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# EFFECT OF HOMEGARDEN AND PARKLAND AGROFORESTRY PRACTICES IN ETHIOPIA ON SELECTED SOIL PROPERTIES

**Wolle HS [1,2], Barberi P[2] and S Carlesi[2]**

**Hailie Shiferaw Wolle**

*Corresponding author email: haile377@gmail.com

[1]Ethiopian Environment and Forestry Research Institute, Bahir Dar Center, Ethiopia

[2]Institute of Life Sciences, Scuola SuperioreSant'Anna Piazza Martiri della Libertà, 33-56127 Pisa, Italy

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## ABSTRACT

Ethiopian agricultural lands are fragile due to inherent unfavourable soil properties, over-exploitation, mismanagement (deforestation, over-grazing and inappropriate land use systems) and harsh weather conditions. These factors are worsened by changing climatic conditions, leading to significant problems in terms of soil erosion and loss of soil fertility. The consequences of such processes can be detected at the economic (agricultural production is currently being jeopardized) and biological (risks of biodiversity loss and habitat fragmentation) levels. However, the use of tree/shrub species in various agroforestry practices can increase soil nutrient supply through nitrogen fixation, improve soil structure, reduce soil erosion and nutrient losses. A study was carried out in the Amhara region, Ethiopia to evaluate the effect of homegarden and parkland agroforestry practices on selected soil chemical properties. Soil samples were taken from 20x20m square plots established in homegarden agroforestry and adjacent agricultural land without trees (control). In parkland agroforestry practice, two dominant tree species in each of the five villages were chosen. Soil samples were taken from the tree at the midpoint of the canopy projection, at 0-15 and 15-30 cm depths. The collected soil samples were air-dried, homogenized and passed through a 2 mm sieve for subsequent soil chemical analysis. The results indicated that all soil chemical properties except total nitrogen were significantly ($P \leq 0.05$) affected by the agroforestry practices. Higher soil organic carbon, organic matter, available phosphorus, and exchangeable potassium were found in the homegarden agroforestry practice, while the lowest values were recorded in without-tree fields (control). All soil chemical properties except soil pH decreased as the soil depth increased. Higher value of organic carbon, available phosphorus, and exchangeable potassium were found in the homegarden agroforestry likely because of a higher proportion of deep-rooted tree/shrub species and species belonging to the legume functional group. Therefore, the homegarden agroforestry practice can be used as an ecologically friendly and sustainable alternative to maintaining soil fertility.

**Key words:** Mixed-effect model, Functional composition, Functional diversity, Soil quality

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## INTRODUCTION

Declining land productivity because of land degradation is a serious problem in most developing countries. This is mainly true for East African countries including Ethiopia, where land degradation is a common feature of farming systems, requiring high external inputs (fertilizers) [1]. The main causes of land degradation include deforestation, soil erosion, and inappropriate land-use systems as a result of increasing population [2, 3, 4, 5]. Hugo *et al*. [6] reported that about 50% of arable lands in Ethiopian highlands are degraded from moderate to severe level. Adding high levels of input such as fertilizer and labour to improve productivity on a degraded farm land ruins the economic situation of most Ethiopian farmers. Instead, land management based on the use of indigenous trees and other locally available resources is relatively inexpensive as it entails little cash investment [7]. Thus, agroforestry could form an alternative farming system that is more ecologically and economically sustainable. Agroforestry practices can potentially improve micro-climate, floral and faunal composition, and other ecosystem components by creating suitable environmental conditions [8,9]. There are various types of agroforestry practices in different parts of Ethiopia. Parklands, homegardens, woodlots, farm boundaries, trees on grazing lands [10, 11] are the most common agroforestry practices. Among these, homegarden agroforestry is defined as a land use system involving integrated management of trees/shrubs, crops and livestock within the compounds of individual houses, where the whole tree-crop-animal system is being intensively managed by family labour [12]. In contrast, parkland agroforestry is a land-use system in which scattered individuals of woody perennials are deliberately preserved in association with crops and/or animals in a spatially disperse arrangement, where there is both ecological and economic interaction between trees and other system components [13]. The presence of trees in the homegarden and parkland agroforestry practices can enhance nutrient addition to the soil and increase nutrient availability for understory plants through nitrogen fixation, creating suitable environment for soil microorganisms and reducing nutrient and moisture losses by erosion and evaporation, respectively [14].

Many studies have emphasized the importance of parkland agroforestry practices on soil improvement [15 – 19]. Despite this, limited information is available on the effects of homegarden and parkland agroforestry practices on selected soil properties in Ethiopia and particularly in the Amhara region. Empirical evidence is required to demonstrate the positive effects of homegarden and parkland agroforestry on selected soil chemical properties and hence it is very relevant to show the importance of integration of trees in farming systems for reversing soil degradation phenomena to regional land users, decision makers and policymakers. Thus, a dedicated study was carried out to evaluate the effect of homegarden and parkland agroforestry practices on selected soil chemical properties. The hypothesis is that species functional diversity, and especially the presence of legume trees plays a crucial role in improving soil fertility through enhanced nutrient cycling and optimized nutrient availability and that effect depends on the type of agroforestry practice (homegarden *vs* parkland).


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## MATERIALS AND METHODS

The study was carried out in five representative villages in four districts of Amhara region, Ethiopia. (Table1andFigure1). First a reconnaissance survey was conducted to have an overview of the characteristics of a representative study village. Next, we contacted the District development agents (DAs) before we started selection of the specific study villages. Based on the information obtained from the DAs, we selected five villages (Addisalem, Kuyu, Mariamwuha, Sendeji and Shal) with both homegarden and parkland agroforestry practice.

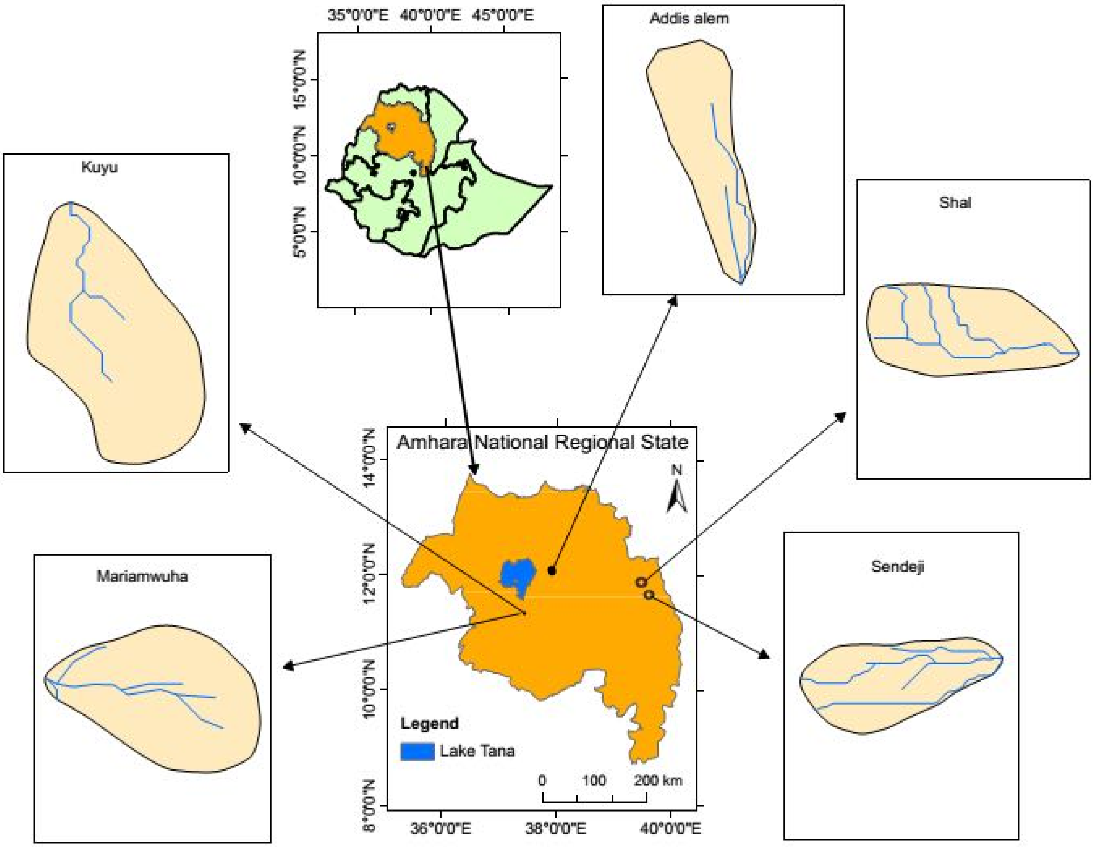


**Figure 1: Map of the study area, with indication of the position of the five villages**

In the homegarden agroforestry practices and adjacent agricultural lands without trees (control), soil samples were taken after the farm characterized by presence of relatively homogenous site conditions (slope and soil type), relatively similar history of the farm land and absence of influence from other trees in four replicates from 20 m x 20 m established square plots in each village. Soil cores were collected at 0-15 and 15-30 cm depths at the four corners and at the centre of each sampling plots [20]. Soil samples taken from the same depths at five points in the square plots were pooled together to form a composite sample.

In parkland agroforestry practices, two dominant tree species in each village were chosen. In total, five tree species (*Croton macrostachyus, Ziziphus spina-christi,*

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*Acacia abyssinica, Acacia seyal* and *Fedherbia albida*) were included from all villages. The area covered by each tree canopy was divided into four radial transects following Hailemariam *et al*. [21] and Tadesse *et al*. [15]. Soil samples were taken in four directions (North, South, East, and West) from each tree at the midpoint of the canopy projection, at 0-15 and 15-30 cm depths, using an auger. Soil samples taken from the same depths in the four directions were pooled together to form a composite sample. The collected soil samples were air-dried, homogenized and passed through a 2 mm sieve for subsequent organic carbon (Walkley-Black), total nitrogen (Kjeldahl method), pH (1:2.5 (%) soil: water suspension), available phosphorus (Olsen method) and exchangeable potassium (ammonium acetate extraction at pH 7) analysis.
Tree and shrub species found in the two agroforestry practices were aggregated by functional groups, namely: (i) high biomass producers (biomass production per year potential in agroforestry practice ranges between 44 and 280 Mgha$^{-1}$), (ii) nitrogen-fixing, and (iii) deep-rooted (trees with rootsmore than fifteen-meter depths) and the root length trait was retrieved from different database.

**Statistical analysis**
A linear mixed-effect model with the village as a random factor was applied for the soil data (soil pH, organic carbon, organic matter, total nitrogen, available phosphorus, and exchangeable potassium) using the *lmer* function of R statistical software [22]. Normality and homogeneity of variance in the dataset were assessed before statistical analysis. For normality, all residuals of the applied model were pooled and their distribution inspected by q-q plots and Shapiro-Wilk test. Homogeneity of variance was assessed by pooling all residuals and plotting them against the fitted values. Tukey HSD was used as *post-hoc* test where appropriate. The analysis was performed using the *lme4* package of the R software, version 3.4.2 [22].

Differences in functional species composition between the two agroforestry practices were analysed using paired t-test as a linear model in R.

## RESULTS AND DISCUSSION

**Soil pH**
The result indicated that soil pH was significantly ($P \leq 0.05$) affected by land-use type (Table 2). On average, the highest soil pH value (7.12) was found in fields without trees (control) while the lowest pH value (6.32) was recorded in the homegarden agroforestry practice. Soil pH ranged from 6.32 to 7.2, revealing moderately acidic soil conditions in both practices. Soil pH increased with increasing depths, as shown in Table 3. The more acidic soils under homegarden agroforestry might be due to the high accumulation of organic matter via tree/shrub litter fall and root biomass. Soil pH increased with increasing depth, an effect that could be associated with higher carbonate levels and reduced weathering effect in subsoil surfaces [23]. Mohammed *et al*. [24] also reported an increase in bases with an increase in soil depth that could be attributed to the downward movement of solutes by leaching.

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**Soil organic carbon and soil organic matter**

Higher soil organic carbon and organic matter were found in the homegarden agroforestry practice, while the lowest values were recorded in fields without tree (Table 2). As compared to parkland agroforestry, homegarden agroforestry showed on average 70.7% higher values of soil organic carbon and 71% higher values of soil organic matter. The values of soil organic carbon and organic matter properties decreased with increasing soil depth (Table3). A higher proportion of functionally important species like legume tree/shrubs, high biomass producing and deep-rooted species were found in homegarden agroforestry practices (Figures2 and 3). Plant species with high biomass production result in high addition of soil organic matter and facilitate biomass decomposition, maintaining high levels of soil organic carbon [25-27]. Differences in functional species composition between the two agroforestry practices resulting in higher organic carbon were also registered in the homegarden agroforestry practice. Similar to organic carbon, higher soil organic matter was found under homegarden agroforestry followed by parkland agroforestry practices.

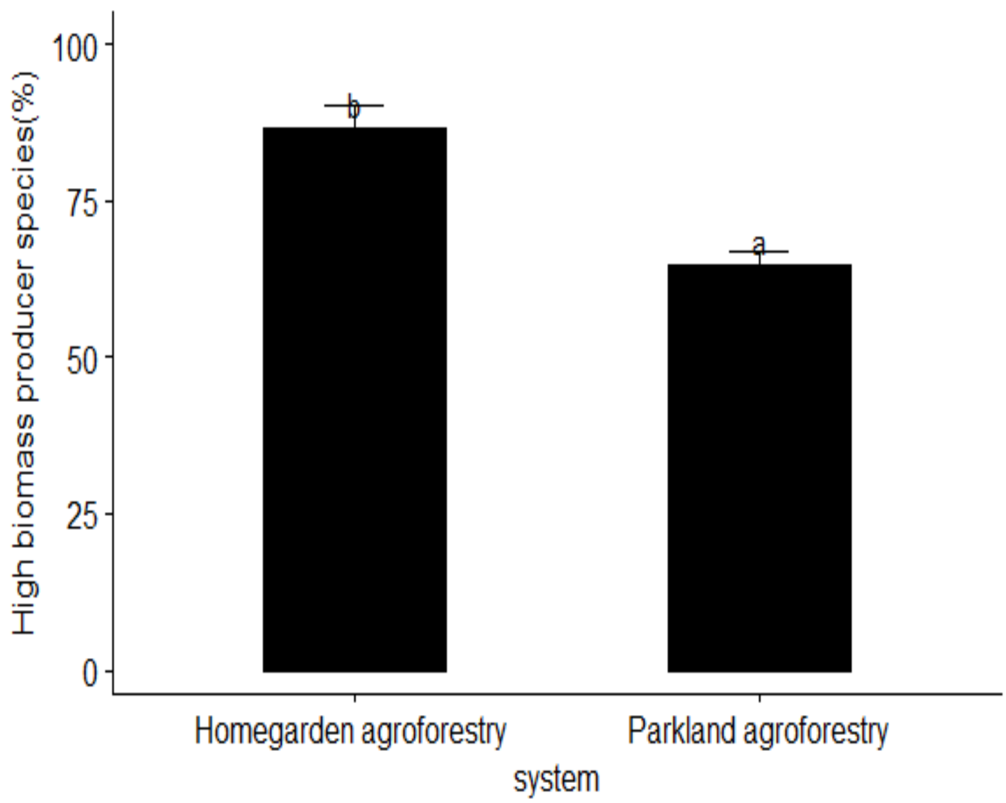


**Figure 2: Proportion of high biomass producing species in homegarden and parkland agroforestry practices in five villages of the Amhara region, Ethiopia. Significance letters (P < 0.05) and standard error bars are shown**

Studies conducted by different authors on the effects of agroforestry on soil organic carbon and organic matter content indicate that higher organic carbon and organic matter content were found under a tree canopy than in open fields [16-19]. This is probably due to higher litterfall and root biomass turnover [28] in agroforestry practices. Moreover, leguminous tree/shrubs in an agroforestry practice add substantial amounts of nitrogen to the soil via litterfall, root and nodule decay and nitrogen fixation [29] and positively affect soil organic carbon and soil organic matter. Furthermore, agroforestry practices provide soil cover and hence decrease soil erosion [30, 31]. The lower soil organic carbon/matter content in fields without trees may be due to more frequent cultivation of the land [32].

**Available phosphorus and exchangeable potassium**

Available phosphorus and exchangeable potassium significantly ($P \leq 0.0001$) varied among land use types and between soil depths. Higher available phosphorus and exchangeable potassium were found in the homegarden agroforestry practice, while the lowest values were recorded in fields without tree (Table2). Compared to parkland agroforestry, homegarden agroforestry showed on average 88.4% higher value of available phosphorus and 86.6% higher values of exchangeable potassium.
Higher exchangeable potassium was found under the homegarden agroforestry and parkland agroforestry practice while the lowest exchangeable potassium was found in fields without tree. This is probably an effect of higher organic matter accumulation in the home garden agroforestry practice which released phosphorus during its mineralization. Subba and Dhara [33] reported that higher available phosphorus and exchangeable potassium was found in fruit-based agroforestry practices of West Bengal, India.

Moreover, a higher proportion of deep-rooted tree/shrub species and legume functional compositions in the agroforestry practice could have contributed to the increase in available phosphorus and exchangeable potassium. Several studies reported that most nitrogen-fixing tree/shrub species increased phosphorus concentrations [34, 17]. Furthermore, plant species with a deep root system can draw upon unavailable soil phosphorous and exchangeable potassium from deeper soil profile [35 -36]. Tree/shrub species in agroforestry practices can also establish mutualistic symbioses with mycorrhizal fungi for their nutrition [37], which stimulate the tree by extending their hyphae to areas of soil beyond the root zones of the plant, increasing the uptake of nutrients and particularly phosphorus [38, 39]. Hence, plant species able to host mycorrhizal fungi in both home garden agroforestry practices are expected to improve soil fertility.

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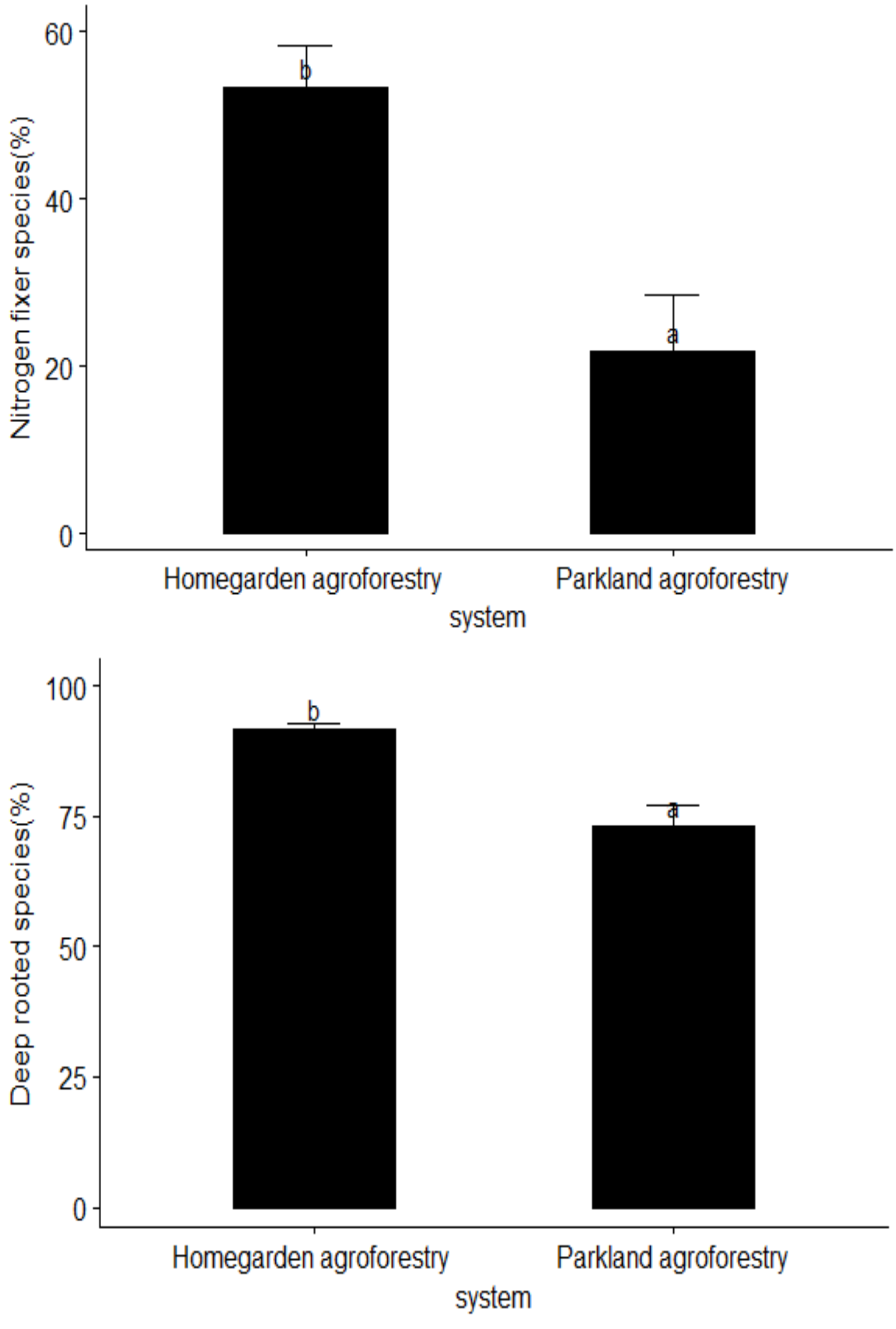


**Figure 3: Proportion of nitrogen-fixing species (left) and deep-rooted species (right) in the homegarden and parkland agroforestry practices in five villages of the Amhara region, Ethiopia. Significance letters (P < 0.05) and standard error bars are shown**

In our study, both exchangeable potassium and available phosphorus decreased with increasing soil depth (Table 3). Panwar and Gupta [40] reported that available phosphorus and exchangeable potassium decreased with increasing soil depths under *Celtis australis* indigenous agroforestry practice of Himachal Pradesh, India. This could be due to the reduction of organic matter content with increasing soil depth.

## CONCLUSION

The results of this study revealed that higher functional compositions of species (legume tree/shrub species, high biomass producing, and deep-rooted species) were found in homegarden agroforestry practices. Higher content of organic carbon, organic matter, available phosphorus, and exchangeable potassium were found under homegarden agroforestry practice. Homegarden and parkland agroforestry practices have been shown to have a positive effect on selected soil chemical properties.

Therefore, homegarden and parkland agroforestry practices can be used as an environmentally friendly and sustainable alternative to maintaining soil fertility. Moreover, farmers should be encouraged to increase their farm land productivity through maintaining high functional diversity in both agroforestry practices. Further research should be done on soil microbial populations associated with homegarden and parkland agroforestry practices and their subsequent effects on soil chemical properties and litter quality (litter decomposition) under the two agroforestry practices.

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**Table 1: Site characteristics of the study villages in the Amhara region, Ethiopia**

| | Village | | | | |
|---|---|---|---|---|---|
| Site characteristics | Addisalem | Kuyu | Mariamwuha | Sendeji | Shal |
| Latitude | 12°6’29’’ N | 11°21’29’’ N | 11°20’39’’ N | 11°40’14’’ N | 11°53’48’’ N |
| Longitude | 37°54’7’’ E | 37°26’7’’ E | 37°25’45’’ E | 39°36’40’’ E | 39°28’23’’ E |
| Zone | South Gonder | West Gojam | West Gojam | North Wollo | North Wollo |
| District | Libokemkim | Yilmanadensa | Yilmanadensa | Habru | Gubalafito |
| Elevation (m a.s.l.) | 2031 | 2292 | 2238 | 1849 | 2027 |
| Precipitation (mm year-1) | 1017 | 1238 | 1238 | 924 | 994 |
| Mean maximum Temperature (°C) | 28.0 | 26.7 | 26.7 | 31.0 | 28.1 |
| Mean minimum Temperature (°C) | 10.7 | 12.4 | 12.4 | 14.9 | 15.2 |

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**Table 2: Mean values (SE) of soil pH, organic carbon, organic matter, total nitrogen, available phosphorus and exchangeable potassium under different land-use types, averaged across five villages of the Amhara region, Ethiopia**

| Parameter | Land use type | | | P value |
|---|---|---|---|---|
| | Homegarden agroforestry | Parkland agroforestry | Agricultural land(fields without trees) | |
| pH ($H_2O$) | $6.32^a$ (0.09) | $6.95^b$ (0.09) | $7.12^b$ (0.09) | < 0.0001 |
| Organic C (%) | $2.22^b$ (0.15) | $1.57^b$ (0.15) | $0.78^a$ (0.15) | < 0.0001 |
| Organic matter (%) | $3.83^b$ (0.27) | $2.72^b$ (0.27) | $1.34^a$ (0.27) | < 0.0001 |
| Total N (%) | $0.20^a$ (0.15) | $0.17^a$ (0.18) | $0.14^a$ (0.17) | 0.117 |
| Available P(mg $kg^{-1}$) | $6.22^c$ (0.25) | $5.50^b$ (0.25) | $2.14^a$ (0.25) | < 0.0001 |
| Exchangeable K (mg $kg^{-1}$) | $382.47^b$ (0.03) | $331.18^b$ (0.03) | $202.91^a$ (0.03) | < 0.0001 |

**Note:** Within each row, means with the same letter are not significantly different at P ≤ 0.05 (Tukey test)

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**Table 3: Mean values (SE) of soil pH, organic carbon, organic matter, total nitrogen, available phosphorus and exchangeable potassium at different soil depths, averaged across three land-use types and five villages in the Amhara region, Ethiopia**

| Parameter | Soil depth (cm) | | P value |
|---|---|---|---|
| | 0-15 | 15-30 | |
| pH ($H_2O$) | 6.77$^a$ (0.08) | 6.81$^a$ (0.08) | < 0.426 |
| Organic C (%) | 1.80$^b$ (0.09) | 1.24$^a$ (0.09) | < 0.0001 |
| Organic matter (%) | 3.12$^b$ (0.16) | 2.14$^a$ (0.16) | < 0.0001 |
| Total N (%) | 0.18$^b$ (0.14) | 0.15$^a$ (0.14) | < 0.0001 |
| Available P (mg $kg^{-1}$) | 5.62$^b$ (0.15) | 3.61$^a$ (0.15) | < 0.0001 |
| Exchangeable K (mg $kg^{-1}$) | 349.68$^b$ (0.01) | 261.36$^a$ (0.01) | < 0.0001 |

**Note:** Within each row, means with the same letter are not significantly different at P ≤ 0.05 (Tukey test)

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