



## Influence of tree species on soil characteristics in subtropical forest ecosystem: a case study in North-West Pakistan

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[Received: Jne 14, 2022 Accepted: November 11, 2022 Published Online: December 03, 2022]

### Abstract

Subtropical forest ecosystem encompasses about 1.7% of the total land area of Pakistan and share in country's forest cover is ~32%. A blend of imperative services is being provided by this ecosystem. Tree species control forest ecosystem and directly influence soil productivity. Soil structure and fertility status are improved by litter fall and humus formation that is greatly dependent on plant species. Present study investigated the role of dominant tree species in improving soil profile concerning subtropical forest ecosystem. The study area was district Lower Dir in North-West Pakistan. Five sites were selected for composite soil sampling to take in three forest cover types i.e. chir pine, blue pine and mixed forests. The collected soil samples were analyzed for physical and chemical characteristics using conventional methods. Soil pH, phosphorus and potassium showed significant influence of forest cover type. Organic matter and nitrogen present in soil showed meaningful relation. However, soil EC and BD results appeared to have low influence of vegetation. Generally, vegetation enhances organic matter in soil due to plant decay and litter fall but non-significant difference was observed for forest cover type.

**Keywords:** Conifers; soil-plant interaction; forest soil; soil-vegetation interaction; pines

### Introduction

Tree species drive forest ecosystem and influence its biotic and abiotic components. Soil under different ecosystems possesses dissimilar characteristics based on the vegetation type. In forest ecosystem, soil structure and fertility status are influenced by litter fall and humus formation which is greatly dependent on plant species (Filipov *et al.*, 2008). The vegetation helps converting larger soil particles into smaller, improving soil structure, increasing soil depth and elevating soil organic matter (Chapman and Reiss, 1992). Tree species composition regulates the biological, physical and chemical characteristics and processes occurring in the soil. For example, the rates of organic matter mineralization and nitrification depend on the type of vegetation (Augusto *et al.*, 2002). The vegetation has positive impact on soil characteristics as the planted soils showed high clay and silt content than the uncovered soil (Dutta and Agrawal, 2002). Trees increase soil water holding capacity and water content was observed to be higher under the forest cover than in the

area without forests (Joffre and Rambal, 1988). Trees also increase nitrogen and organic carbon in the soil and reduce soil erosion. Some tree species enhance soil fertility and decomposition by supporting relevant flora and fauna i.e. fungi and bacteria (Wardle, 2006). Moreover, soil defines the species abundance and their traits (Schimel *et al.*, 1994). The growth of plant roots is directly influenced by soil structure and texture (Angers and Caron, 1998). In consequence, organic matter and structure of soil are improved due to the root secretions and productions of debris (Brady and Weil, 2008). Litter decomposition is a fundamental ecosystem process that upholds ecosystem productivity.

Tree species contribute to the soil carbon cycle by adding biomass and dead organic matter to it. Biogeochemical cycles in the forest ecosystems are closely associated with the transformation of the litter by soil organisms as well as the intake of above and belowground litter input. Although the overall litter fall does not change substantially between tree species but the deciduous tree's litter decomposition rates are considerably greater than coniferous trees. The difference in the litter calcium and litter lignin along with plant secondary

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**Cite This Paper:** Khan, K.A., S. Khan, M. Ahtasham, S.U. Malik, M. Saleem and M.I. Ashraf. 2022. Influence of tree species on soil characteristics in subtropical forest ecosystem: a case study in North-West Pakistan. *Soil Environ.* 41(1): 135-141.

metabolites such as terpenes and tannins always effects the microbial decomposition and the activities of earthworm in the soil. In context of growing importance of agroforestry, trees at various ages show different effects on soil as well as crop growth. Tree diameter, height and crown size affect yield of agriculture crops by interrupting sunlight availability (Bargali *et al.*, 2009). The ecosystem revival should be assessed to establish appropriate tree species and silviculture system for ecosystem sustainability. However, other factors like contamination, climate, geology and natural disasters strongly influence the tree species. Therefore, tree species along with other influencing factors such as topography and water flow should be a concern during forest management and planning (Khan *et al.*, 2019).

Generally, forest soils contain higher amount of organic matter than other soils such as mineral soil. A thicker litter layer, low carbon and organic matter content was observed in the coniferous forest, as compared to broadleaved forest that is composed of thinner litter layer, higher pH, and carbon content. Mineral and nutrients (e.g. carbon, nitrogen and phosphorus) recycling is faster through the residue of broadleaved tree species than in coniferous tree species. In coniferous forests, nitrification and ammonification rate is slow as compared to broadleaved forest.

The characteristics of forest soils are significantly different in terms of chemical, biological and physical, properties from other soils and land-uses i.e. agricultural. The distinctive feature of forest soil is the presence of well-developed forest floor with organic matter and litter layer, deep root system of trees, well-known microbial activities. Canopy of trees also provide shade to the forest soil and aids in maintaining the temperature and moisture conditions. Most forests of Pakistan are in northern hilly areas of the country whereas most of the country's commercial activities are conducted in the plain areas. Although forests have minor role in Pakistan's economy but the economic activities in plain areas can be affected by any natural disturbance in the forest ecosystems dominated by sub-tropical and temperate forests.

The influence of litter type and decomposition rate was not consistently studied in subtropical forest ecosystem of Pakistan. This is imperative to study the trees impacts on soil for better ecosystem management. Present study explored the influence of dominant trees species on soil features in subtropical forest ecosystem. The core objective of this study was to investigate the impacts of forest cover types i.e. chir pine (*Pinus roxburghii*), blue pine (*Pinus wallichiana*) and mixed forest on the soil characteristics.

## Material and Methods

### Study area

District Lower Dir, situated at 34° 37' to 35° 21' N and 7° 30' to 72° 21' E in North-West Pakistan was selected for this study. It is positioned in Khyber Pakhtunkhwa, which is the most forested province of Pakistan (Ali *et al.*, 2020a). Lower Dir is enclosed by mountains and about 70% of the ground comprised of rough topography, steep slopes, uneven sloppy landscapes and rolling gradient, which are linked to the Hindukush ranges. Local climatic data indicated July as the hottest month with temperature range of 15.67-32.52°C, whereas temperature in January and February is extremely cold and is generally below freezing point. The average maximum and minimum temperatures are 11.22°C and 2.39°C, respectively. From mid-November to March there is an extremely cold winter. The study area receives the highest rainfall in March (~242.22 mm) and the lowest in July, October and November. During the months of January, February, August and December relative humidity remains high (Wahab *et al.*, 2008). Shagai, Benschahi and Laram are the famous tops of the area having height of 7000-8000 feet. District Lower Dir is a transition zone of subtropical pine and moist temperate forests. Phulai (*Acacia modesta*), Diar (*Cedrus deodara*), Bakain (*Melia azedarach*), Mulberry (*Morus alba*), Chir (*Pinus roxburghii*), Kahu (*Olea ferruginea*), Kail (*Pinus walliichiana*), Chinar (*Platanus orientalis*), Ber (*Ziziphus mauritiana*), Oak (*Quercus incana*), Poplar (*Populus*), Ailanthus (*Ailanthus altissima*), Sufaida (*Eucalyptus camaldulensis*) and Robinia (*Robinia pseudoacacia*) are the dominating tree species of the region.

### Methods

The primary purpose of this investigation was to examine the impact of leading tree species of Lower Dir forests on the underneath land and to study the association among chir pine (*Pinus roxburghii*), blue pine (*Pinus wallichiana*) and mixed forest cover effects on soil. To determine the impact of tree species on soil, physical and chemical characteristics such as pH, bulk density (BD), soil organic carbon (SOC), electrical conductivity (EC), soil phosphorus, soil nitrogen and soil potassium was estimated by selecting sites and collecting soil samples.

In the study area, five sites were selected for soil sampling. These sites were randomly selected keeping in view that the selected forest types could acquire equal part in soil sampling. These selected sites included two from Toormang and one site from each Malay, Laram, and



Luqman-Banda; individually site were further categorized into three, based on forest cover type i.e. blue pine forest, chir pine forest, and mixed forest. In total, 45 composite samples were collected taking into consideration three replications.

Composite sampling method was employed for the collection of soil samples. For the true demonstration of total soil of the plot, this method was preferred. Seven soil samples were collected from different locations of the plot and mixed with each other. Soil samples from three depths of 0-15, 15-30 and 30-45 cm were assembled. These samples were carried to the laboratory, desiccated and grounded in mortar media, passed via two mm stainless steel sieve and stored in plastic bottle. The analysis of these samples was carried out in Soil and Water Testing Lab Rawalpindi.

The collected soil samples were analyzed for BD, pH, phosphorus (P), potassium (K) and SOC using conventional methods described in Page *et al.* (1982). The SOC was estimated using Loss on Ignition (LOI) method. The destruction of organic matter and structural water losses from clay minerals resulted in weight loss of material at temperature above 400°C (Hoogsteen *et al.*, 2018). Soil EC is the measure of salts present in the soil that influences many biochemical processes. Soil microbial activities and nutrients

availability to plants are directly influenced by EC. The values of soil EC were determined by EC probe. This probe was immersed in the standard solution (1.41 dS m<sup>-1</sup> at 25 °C). After 10 seconds of stabilization reading was recorded (Adviento *et al.*, 2006). Acidity or alkalinity of the soil was examined by pH meter. Before getting actual readings, pH meter was standardized with the buffer solution of known pH. Phosphorous is an essential plant nutrient and its amount usually ranges between 0.1-3 g Kg<sup>-1</sup> in soils. The primary source of P is the underlying parent material while plant remains are the secondary sources. In forest ecosystem, phosphorus is usually low in the soils. Accessibility of P to the vegetation is influenced by soil-plant bonding. Soil P was measured using Olsen method. Potassium is critical for optimal tree growth. It has a significant role in plant physiological reactions such as production of enzymes, protein synthesis, sugar transport, metabolism, and photosynthesis. Soil K was approximated by flame photometer.

The collected data was analyzed to check the statistical significance of the BD, pH, EC, SOC, P, K and different species' impacts on soil using two-way ANOVA (analysis of variance) with repetition. Two-way ANOVA was used because this study compared the effect of different forest

**Table 1: Average bulk density of soil by forest cover type at three depths**

Cover type	Bulk density (g cm <sup>-3</sup> )			Mean	
	0-15	15-30	30-45		
Soil depth (cm)					
Blue pine forest	1.138	1.238	1.188	1.188	
Chir pine forest	1.076	1.177	1.127	1.127	
Mixed forest	1.240	1.452	1.346	1.346	
Mean	1.151	1.289	1.220		
<b>ANOVA*</b>					
Sources of variation	SS	df	MS	F	p value
Soil depth	0.144	2	0.07	1.7	0.19
Forest cover	0.197	2	0.09	2.36	0.10

\*Level of significance: 95%

**Table 2: Average pH values of soil by forest cover type at three depths**

Cover type	pH			Mean	
	0-15	15-30	30-45		
Soil depth (cm)					
Blue pine forest	6.419	6.292	6.384	6.365	
Chir pine forest	6.370	6.498	6.501	6.456	
Mixed forest	6.860	6.680	7.101	6.880	
Mean	6.550	6.490	6.662		
<b>ANOVA*</b>					
Sources of variation	SS	df	MS	F	p value
Soil depth	0.227	2	0.113	0.531	0.592
Forest covers	2.267	2	1.134	5.302	0.009

\*Level of significance: 95%



cover factors on soil having numerous observations of each factor. The sites represented replications while soil attributes were taken as treatment. All tests were applied at 95 % significance level ( $\alpha=0.05$ ).

## Results and Discussion

The results for soil physical and chemical characteristics investigated in this study along with statistical analysis are described here.

### Soil bulk density (BD)

The results of soil analysis for BD are shown in Table 1. The highest BD (1.188) was observed for blue pine forest at 30-45 cm depth while the lowest BD was (1.076) at 0-15 cm depth. Generally, the highest BD was noticed for mixed forest cover followed by blue pine and chir pine forests. In general, soil BD was higher at the depth of 15-30 cm while lower at 0-15 and 30-45 cm depths. Statistical analysis (ANOVA) showed non-significant difference in soil BD ( $p=0.11$  and  $0.20$ ) under all types of forest cover and soil depths, respectively.

Almost similar types of findings were reported by Dutta and Agrawal (2002). They studied five plant species and reported the highest BD for angiosperm species i.e. *Casuarina equisetifolia*. The impacts of tree species on soil physical properties were studied by Parthiban and Rai (1994) in Tamil Nadu, India. They reported that the highest BD was found in soil under *Bambusa bambos*. Han *et al.* (2021) reported the lowest soil BD under coniferous species. There were no concrete findings about the impact of species on soil physical properties, this might be due to impact of other factors such as movement of heavy machinery on the soil.

### Soil pH

The results for pH analysis are presented in Table 2. The values below 7 indicate acidic soil while greater than 7 means alkaline soil. On average, all forest conditions investigated in this study showed slightly acidic conditions. The lowest pH value was 6.292 for blue pine forest at 15-30 cm depth whereas the highest pH value was 7.101 for mix forest at 30-45 cm depth. Statistical analysis (ANOVA) indicated significant difference ( $p$  value: 0.009) in soil pH among forest cover type whereas non-significant difference ( $p$  value: 0.592) among soil depth. Generally, slightly acidic soils are considered good due to optimum nutrients availability to plants.

Soil pH under *Acacia species* was reported to be ranged from 3.55 to 5.5 while under Eucalyptus trees it was close to

6 in an investigation conducted in Australia (Leonard and Field, 2003). In mixed forests, soil acidity was decreased because of broad-leaved species such as *Quercus incana* and other bushy flora. The finding of this investigation agreed with Vanguelova *et al.* (2005). They stated that litter of conifer forests has high acidifying power compared to most broadleaved tree species. However, acidity of soil is also associated with other soil activities and fluxes like carbon and nitrogen cycles and pools.

### Soil electrical conductivity (EC)

The results of soil analysis for EC are shown in Table 3. Generally, EC values were slightly higher (0.698) for mixed forest whereas lower (0.660) for soils covered by blue pine forests. Further, mean lowest EC value (0.623) was observed for 0-15 cm soil depth and the highest (0.723) for 15-30 cm on average. Statistical analysis indicated non-significant difference for EC among soil depths and forest cover.

Above 30 cm depth, soil EC was observed  $0.958 \text{ dS m}^{-1}$  and  $0.654 \text{ dS m}^{-1}$  in chir pine forest and mixed forest cover respectively.. This was lower in blue pine forests ( $0.472 \text{ dS m}^{-1}$ ). Blue pine soil EC decreased while under chir pine forest increased toward depth and soil EC for mixed forest cover had the same value.

### Soil organic matter (SOM)

The highest percentage (2.119) of SOM was found under mixed forest cover whereas the lowest (1.598) was under chir pine forest (Table 4). The soil under chir pine forests had the lowest organic matter as compared to the rest. Generally, SOM decreased with the increase in soil depth. Statistical analysis indicated non-significant difference for SOM among soil depths and forest covers.

Our findings are in agreement with the results of Augusto *et al.* (2002) who reported that the influence of tree species on soil richness differed based on the kind of bedrock, climate and silviculture regime. Ali *et al.* (2020b) also reported lower SOM in chir pine forests compared to other forest types in Khyber Pakhtunkhwa, Pakistan.

### Soil phosphorus (P)

Table 5 shows results for soil P analysis under different forest covers. The highest amount of P (4.882) was found in soil under mixed forest whereas the lowest (2.605) was in soil under chir pine forests. On average, the lowest soil P was at medium depth (15-30cm). Statistical analysis indicated significant difference for soil P among forest cover with a  $p$



**Table 3: Average values of soil electrical conductivity (EC) by forest cover type at three depths**

Cover type	EC ( ds m <sup>-1</sup> )			Mean	
	0-15	15-30	30-45		
Soil depth ( cm)	0-15	15-30	30-45	Mean	
Blue pine forest	0.732	0.776	0.472	0.660	
Chir pine forest	0.426	0.662	0.958	0.682	
Mixed forest	0.710	0.730	0.654	0.698	
Mean	0.623	0.723	0.695		
<b>ANOVA*</b>					
Source of variation	SS	df	MS	F	p value
Soil depth	0.079	2	0.039	0.221	0.802
Forest cover	0.010	2	0.005	0.030	0.970

\*Level of significance: 95%

**Table 4: Average values of soil organic matter by forest cover type at three depths**

Cover type	Soil Organic Matter (%)			Mean	
	0-15	15-30	30-45		
Soil depth (cm)	0-15	15-30	30-45	Mean	
Blue pine forest	2.484	1.929	1.832	2.082	
Chir pine forest	1.497	1.617	1.679	1.598	
Mixed forest	2.583	2.172	1.603	2.119	
Mean	2.188	1.906	1.705		
<b>ANOVA*</b>					
Source of Variation	SS	df	MS	F	p value
Soil depth	0.597	2	0.298	1.641	0.207
Forest covers	0.859	2	0.429	2.363	0.108

\*Level of significance: 95%

**Table 5: Average values of soil Phosphorus by forest cover type at three depths**

Cover type	Soil Phosphorus (mg kg <sup>-1</sup> )			Mean	
	0-15	15-30	30-45		
Soil depth (cm)	0-15	15-30	30-45	Mean	
Blue pine forest	4.466	2.082	3.776	3.441	
Chir pine forest	2.024	2.146	3.646	2.605	
Mixed forest	5.660	4.144	4.842	4.882	
Mean	4.050	2.791	4.088		
<b>ANOVA*</b>					
Source of variation	SS	df	MS	F	p value
Soil depth	17.211	2	8.605	1.891	0.166
Forest covers	39.429	2	19.714	4.331	0.021

\*Level of significance: 95%

value of 0.021. There was a non-significant difference among soil depths for phosphorous availability.

This existing study extends the exploration of Sabo and Ghani (2007) on influence of *Acacia* species on underneath soil fertility status in Galambi Forest Reserve Bauchi, Nigeria. Soil analysis showed that the concentration of calcium, potassium, nitrogen, phosphorous, organic matter, sodium and cation exchange capacity were significantly higher under the tree cover compared to open areas.

### Soil potassium (K)

The results of soil analysis for K are presented in Table 6. On average, the highest value of K (94.667) was found in soil under mixed forest cover whereas the lowest was 76.333 in soil under blue pine forest. Generally, the amount of K increased with the increase in soil depth. Statistical analysis indicated significant difference for soil K among forest cover with a *p* value of 0.050. There was a non-significant difference among soil depths for K availability.



## Soil nitrogen (N)

Table 7 shows the results for N analysis in soil under

organic matter showed meaningful relation. However, soil EC and BD results showed little influence of vegetation.

**Table 6: Average values of soil potassium by forest cover type at three depths**

Cover type	Soil potassium (mg kg <sup>-1</sup> )				
	0-15	15-30	30-45	Mean	
Soil depth (cm)					
Blue pine forest	75	90	64	76.333	
Chir pine forest	90	78	86	84.667	
Mixed forest	80	86	118	94.667	
Mean	81.667	84.667	89.333		
ANOVA*					
Source of variation	SS	df	MS	F	p value
Soil depth	1097.778	2	548.888	0.933	0.402
Forest covers	3751.111	2	1875.556	3.190	0.050

\*Level of significance: 95%

**Table 7: Average values of soil Nitrogen by forest cover type at three depths**

Cover type	Soil Nitrogen (%)				
	0-15	15-30	30-45	Mean	
Soil depth (cm)					
Blue pine forest	0.124	0.091	0.137	0.117	
Chir pine	0.108	0.096	0.112	0.105	
Mixed forest	0.087	0.094	0.093	0.091	
Mean	0.106	0.094	0.114		
ANOVA*					
Source of variation	SS	df	MS	F	p value
Soil depth	0.005	2	0	1.412	0.257
Forest covers	0.003	2	0	0.863	0.430

\*Level of significance: 95%

different forest cover. The highest value of soil nitrogen was found in soil under blue pine forest whereas the lowest was in soil under mixed forests. There was no trend found with the change in soil depth. Statistical analysis indicated non-significant difference for Soil among soil depths and forest covers.

Our results are consistent with the findings of Hagen *et al.* (2004) who reported non-significant difference for soil nitrogen under different tree species. On the other hand, our results do not agree with the conclusions of Vesterdal *et al.*, (2008) because they found significant difference in soil N under different tree species in Denmark.

## Conclusions

Tree species manipulate forest ecosystem and influence other system mechanisms. Dominant tree species modify soil characteristics and processes. It was concluded that tree species influence soil in a diverse manner. The analysis for chemical and physical, characteristics of soil indicated the control of trees in forest ecosystem. Soil pH, P and K showed significant influence based on forest cover type. Soil N and

Generally, vegetation enhances SOM in soil due to plant decay and litter fall but non-significant difference was observed based on forest cover type. The resilience of the ecosystems should be estimated to determinate the most appropriate tree species and silvicultural management. Further, the tree species are strongly influenced by other factors such as climate and physiography. Therefore, the tree species should not be the only matter of concern during the forest management and planning. More investigations are required to better understand the influence of tree species on forest ecosystem in general and on soil fertility in specific.

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