# Characterization of the Effect of Four Leguminous Tree Species on soil fertility under Agroforestry in the Arid Environment of District Bahawalpur, Pakistan

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***Abstract-*** A three-year field study was conducted to evaluate the effect of four leguminous tree species (*Albizzia lebbek*, *Dalbergia sissoo*, *Prosopis cineraria* and *Vachellia nilotica*) on soil physiochemical properties for soil fertility. The investigation was carried out utilizing a randomized complete block design, with four replicates per tree species. Results revealed significant differences between species and soil depth having profound effect on all soil properties analyzed. Interaction between species and soil depth was significant for pH and the interaction between species and soil depth was only significant for OC. Maximum soil pH was observed from 0-30 cm soil depths in all trees species. The highest soil pH 8.26 and soil moisture 19.72% was found in *D. sissoo*. At 0-15cm, maximum saturation percentage 36.77% was found in *D. sissoo.* EC content of the soils ranged from 2.31 $mScm^{-1}$ in *V. nilotica* at 15-30cm depth to 0.52 $mScm^{-1}$ in *P. cineraria* at the depth of 45-60cm. Maximum SOM was found at the depth of 0-15cm (0.61%) while minimum was observed at the depth of 45-60cm (0.35%) in *D. sissoo*. Under *V. nilotica* canopy at the 0-30cm (0.56%), 30-60cm (0.43%) the soil organic matter did not differ significantly. Highest soil organic carbon percentage was in *V. nilotica* (0.35%). The soil bulk density ranged from 1.09 to 1.37 $g/cm^3$. At soil depths 0- 15 and 15-30cm in *D. sissoo* were sandy loam, whereas, in all other species at all soil depth it was loam. The soil structure was good to moderate in all cases under all species. The sand fraction was lowest under three species except *P. cineraria* (68.02%). Nitrogen was maximum found under the canopy of *V. nilotica* (11.1mg/kg) at the depth of 15-30cm. It was 9.1mg/kg under the canopy of *D. sissoo* at the depth of 15-30 cm. Available potassium was highest in 0-30cm in *A. lebbek* (109mg/kg). The study highlights importance of considering these tree species and soil depth when evaluating soil properties for soil fertility. The study provides valuable insights into the impact of leguminous tree species on soil health and fertility, which can inform future forestry and agricultural practices.

**Key words:** Agroforestry, Arid, Soil fertility, , Physiochemical, Nitrogen Fixing

## I. Introduction

Arid environment is defined by its declined soil fertility, extremely low and erratic precipitation, frequent water scarcity periods, and elevated temperatures that impede plant productivity [1,2]. In arid and semi-arid environment, plant productivity is reduced due to slow down in photosynthesis caused by the specific edaphic and climatic conditions [3]. Soil damage has occurred as a result of the removal of trees due to numerous misconceptions. Soils experience erosion from both wind and water, which leads to a loss in crop output [4,5]. Crop productivity in Pakistan is dependent on precipitation, canal water, and groundwater. The soils exhibit a composition of sand and clay, characterized by a relatively low presence of organic matter [6]. Several scholars have proposed methods to enhance soil fertility, hence improving economic situation of farming communities. In this context, soil is enriched via the use of mulching, crop residues, litter, and household wastes. The practice of using farmyard manures, crop rotation, and intercropping is widely employed in improving soil fertility [7].

Several limitations exist when utilizing chemical fertilizers for increased crop production [7,8]. Still, there is limited knowledge regarding effect of various trees species on improving soil fertility. This lack of knowledge hinders the widespread acceptance of integrating tree crops into farming techniques. Integrating native tree species is another sustainable method to improve and sustain soil fertility. The process of decomposing fallen leaves and litter enhances the organic matter content in the soil, hence improving its fertility [8]. The presence of indigenous nitrogen-fixing tree species with elevated photosynthetic rates and improved nutrient utilization efficiency leads to higher biomass productivity [9]. Majority of rural inhabitants are impoverished agricultural workers; therefore, the incorporation of tree species does not necessitate any specific aid. Traditionally, tree species are employed in conjunction with crops to shield them from adverse weather conditions. The surrounding fields are populated by shrubs and trees, which are part of the indigenous flora.

Soils beneath the woody vegetation canopy exhibit higher fertility compared to the open areas [4]. Earlier researches by many researchers have revealed the significance of preserving woody vegetation for soil fertility [10-12]. In a study by [9] concluded that native leguminous woody plants, characterised by a faster photosynthetic rate and improved nutrient use efficiency, exhibited remarkable growth and productivity. Agroforestry exerts beneficial effect on physicochemical qualities of soil, resulting an increase in crop productivity and farmer's income. Additionally, it aids in preservation of land and water resources to enhance ecosystem quality [13]. Trees and shrubs promote the buildup of nutrients and improves soil fertility. Presence of thick vegetation aids in decreasing the speed of wind and rainfall, so safeguarding the soil from erosion [4].Woody vegetation has a crucial role in ensuring food security and reducing poverty, while also providing a range of advantages [8,14-16]. Farmers deliberately choose different types of woody species for their farms relying upon diverse economic, cultural, and environmental roles. They also make efforts to preserve the diversity of these species [15].

Agroforestry can serve as a viable approach to address the ecological issue and simultaneously maintain crop production [17,18] . This system combines the growth of trees with the cultivation of crops and or the production of animals on the same land, either by arranging them in a specific spatial pattern or by following a specific temporal sequence [19]. Agroforestry, via effective integration of trees, can contribute to the conservation of natural ecosystems by implementing sustainable land management practices, such as reforestation, and maximizing the use of resources. Furthermore, agroforestry has the ability to alleviate climate change by implementing several methods that enhance carbon absorption, resulting in a reduction of greenhouse gas (GHG) emissions [20]. Additionally, the system has the ability to enhance biodiversity by integrating diverse species of plants/crops, which can serve as habitats for various wild fauna [21] . In addition to its favorable environmental effects, numerous studies have also emphasized the socio-economic advantages of agroforestry for rural populations. Introducing a varied agro-ecosystem that incorporates both trees (for timber and fruits) and livestock could offer the community different sources of income, hence fostering economic resilience [22]. Moreover, the system has the potential to enhance household food security by providing a wider range of food sources [23]. Therefore, agroforestry has the potential to address the current socio-economic challenges.

The interaction between trees and soil encompass biological mechanisms that facilitate the alteration in biological and physical properties as well as fertility of soil. The soil macrofauna, specifically, has demonstrated its sensitivity as an indicator of changes in vegetation cover [24,25]. Furthermore, it has substantial effect on breakdown and on nutrients cycling [26,27]. These factors encompass a greater concentration of soil nutrients [28], and development of seedlings and agricultural plants beneath their canopy [29]. Arrangement and characteristics of plants within cropping possess major impact on soil biological properties [30,31]. Number and richness of soil macrofauna can be influenced by the specific trophic and microclimatic circumstances surrounding the plants [32]. The presence of dispersed trees enhance soil fertility [33]. However, the extent of this improvement is contingent upon the specific tree species and their functional traits [34]. Additionally, the arrangement and spatial distribution of the trees, and the management practices employed, also influence their impact on physical and chemical properties of soil [35,36].

*Albizia lebbek* is a versatile legume tree that sheds its leaves annually and is of moderate size. It serves as a valuable resource for both fuel and timber. It is commonly utilized as shelter belts and shade trees [37,38]. *Dalbergia sissoo* (Sheesham or Tali) is of medium to large size versatile tree and provides timber, fuel, fodder, and is also utilized for medicinal purposes traditionally. Agroforestry allows for its cultivation without the need for irrigation, while watering is necessary during the initial summer season [39]. *Prosopis cineraria* (Jand or Jandi) is a very good fodder tree for arid areas. The tree can be looped and the firewood and timber can also be used for household purposes. If it is cut at the ground level, it coppices profusely, giving rise to multiple coppice shoots [40]. *Vachellia nilotica* (Kikar) is a multifunctional tree, offering multiple resources services. It is a valuable source of animal feed, and can be particularly significant in arid areas [38]. The integration of diverse tree species into farming systems in arid and semi-arid regions is a sustainable approach to improving soil fertility, agricultural productivity, and community livelihoods.

## II. Materials and methods

Climate of district Bahawalpur is arid to semi-arid. Vegetation cover is low because of higher temperature and lower humidity along with erratic precipitation. The district is among the one of the hottest regions of Pakistan. Soils in District Bahawalpur comprises of sandy, loamy and clayey in nature [41].

**Experiment design**

The investigation was carried out utilizing a comprehensive randomized block design, with four replicates per tree species. Data collection was conducted in a random sample of twenty rural union councils from each tehsil. Soil sampling was conducted beneath the canopy cover along transects aligned with the cardinal points. Sampling was conducted at four distinct soil depths ranging from 0-60 cm along four transects over the study period of 2021-2023. A composite sample was created by blending the four cores obtained from each of the four cardinal transects. The collection of samples involved the utilization of a soil auger and a sampling shovel, as stated by [42] . 20 soil samples were taken around the trees from each tehsil. Immediately after collection, moist samples were divided in two parts. Simultaneously, 100g fresh moist samples were taken separately in moisture box for the determination of moisture content. Remaining portion of soil sample was packed in separate polythene bags, brought to the laboratory, and processed for analyzing physical and chemical attributes.

**Physical and chemical properties of soil**

Subsequent soil physico-chemical parameters were determined as described by [43].

**Soil Structure and texture**

It was measured by using methodology as described by [44] . Different size sieves were used for measuring soil texture. Hydrometer method was used for particle size analysis.

**%Clay in soil:**

%Clay in Soil (w/w) = (Rc - Rb)×100/(Oven Dry Soil (g))

**% Silt in soil:**

%Silt (w/w) = [%Silt + Clay (w/w)]-[%Clay (w/w)]

**% Sand in soil:**

%Sand (w/w) = Sand weight×100/(oven-dry soil(g))

**Soil reaction (pH)**

Soil pH was measured by a digital pH meter.

**Soil Electrical Conductivity (EC)**

EC meter was used to measure EC in a saturated paste extract.

**Bulk density**

Core method was used for the determination of bulk density in soil [45]. Bulk density (ρb) was determined as:-

ρb (Mg $m^{-3}$) =(Oven Dry Weight of the Soil (g))/(Bulk Volume of the soil sample(cm3))

**Organic Matter Percentage (OM)**

The percent soil organic matter (SOM) was calculated by multiplying the percent organic carbon by a factor of 1.724 [46]. OM is determined through the equation:-

%Organic Matter (w/w) =1.724×%Total Organic Carbon

**Soil organic carbon (SOC)**

Soil carbon, was measured by using the formula:-

$SOC = \rho b \times D \times \%C$

Whereas: SOC = Soil Organic Carbon Stock, ρb = Soil Bulk Density, D= the total depth at which the sample was taken. % C = Carbon concentration (%) amounting to 0.47 of biomass or taken from lab measurements [47,48]

**Soil Moisture**

Soil moisture was calculated by the Gravimetric method:- %Moisture in Soil (ϴ) = (Wet Soil (g)-Dry Soil (g))/(Dry Soil (g))×100

**Saturation percentage**

Saturation percentage was determined as:-

SP= (Loss in weight after oven drying (g))/(Total weight of soil after oven dry weight (g))×100

**Nutrient availability in the soil for plant growth**

Available nutrients were determined by the methodology described by [49]. The amount of nitrogen in the soil, primarily in organic form, was determined through wet digestion using the widely recognized Kjeldahl process.

For Total Available Phosphorus in Soil: Total Available P(ppm)= P (ppm)×A/Wt×50/V

Where: A= Total volume of the digest (mL), Wt= Weight of the air-dry soil (g), V= Volume of digest used for measurement (mL)

Soluble Potassium is the measure of the amount of K extracted from the soil by water.

Soluble K(ppm)=ppm K K (from calibration curve)×A/Wt

**Statistical analysis**

*Statistix* 8.1 was used for statistical analysis. The data was analyzed by using Complete Randomized Block Design (RCBD) using two-way analysis of variance (ANOVA).

## RESULTS AND DISCUSSION

**Analysis of effect of four leguminous trees species on soil**

A significant difference in soil physical and chemical properties have been reported by [50]. Long-term agricultural practices and land-use changes decrease in organic matter, organic carbon, total nitrogen and available potassium contents [51]. Same results are also reported by [52] while study agricultural soils in comparison with forest soils. [53] states that trees affect the chemical conditions of the soil, because of decomposing above and below ground biomass. A study by [54] discovered that physicochemical properties such as soil pH and organic carbon were significantly influenced by different land-use systems. [33] showed higher levels of SOC, N, P, K, and Ca under the tree cover. The vertical bars on figures show standard deviation and different letters indicate significant differences ($p<0.05$) between species.

1. **Soil texture and Structure**

At soil depths like 0- 15 and 15-30cm in *D. sissoo* were sandy loam and 30-45cm to 45-60cm, the soil texture was found as loam. Whereas, in all other species at all soil depth it was loam. The soil structure was good to moderate in all cases under all species. The sand fraction was lowest under three species (*D. sissoo*, *v. nilotica* and *A. lebbek*) and highest under *P. cineraria* (68.02%). The clay fractions, on the other hand, were did not significantly differ under four tree species at varying depths (13.5%). While silt contents showed fluctuations across the trees species but remain non-significant for soil depth.

2. **Soil pH**

A slight decline in soil pH was observed in response to increasing soil depths (Figure1). Our results are in line with the earlier study [42] stating that pH varied significantly between soil depth classes; where pH was higher near the surface than deeper depths. Soil acidity (lower soil pH) limits crops productivity. Higher soil pH as observed under tree canopies would have an effect on nutrient supply especially available phosphorus which is usually limiting in Pakistani soils. Thus trees helps in nutrient supply to plants through alkaline soils by increasing soil pH and ultimately enhancing soil fertility. These outcomes are supported by [55].

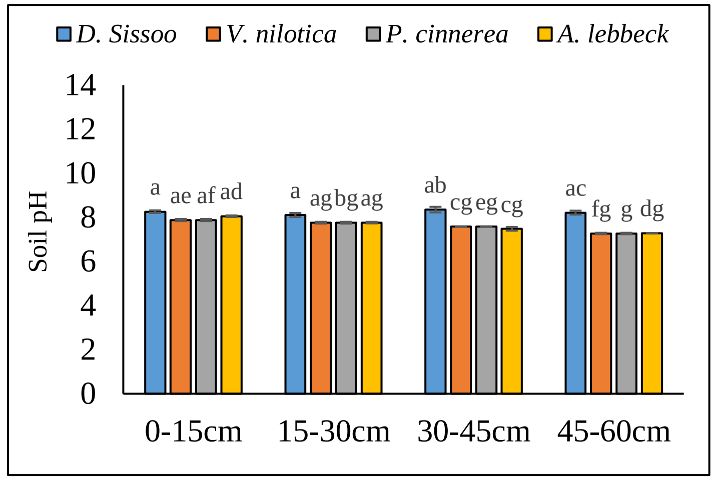


Figure1. Soil pH at varying levels of soil depths among tree species

3. **Soil Electrical Conductivity (EC)**

The EC content of the soils showed a gradual decrease in response to increasing soil depths (Figure2). It is clear that a significant decrease in electrical conductivity was recorded with an increase in soil depths. A decrease in electrical conductivity in response to increasing soil depth have been reported by [56].

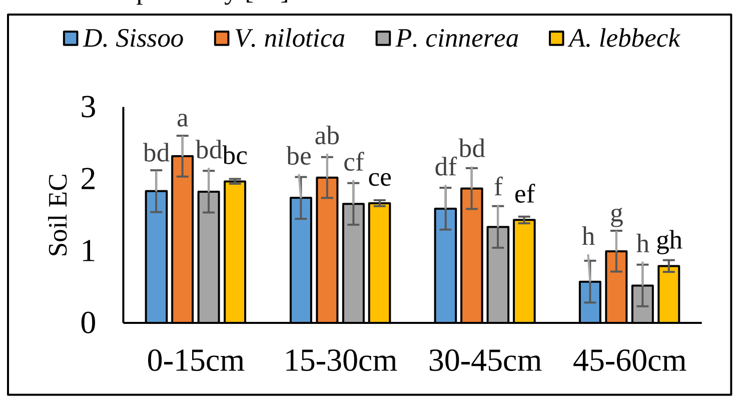


Figure2. Soil EC at varying levels of soil depth among tree species

4. **Soil Bulk density**

The soil bulk density ranged from 1.09 $g/cm^3$ to 1.37 $g/cm^3$ (figure 3). These results indicated that soils are normal under the crown of trees and lower compaction helps in easier root penetration in the soil. The high values of soil bulk density observed under silvopastoral system [57]. This increase in soil bulk density was related to high values in soil resistance to penetration under its crown. Comparing our results with [58] and [59]. Likewise, [60] found that crown cover by any tree species they evaluated in their research significantly reduced the bulk density of the soil surface (16 to 22%).

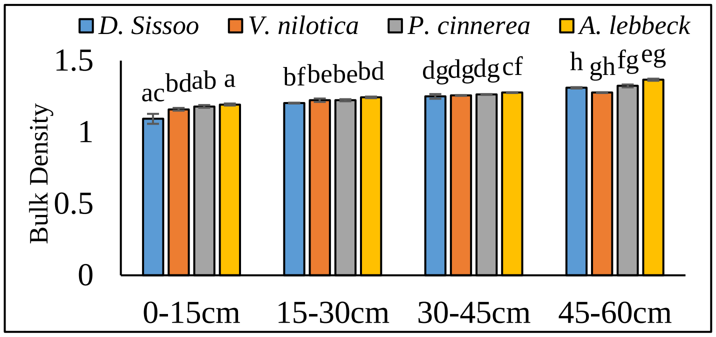


Figure3. BD at varying levels of soil depths among tree species

5. **Soil Organic Matter (SOM)**

The results of soil organic matter percentage shows that soil organic matter percentage declines with increasing soil depths ((figure 4).). our results concurred with earlier studies by [48] stating maximum soil organic matter is found in 0-30cm and [42] stating organic matter is concentrated near the soil surface because of presence of decomposing leaf and litter under the canopy of trees. Similar findings have also been reported by [61]. In another study by [62] showed the microbial and soil organic matter concentration more in shallow than deeper soil profile.

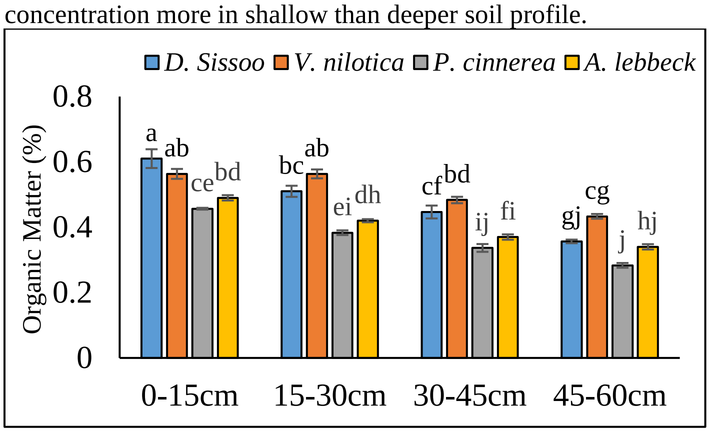


Figure4.SOM (%) at varying levels of soil depths among tree species

6. **Soil Organic Carbon (SOC)**

There was significant difference for soil organic carbon for the four species under varying soil depths (figure 5). It was observed that with increasing soil depth, soil organic matter and soil organic carbon decreased. A reduction in soil organic carbon with increasing soil depths have been reported by [63-65]. The maximum percentage of soil organic carbon in the upper layers of soils is due to presence of decomposing leaf and litter. These investigations are in line with [66].

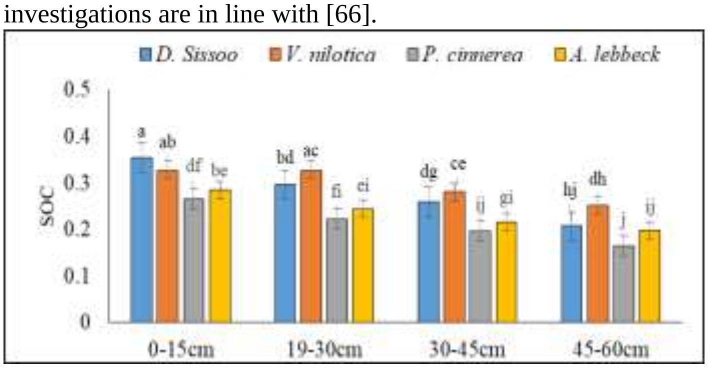


Figure5 SOC at varying levels of soil depths among tree species

7. **Soil Moisture (%)**

Soil moisture percentage showed a gradual increase in response to increasing soil depths (Figure6). Trees roots are able to go in to deep soil profile for search of soil moisture. Our results are in accordance with [67,68] stating higher soil moisture under trees. The tree shade can reduce evapotranspiration from understory plants resulting in increase in soil water content [69].

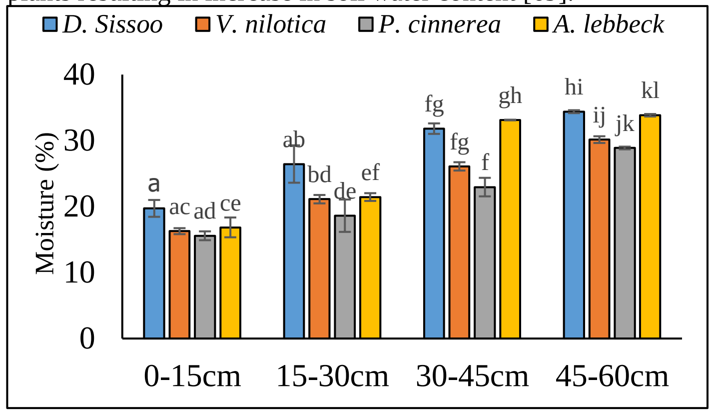


Figure6. Moisture (%) at varying levels of soil depths among tree species

8. **Soil Saturation percentage (SP)**

Saturation percentage decreased with increasing soil depth (Figure7). Our results are in accordance with earlier studies by [70] stating that saturation percentage is an important tool in describing soil texture and reported that sandy loam to loam soils have saturation percentage values between 20 and 35%. A decrease in SP has also been reported in an earlier study by [71] in response to increasing soil depths which concurred with our results.

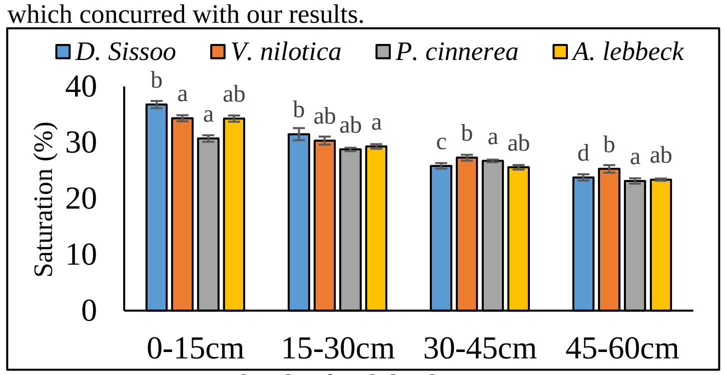


Figure7. SP at varying levels of soil depths among tree species

9. **Nutrient availability in the soil for plant growth**

Trees cause a significant improvement in soils physical and chemical properties that are directly linked with soil fertility. [72] observed that the average soil organic carbon significantly increased under agroforestry as compared to mono-cropping and this was found to increase with tree age. Studies of soil enrichment services through litter fall showed that approximately 20% of the required phosphorus, 77% of required nitrogen and 67% of required potassium could be delivered from the Ficus litter [73]. [74]studied the effects of five multi-purpose tree species on soil under agroforestry and found that all soil hydro-physical characteristics were greatly improved. While relating the effect of trees, [75] found higher concentrations of nutrients in the soil under the crown. [76] observed that trees improve the fertility of soils under their crowns. Even non-N-fixing trees release organic matter, recycle nutrients and thereby, significantly enhance all the properties of the soil [77].

The results of the study indicated a gradual decrease in soil nitrogen with increasing soil depth (Figure7). A decrease in soil nitrogen with increasing soil depths have been reported by many researchers under diverse cropping and trees species [78-80].

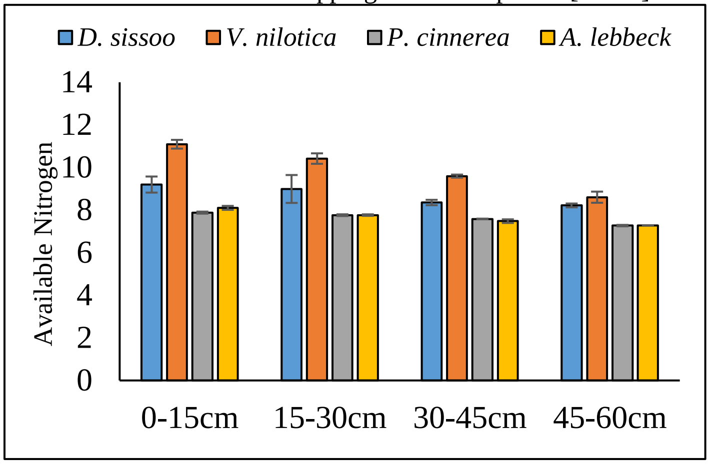


Figure8. Available soil Nitrogen at varying levels of soil depths among tree species

The available phosphorus contents showed a declining trend with increasing soil depths. Our study was in contrast to an earlier work stating an increase in available phosphorus with increase in soil depths is reported by [78]. The difference is attributable to differences in SOM content, pH of the soils, severity of erosion and leaching, types of crops grown and intensity of cultivation.

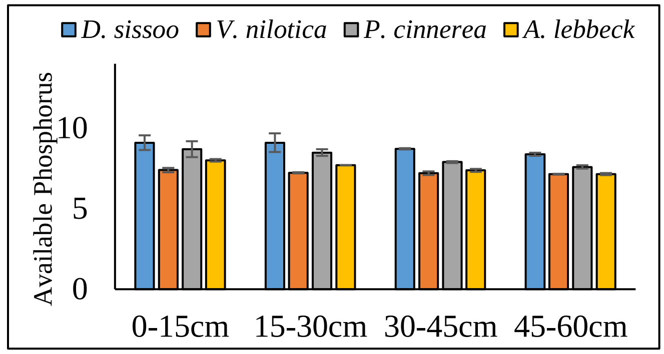


Figure.9 Available soil Phosphorus at varying levels of soil depths among tree species

The available potassium contents showed fluctuations with trees species and increasing soil depths (figure10) in accordance with [80].

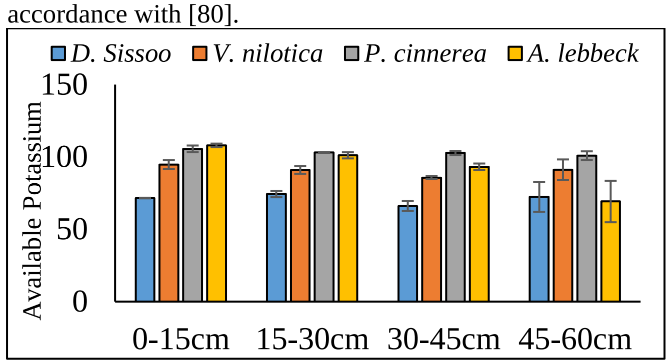


Figure.10 Available soil Potassium at varying levels of soil depths among tree species

## III. CONCLUSION

Under severe weather and economic conditions, farmers are unable to meet increasing demand for food, fiber, and shelter using traditional methods of improving soil fertility. The widespread utilization of chemical fertilizers exacerbates soil fertility issues and incurs high costs. Integrating native tree species into farming systems can help improve soil fertility through the decomposition of leaf litter and other organic matter, which increases soil organic matter content. Nitrogen-fixing tree species in particular can boost soil nutrient levels. The research presented highlights the critical role of trees in enhancing soil fertility and productivity in arid and semi-arid environments. Agroforestry can enhance biodiversity, sequester carbon, and provide farmers with diverse income sources and food supplies. Trees through their phytoremedial actions and changes in soil properties exert significant positive effects on soil fertility improvement; thus, properly planned integration of trees with crop can results in higher crop production.

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