment couple withstand characteristics and understory vegetation, the SOC and nutrient contents, soil stocks, and soil stoichiometries in this region.

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