A Comparative Study of the Effects of Cordia africana, Ficus sur and Manihot esculenta on Soil Chemical Properties in an Agroforestry System

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Abstract

in Krakow, Poland The incorporation of woody components ensures the sustainability of land productivity through complementary resource acquisition and nutrient cycling. Hover, the integrated species, however, play a major role in determining the environmental impact of agroforestry practices. In order to compare the effects of woody plants on various soil chemical properties, three agroforestry species: Cordia africana, Ficus sur, and Manihot esculenta were selected from three different elevation ranges; and the soil samples were collected from the canopy zone and outside the tree canopy influence. As a result, all of the agroforestry species in the current study have demonstrated a significantly favorable impact on the soil chemical properties inside the canopy. Focusing solely on the effects of individual species on the soil, Cordia Africana and Ficus sur did not significantly differ in the bulk of the measured soil chemical property measures. Manihot esculenata, on the other hand, had much lower impact in comparison to the first two, showing that it is the least important species for enhancing soil quality. The influence of agroforestry species on soil chemical properties is similar across all elevation ranges for the majority of the parameters, indicating that the impact of agroforestry species on soil property is stronger than the impact of elevation. Therefore, in an agroforestry system, woody plants, Cordia Africana and Ficus sur perform a significantly larger role of improving the soil than the tuber crop Manihot esculenata, which in turn has a strong negative impact on the soil's available potassium and cation exchange capacity.

Background Of The Study

Agroforestry is a dynamic ecologically based strategy for managing natural resources and land in which trees or shrubs are combined with crops and/or pastures on the same area unit (Aloa and Shuaibu, 2013, Nair, 2005). According to the most recent definition, the integration of components in agroforestry can occur either in a geographical mixture or in a temporal arrangement, and there are interactions between the woody and non-woody components on an ecological and economic basis (Leakey, 2017).

Agroforestry is a globally expanding land-use option that is economically viable for environmental restoration and sustainable agricultural development (Djalilov *et al.*, 2016; Marques *et al.*, 2022; Tomar *et al.*, 2021), and provide a wide range of economic, sociocultural, and environmental benefits (Kumar, 2016; Kuyah *et al.*, 2017). Environmentally, agroforestry practices play a great role in improving soil quality by controlling soil erosion, improving soil fertility, and enhancing the moisture holding capacity of the soil (El Tahir and Vishwanath, 2015; Kuyah *et al.*, 2016; Young, 2002). Agroforestry practices improve the physicochemical characteristics of the soil, which in turn results in better soil productivity (Kang and Akinnifesib, 2000, Rachel *et al.*, 2012). Agroforestry based land management improves the soil pH (Pinho *et al.*, 2012), and the soil nutrient availability (Isaac and Borden, 2019; Manjur *et al.*, 2014; Sileshi *et al.*, 2020; Wang *et al.*, 2022); by increasing the content of soil organic carbon and total nitrogen (Lian *et al.*, 2019; Lu *et al.*, 2015).

Agroforestry is widely used worldwide and throughout the African continent as a strategy to boost resilience, increase diversification, bridge gaps in nutrition and food security, and mitigate the effects of climate change (Aklilu and Tigist, 2017; Brown *et al.*, 2018; Kuyah *et al.*, 2020; Sheppard *et al.*, 2020; Sisay and Mekonnen, 2013; Yirga 2019;). Indigenous agroforestry practices that have evolved over time are present in the southern region of Ethiopia (Alemu, 2016). Agroforestry is a prevalent way to manage watersheds in the Kindo Didaye areas. Home gardens, boundary plantations, live fences, woodlots, coffee shade trees, as well as cassava (*Manihot esculenata*) alley cropping, are also becoming more popular.

The interacting species in the parkland should support the long-term sustainability of soil quality because the main objective of the land use system is to boost agricultural production. It has been documented how parkland agroforestry practices affect soil (Wolle *et al.*, 2021; Tsedeke *et al.*, 2021; Bussa and Feleke, 2020; Asfaw, 2016, among others). The effect of particular agroforestry species on soil chemical quality, however, is little understood. Furthermore, the question Does the change in preference of agroforestry species have an impact on soil chemical properties in the study area?" and "does the influence of agroforestry species on soil chemical properties vary along the elevation gradient?" have not been elucidated in detail. Answering these questions is important since, the current expansion of Cassava (*Manihot esculenata*) crop at the expense of the other important woody species in the Agroforestry system is becoming a critical issue of agricultural soil quality sustainability. As a result, it was hypothesized that: I) soil chemical property differences inside and outside of the canopy of agroforestry species is significant; II) the influence of agroforestry species on the soil chemical property is species specific; and III) the impact of agroforestry species on soil chemical properties is also affected by elevation.

Methodology

2.1 The study area description

Sime Dolaye watershed is located in Kindo Didaye woreda, Wolaita Zone, Southern Ethiopia, between 6° 42' 30" and 6° 45' 0" North latitudes and 37° 19' 10" and 37° 21' 40" East longitudes (Fig. 1). The watershed features undulating topography, with elevations ranging from 856 to 2285 meters above sea level. About 6 percent of the land is flat, 28 percent are gentle elevation zone, 30 percent are undulating, and 35 percent are steep elevation zone. The elevation zones are south-facing, with all drainage flowing into the Deme River. In the studied region, no extensive soil surveys have been conducted. According to the local community's classification, the primary soil types are black-brown to black clay soils.

The *Sime* watershed is representative of the *Weyna-dega* agro-ecological zone's moist climate (3 percent *dega*, 78 percent *weyna-dega* and 19 percent kola). The average annual rainfall is around 1260 mm, and the average temperature is 21 degrees Celsius. *Belg* and *kiremt* are the two rainy seasons, respectively. *Belg* is the rainy season, which lasts from March through May. Between June and September, the *kiremt* season, which is the longest rainy season, begins.

Over 65.4 percent of households have less than 0.19 hectares of land. As a reaction to the land shortage and productivity challenges in this area, the most widely employed land management strategies are agroforestry-based land use systems combined with additional measures such as bench terraces. Some of the more common agroforestry practices are home gardens, parklands, coffee-shade trees, woodlots, boundary plantations, alley cropping, and windbreaks. *Cordia Africana* and *Ficus sur* are highly preferred tree species in the area for timber, animal fodder, and soil fertility maintenance in the parkland setting. Cassava (*Manihot esculenata*), inset (*Ensete ventricosum*), banana (*Musa paradisiacal*), Taro (*Solanum tuberosum*), *Coffee Arabica*, Pea, and *Zea mays* are among the key crops commonly incorporated in agroforestry systems in the study area.

2.2 Sampling Methods and Sample Size Determination

2.2.1. Sampling methods and sample size determination for household survey

To select sample respondents for the household survey, a two-stage sampling technique was used. Primarily, Sime watershed was chosen for this study because it has strongest agroforestry-based watershed management practices in the Kindo Didaye Woreda. The elevation zone cluster based stratified random sampling method was then used to choose the most dominant, economically and ecologically desirable agroforestry species in the watershed, which has a total population of 3,490 people or 698 households. The population proportionate samples were taken based on the size of household heads in each cluster. According to Kothari (2004)'s calculation, the total sample size for the household survey is 101, as shown in Eq. 1.

$$n = \frac{z^2.p.q.N}{e^2(N-1)+z^2.p.q} n = \frac{z^2.p.q.N}{e^2(N-1)+z^2.p.q}$$ ………………………………… Eq. 1

Where n = sample size, z = standard variation at a given confidence level, p = sample proportion, q = 1-p, e = given accuracy rate or tolerable error, and N = population are all calculated using a table displaying area under the normal curve. The intended precision rate or acceptable error is considered to be 9, i.e. e = 9% or 0.09, z = 1.96 (desired confidence level is 96% and value taken from table), and p = 0.5 (sample proportion). q = 0.5 (1-0.5), or 1-p. The following proportional allocation formula by Kothari (2004) was used to determine sample size at the cluster level:

$$ni = Ni \mathbf{X} n/N \text{———} (2)$$

Where ni is the sample size percentage to be estimated, Ni is the stratum population proportion, n is the sample size, and N is the overall population. Structured questionnaire was filled by the trained data collectors from each household heads in person from each elevation range (Table 1). In addition, focus groups discussions (FGD) were held to help triangulate the survey results.

Table 1
Classification of cluster based on altitude and household sample size

S/N	Cluster	Elevation ranges	Household number	Proportional sample size
1	Upper	2121–2285	211	31
2	Middle	1351–2120	304	44
3	Lower	856–1350	183	26
Total			698	101

As a result of the household survey, the top three community-preferred species in terms of economic value, and ecologically desirable characteristics, *Cordia Africana*, *Ficus sur*, and *Manihot esculenata*, were chosen for investigation of their impact on soil quality (Table 2).

Table 2
Top-21 dominant, and community-preferred agroforestry trees, shrubs and herbs in the Sime watershed

No	Species name	Frequency	Percent	Cluster	Family name	Local name	Classification
1	*Cordia Africana*	97	96.0	U	Boraginaceae	Moqottaa	Tree
2	*Ficus sur*	87	88.1	U	Moraceae	Ettaa	Tree
3	*Manihot esculenata*	89	88.1	U	Euphorbiaceae	Mitta-Boyyiya	Shrub
4	*Ensete ventricosum*		88.0	U	Musaceae	Uuttaa	Herb
5	*Persea americana Mill.*	86	85.1	M/L	Lauraceae	Avocaduwa	Tree
6	*Mangifera indica*	83	82.2	M/L	Anacardiaceae	Mangguwa	Tree
7	*Coffee arabica*	81	80.2	M/L	Rubiaceae	Tukkiya	Shrub
8	*Euclayphtus species*	74	73.2	U	Myrtaceae	Zaafiya	Tree
9	*Ficus vasta*	64	63.4	M/L	Moraceae	wolaa	Tree
10	*Solanum tuberosum*	64	63.4	U	Solanaceae	Donuwaa	Herb
11	*Carica papaya*	63	62.4	M/L	Caricaceae	Papayaa	Tree
12	*Juniperus procera*	62	61.4	U	Cupresaceae	Xiiddaa	Tree
13	*Euphorbia tirucalli*	58	57.4	M/L	Euphorbiaceae	Maxuwa	Shrub
14	*Crotonmacrostachyus*	57	56.4	U	Euphorbiaceae	Ankka	Tree
15	*Jatropha curcas*	57	56.4	U	Euphorbiaceae	Kobbuwa	Shrub
16	*Grabilia Rebosta*	55	54.5	U	Proteaceae	Girabiliya	Tree
17	*Feidhebia albida*	53	52.5	U	Mimosaceae	Borituwa	Tree
18	*Vertiveria zizaniades*	52	51.5	U/M	Gramineae	Vetiverya	Herb
19	*Jacaranda mimosfolia*	51	50.5	L	Bignoniaceae	Jacaranda	Tree
20	*Cosuarina equisetifolia*	50	49.5	U	Casuarinaceae	Shuwashuwe	Tree
21	*Milletia ferrginea*	47	46.5	U	Fabaceae	Zagiya	Tree

Where, U is upper, M is middle, and L is lower elevation zone clusters. Source (Feld survey, 2020).

2.2.2. Soil sampling procedure and sample size determination

For this descriptive study design, the two multipurpose tree species (*Cordia africana* and *Ficus sure*) and matured *Manihot esculenata* were selected from each cluster based on the household survey (Table 2) and focus group discussion (FGD) to investigate their impact on soil chemical properties in the agroforestry system. *Cordia africana* and *Ficus sur* with a diameter at breast height (DBH) of 35–40 cm, a crown diameter of 15–20 m, and a height of > 15 m were chosen from the parkland agroforestry system. With utmost caution, the soil samples were taken from scattered individuals of the target trees to minimize *Manihot esculenata* overlapping effects from other species. The canopy boundary was marked on the ground for a three-year-old *Manihot esculenata* from a parkland agroforestry set-up to ensure that the canopy was free of other species' impact. No manure or household wastes were employed in the research plots, and no inorganic fertilizers were used in the last 10 years except similar common crops rotated under all the agroforestry species. The control samples were taken outside the canopy, which had equivalent conditions to the inside canopy in all other ways except for the study species' canopy presence.

Soil samples were taken from the top 30 cm soil depth of each tree and *Manihot esculenata* within a 3 m radius under the copy and 15 m away from the trunk from four dimensions of each tree and *Manihot esculenata*. The soil samples from each sampling location were then mixed to produce 1 kg representative samples of each agroforestry species and sampling location. As a consequence, a total of 54 composite samples were obtained from each tree species and the *Manihot esculenata* crop canopy, with three replications at each cluster (3 trees/cassava*3 replications*3 clusters*2 sampling location).Then, the soil samples were air dried and submitted to Wolaita Sodo soil testing laboratory for analysis of soil pH, percent organic carbon (%OC), total nitrogen (TN), available phosphorus (Av.P), available potassium (Available potassium), and Cation-exchange capacity (CEC).

For the soil pH measurement, a 1:2.5 soil to water ratio was used to make a soil water suspension. The contents were allowed to settle for 30 minutes before the pH was measured with a pH meter and a combination glass electrode. The Walkley and Black method was used to evaluate the OC of all soil samples, in which the organic matter was oxidized by potassium dichromate in the presence of concentrated H_2SO_4. Using a diphenylamine indicator, the excess potassium dichromate was back titrated with ferrous ammonium sulphate (Walkley and Black, 1934). The Kjeldahl Method was used to calculate the TN available in soil (Bremner and Mulvaney, 1982). Olsen extraction (0.5 M $NaHCO_3$) was used to assess the Av.P (Olsen and Sommers, 1982). The amount of potassium that was available was determined using the Neutral Ammonium Acetate extraction method (Merwin and Peech, 1951). A flame photometer was used to estimate the extracted sample. The soil's cation exchange capacity (CEC) was measured using 1M ammonium acetate (pH 7) (Van Reeuwisk, 2002).

2.2.3. Statistical Analysis

To maintain the normal distribution, the data was log-transformed and a two-way ANOVA was performed. Because the interaction effect was found to be insignificant for all factors, the effects of the main factors were run. As a result, agroforestry species were studied as the primary factor, elevation zone as a blocking factor, while sample points (inside/outside the canopy) as a control factor. The post-hock comparison of treatment means were performed using Tukey test at $P < 0.05$ probability level. The data were processed using Statistica 14.0.0.15 (1984–2020) software, and bar graphs were produced using Microsoft Excel.

Results

3.1 Soil chemical property variations with distance from canopy in agroforestry species

The soil available potassium, pH, percent organic carbon, total nitrogen, available phosphorus, and percent silt were all significantly higher under the canopy than outside the canopy of all three agroforestry species at $p < 0.05$. Similarly, the soil CEC of *Cordia Africana* and *Ficus sur* was significantly higher under the canopy than outside the canopy, while no significant difference was observed between under and outside the canopy of *Manihot esculenata* (Table 3).

Table 3

Variations in soil chemical properties with distance from canopy in agroforestry species. Descriptive Statistics; N = 54 (Mean ± Std. Dev.). Note: Av. K for (available potassium), pH for (soil pH), %OC for (percent organic carbon), TN for (total nitrogen), and Av. P for (available phosphorus), and CEC for (Cation exchange capacity).

Agroforestry species/ Sampling location	**No**	**Av. K (g Kg^{-1})**	**pH**	**%OC**	**TN (mg/L)**	**Av. P (mg Kg^{-1})**	**CEC (Cmole Kg^{-1})**
Cordia Africana	**18**	**0.34 ± 0.06**	**6.10 ± 0.55**	**1.56 ± 0.48**	**0.14 ± 0.04**	**3.02 ± 2.28**	**20.38 ± 6.94**
Inside canopy	9	0.39 ± 0.06a	6.56 ± 0.38a	1.89 ± 0.48a	0.17 ± 0.04a	4.62 ± 2.19a	24.02 ± 6.49a
Outside canopy	9	0.30 ± 0.02b	5.64 ± 0.19b	1.22 ± 0.05b	0.11 ± 0.02b	1.42 ± 0.73b	16.73 ± 5.49b
Ficus Sur	**18**	**0.34 ± 0.05**	**5.88 ± 0.54**	**1.96 ± 1.06**	**0.17 ± 0.06**	**3.53 ± 2.28**	**25.52 ± 7.39**
Inside canopy	9	0.38 ± 0.04a	6.27 ± 0.33a	2.68 ± 1.11a	0.22 ± 0.03a	5.25 ± 1.99a	31.22 ± 3.47a
Outside canopy	9	0.29 ± 0.02b	5.49 ± 0.40b	1.24 ± 0.04b	0.12 ± 0.01b	1.80 ± 0.66b	19.82 ± 5.56b
Manihot esculenata	**18**	**0.24 ± 0.03**	**5.31 ± 0.45**	**1.34 ± 0.26**	**0.13 ± 0.02**	**2.02 ± 1.14**	**11.19 ± 7.57**
Inside canopy	9	0.26 ± 0.02a	5.50 ± 0.22a	1.52 ± 0.26a	0.15 ± 0.02a	2.77 ± 1.10a	12.65 ± 8.37a
Outside canopy	9	0.21 ± 0.01b	5.12 ± 0.56b	1.16 ± 0.09b	0.11 ± 0.01b	1.27 ± 0.53b	9.73 ± 6.85ab

3.2 A comparison of the impact of agroforestry species on soil chemical properties

The majority of the assessed soil chemical property metrics for *Cordia Africana* and *Ficus sur* did not differ significantly (Fig. 2(A) and 2 (B)). *Manihot esculenata* had significantly lower available potassium, CEC and soil pH than *Cordia Africana* and *Ficus Sur*. *Ficus sur* had significantly higher soil TN than *Cordia Africana* and *Manihot esculenata*. Similarly, soil under *Ficus sur* had a significantly higher percent organic carbon, and available phosphorus, than soil under *Manihot esculenata*, but these parameters were not significantly different between *Manihot esculenata* and *Cordia Africana*.

3.3 Soil chemical property differences between agroforestry species along the elevation gradient

In the upper, middle, and lower elevations, the soil under *Manihot esculenata* revealed significantly lower available potassium (Available potassium) than *Cordia Africana* and *Ficus sur, while* no significant difference was observed between *Cordia africana* and *Ficus Sur* (Table 4). There was no significant difference between the agroforestry species in moderating the soil pH at the upper elevation as well as the lower elevations. However, variation was observed in the soil pH at the middle elevation under agroforestry species, with substantially lower values under *Manihot esculenata* at middle elevation zone. In all elevation ranges, the differences in percent organic carbon, total nitrogen, and available phosphorus, under the agroforestry species were not significant. In the upper elevation range, the soil cation exchange capacity was significantly higher under *Ficus sur Cordia africana* compared to *Manihot esculenata*, whereas under Ficus sur was significantly higher than *Manihot esculenata* at middle elevation.

Table 4

Soil chemical property differences between agroforestry species grouped along the elevation gradient. Descriptive Statistics; N = 18 (Mean ± Std. Dev.). The soil properties comparison were made between the agroforestry species at each elevation separately. Note: Av. K for (available potassium), pH for (soil pH), %OC for (percent organic carbon), TN for (total nitrogen), and Av. P for (available phosphorus), and CEC for (Cation exchange capacity).

Agroforestry species	Elevation	Av. K (g Kg^{-1})	pH	%OC	TN (mg/L)	Av. P (mg Kg^{-1})	CEC (Cmole Kg^{-1})
Cordia Africana	Upper	0.30 ± 0.03a	6.05 ± 0.59a	1.33 ± 0.21ab	0.12 ± 0.02ab	2.93 ± 2.34ab	18.57 ± 5.51ab
Ficus Sur	Upper	0.33 ± 0.04a	5.97 ± 0.39ab	1.65 ± 0.49a	0.15 ± 0.04a	3.32 ± 3.12a	24.00 ± 8.08a
Manihot esculenata	Upper	0.23 ± 0.02b	5.32 ± 0.72ab	1.19 ± 0.13ab	0.12 ± 0.02ab	1.34 ± 0.70ab	1.35 ± 0.70c
Cordia Africana	Middle	0.37 ± 0.09a	6.03 ± 0.36a	1.51 ± 0.31ab	0.14 ± 0.04ab	3.24 ± 2.46ab	23.83 ± 7.04ab
Ficus Sur	Middle	0.35 ± 0.07a	5.83 ± 0.52ab	1.88 ± 0.70a	0.17 ± 0.06a	3.56 ± 2.21a	26.37 ± 7.46a
Manihot esculenata	Middle	0.24 ± 0.04b	5.20 ± 0.26bc	1.29 ± 0.15ab	0.13 ± 0.02ab	1.85 ± 1.11ab	15.67 ± 2.15b
Cordia Africana	Lower	0.36 ± 0.04a	6.22 ± 0.73a	1.82 ± 0.70ab	0.16 ± 0.05ab	2.89 ± 2.47ab	18.73 ± 7.89ab
Ficus Sur	Lower	0.34 ± 0.06ab	5.83 ± 0.74ab	2.35 ± 1.67a	0.18 ± 0.07a	3.70 ± 1.73a	26.20 ± 7.79a
Manihot esculenata	Lower	0.24 ± 0.04c	5.42 ± 0.30ab	1.55 ± 0.34ab	0.15 ± 0.03ab	2.88 ± 1.10ab	16.57 ± 3.82ab

3.4 Soil chemical properties differences among the agroforestry species along the elevation gradient

Table 5 shows that available potassium (Available potassium), soil pH, percent organic carbon (percent OC), total nitrogen (TN), and available phosphorus (Av.P) for each of the agroforestry species were not significantly different along the elevation gradient. Cation exchange capacity (CEC) did not differ under *Cordia Africana* and *Ficus sur* along elevation gradient. However, the soil CEC variation under *Manihot esculenata* was significant along the elevation gradient, with the highest value in the lower elevation, and lowest value in the upper elevation, while no significant difference were found between middle and lower elevation (Table 5).

Table 5

Variation in soil chemical properties among agroforestry species is different elevation zones, and comparison across agroforestry species. Descriptive Statistics; N = 54 (Mean ± Std. Dev.). Note: Av. K for (available potassium), pH for (soil pH), %OC for (percent organic carbon), TN for (total nitrogen), and Av. P for (available phosphorus), and CEC for (Cation exchange capacity).

Agroforestry species / elevation	**Av. K (g Kg^{-1})**	**pH**	**%OC**	**TN (mg/L)**	**Av. P (mg Kg^{-1})**	**CEC (Cmole Kg^{-1})**
Cordia Africana	**0.34 ± 0.06a**	**6.10 ± 0.55a**	**1.56 ± 0.48a**	**0.14 ± 0.04a**	**3.02 ± 2.28ab**	**20.38 ± 6.94a**
Upper	0.30 ± 0.03ab	6.05 ± 0.59ab	1.33 ± 0.21ab	0.12 ± 0.02ab	2.93 ± 2.34ab	18.57 ± 5.51ab
Middle	0.37 ± 0.09a	6.03 ± 0.36ab	1.51 ± 0.31ab	0.14 ± 0.04ab	3.24 ± 2.46a	23.83 ± 7.04a
Lower	0.36 ± 0.04ab	6.22 ± 0.73a	1.82 ± 0.70a	0.16 ± 0.05a	2.89 ± 2.47ab	18.73 ± 7.89ab
Ficus Sur	**0.34 ± 0.05a**	**5.88 ± 0.54a**	**1.96 ± 1.06a**	**0.17 ± 0.06a**	**3.53 ± 2.28a**	**25.52 ± 7.39a**
Upper	0.33 ± 0.04ab	5.97 ± 0.39a	1.65 ± 0.49ab	0.15 ± 0.04ab	3.32 ± 3.12ab	24.00 ± 8.08ab
Middle	0.35 ± 0.07a	5.83 ± 0.52ab	1.88 ± 0.70ab	0.17 ± 0.06ab	3.56 ± 2.21ab	26.37 ± 7.46a
Lower	0.34 ± 0.06ab	5.83 ± 0.74ab	2.35 ± 1.67a	0.18 ± 0.07a	3.70 ± 1.73a	26.20 ± 7.79a
Manihot esculenata	**0.24 ± 0.03b**	**5.31 ± 0.45b**	**1.34 ± 0.26a**	**0.13 ± 0.02a**	**2.02 ± 1.14ab**	**11.19 ± 7.57b**
Upper	0.23 ± 0.02ab	5.32 ± 0.72ab	1.19 ± 0.13ab	0.12 ± 0.02ab	1.34 ± 0.70ab	1.35 ± 0.70c
Middle	0.24 ± 0.04a	5.20 ± 0.26ab	1.29 ± 0.15ab	0.13 ± 0.02ab	1.85 ± 1.11ab	15.67 ± 2.15ab
Lower	0.24 ± 0.04a	5.42 ± 0.30a	1.55 ± 0.34a	0.15 ± 0.03a	2.88 ± 1.10a	16.57 ± 3.82a

3.5. Correlation of some important dependent variables

Table 6 displays the results of a correlation study between a few dependent variables. It reveals a strong positive relationship between available potassium and pH (R = 71%), percent organic carbon (R = 57%), total nitrogen (R = 67%), available phosphorus (R = 60%), and cation exchange capacity (R = 69%). The percent of organic carbon, total nitrogen, available phosphorus, and cation exchange capacity were all positively correlated with pH (R = 57%, R = 57%, R = 62%, and R = 54% respectively). Additionally, there was a correlation between soil organic carbon content and available phosphorus (R = 55%), total nitrogen (R = 77%), and cation exchange capacity (R = 52%). Furthermore, there was a strong positive correlation between total nitrogen and available phosphorus (R = 63%), CEC (R = 57%). Similarly, there was a strong correlation between available phosphorus and CEC (R = 65%).

Table 6

Correlation of some important dependent variables. Note: Av. K for (available potassium), pH for (soil pH), %OC for (percent organic carbon), TN for (total nitrogen), and Av. P for (available phosphorus), and CEC for (Cation exchange capacity).

Correlations: The R-values with red colors marked correlations are significant at p < 0.05 N = 54 (Case-wise deletion of missing data). * Refers a significant correlation between variables.

Variable	Means	Std. Dev.	Av. K (g Kg^{-1})	pH	%OC	TN (mg/L)	Av. P (mg Kg^{-1})	CEC (Cmole Kg^{-1})
Av.K	0.31	0.07	1.00					
PH	5.76	0.61	0.71*	1.00				
%OC	1.62	0.72	0.57*	0.57*	1.00			
TN	0.15	0.05	0.67*	0.57*	0.77*	1.00		
Av.P	2.86	2.04	0.60*	0.62*	0.55*	0.63*	1.00	
CEC	19.03	9.33	0.69*	0.54*	0.52*	0.57*	0.65*	1.00

Discussion

4.1 The impact of agroforestry species on soil chemical properties

The role of woody species in managing the soil quality of agricultural land is one of the factors promoting the growth of agroforestry systems in developing nations. Regardless of species differences and elevation differences, the soil's available potassium, pH, percent organic carbon, total nitrogen, and available phosphorus were all significantly greater beneath the canopy of agroforestry species than outside the canopy. This better soil properties under the canopy than that outside the canopy may be due to the high rate of organic matter production and efficient nutrient cycling mechanism, including mineralization of leaf litter and fine roots (Alemayehu, *et al*., 2016). Asfaw (2003) also noted that the soil quality in cases of *Cordia africana* was greater inside the canopy zone than outside. The findings show that tree canopy effect changed the pH of the soil, increasing the release of potassium, total nitrogen, and available phosphorus concentration from organic matter. The percentage of organic carbon, total nitrogen, available phosphorus, and cation exchange capacity are all positively associated with soil pH, according to the correlation analysis of independent variables (Table 6). Farmland with dispersed trees had drastically lower soil pH, available potassium, and available phosphorus the farther away from the trees you were (Yadessa *et al*., 2009; Yadessa *et al*., 2001). In an alley cropping system, the levels of soil organic carbon, accessible nitrogen, phosphorus, and potassium were highest close to the tree canopy (Sirohi *et al*., 2022). Additionally, this demonstrates how the soil patches created by the tree canopy can restore some soil qualities and improve the sustainability of nutrient availability for crop production in small-scale farming systems.

4.2 Comparison of the effects of different agroforestry species on the soil chemical properties

Although there is a numerical difference, *Cordia Africana* and *Ficus sur* did not substantially differ in the majority of the metrics when agroforestry species were assessed for their influence on the chemical characteristics of soil beneath the influence zone (Fig. 2(A) and 2 (B)). Due to *Manihot esculenata*'s perceived economic value in the eyes of land users, it has been overwhelmingly expanding on farmlands in Southern Ethiopia at the expense of other woody perennials and agricultural crops (Mulualem and Dagne, 2015). In comparison to *Manihot esculenata*, the soil under *Cordia Africana* and *Ficus Sur* had much higher levels of available potassium, cation exchange capacity, and pH, however the differences between the two were not statistically significant. This may be connected to a plant's ability to extract the available potassium and other basic cations. In the agroforestry system, *Manihot esculenata* uses the surface nutrients, but *Cordia Africana* and *Ficus Sur* have a better chance of drawing nutrients from deep soil layers and pumping them up to the surface soil. The involvement of *Cordia Africana* and *Ficus Sur* in improving soil pH in comparison to *Manihot esculenata* is a very significant attribute to consider when choosing the optimum species for an agroforestry system to achieve sustainable land productivity (Neina, 2019).

Different agroforestry species have different amounts and types of litter, which affects soil characteristics and microbial biomass differently depending on the species (Getaneh *et al*., 2022, Liu *et al*., 2022; Szott *et al*., 1991; Yohannes *et al*., 2020). *Ficus sur* had a bigger effect on the total nitrogen in the soil in the current study than *Cordia Africana* and *Manihot esculenata*. On the other hand, there were no appreciable differences between the impacts of Cordia Africana and *Manihot esculenata* on the total nitrogen in the soil. The *Ficus Sur* tree's contribution to maintaining a higher amount of litter production and a quick decomposition rate may be connected to the increased soil total nitrogen derived from the canopy of the tree. The native fig *Ficus* species had the second-fastest rate of litter decomposition in the trial when compared to other woody species (Mutshekwa *et al*., 2020). *Ficus* species have a beneficial effect on the soil in the agroforestry system (Dhanya *et al*., 2013). *Manihot esculenata* and *Cordia Africana* showed no differences in their soil organic carbon and accessible phosphorus contents, but *Ficus sur* had much higher levels of both. Since the control of ecosystem carbon storage and nutrient cycling is greatly influenced by the pace of litter decomposition, soil fertility is governed by this rate of decomposition (Bossa *et al*., 2005; Santiago, 2007; Wardle, 2002). The current study's observation of different soil property variations under various species in an agroforestry system is therefore linked to potential differences in litter quality and decomposition rates. This justification leads us to the conclusion that the *Ficus sur* generally plays a superior function in enhancing agricultural land productivity. However, the numerical results of the current study show that *Cordia africana* also plays a major role in improving soil fertility compared to *Manihot esculenata*. Several studies back up this justification (Abdella *et al*., 2020; Abraham, 2014; Yadessa *et al*., 2009; Yadessa *et al*., 2001; Zebene, 2003). For the improvement of soil fertility, native plants like *Cordia africana* and *Ficus sur* are preferentially preserved on smallholder agricultural land (Lemage and Legesse, 2018), albeit their contributions vary according on the particular goal. The soil pH and Available K of *Manihot esculenata* were substantially lower than those of *Cordia Africana* and *Ficus Sur*. This may be as a result of the crop's huge nutrient extraction ability in an agroforestry system. Large amounts of nutrients, particularly potassium, are extracted from the soil by *Manihot esculenata* (Howeler 1991). According to Byju and Suja (2019), the cassava tuber contained roughly 60% of the potassium that was exported after harvest. K and calcium (Ca) accumulate in considerable amounts in *Manihot esculenata* (Howeler, 1985). The current soil condition in our study shows that, although not statistically significant, the soil CEC is lower and the soil pH has likely decreased because of the higher rate of basic cation depletion by *Manihot esculenata* compared to *Ficus sur* and *Cordia Africana*. In a similar manner, *Manihot esculenata* increases the mining of soil nutrients during crop harvest by storing a significant amount of readily available P and nitrogen in the tuber (Howeler, 1985).

4.3 Soil chemical property differences between agroforestry species along the elevation

Comparisons of the agroforestry species at various elevation ranges were conducted to ascertain whether the variation in elevation affects the impact of agroforestry species on the chemical properties of the soil. As a result, *Manihot esculenata* showed considerably decreased potassium availability in the soil at the upper, middle, and lower elevations, compared to *Cordia Africana* and *Ficus sur*, although the latter two responded similarly at all elevations. *Manihot esculenata*, which stores a significant quantity of potassium in the biomass of its tubers, is most likely to blame for this since it mines potassium from the soil through tuber harvesting (Byju and Suja, 2019).

Along the elevation gradient the pattern of agroforestry species' influence on soil pH is erratic. The impact of agroforestry species on the soil pH, percentage of organic carbon, total nitrogen, and available phosphorus is statistically similar at both higher and lower elevations. Comparing *Manihot esculenata* to *Ficus sur* and *Cordia africana*, measurements show that it has statistically significantly lower available potassium at lower elevations, significantly lower pH at middle elevations, and significantly lower cation exchange capacity at upper elevation. In all elevations *Ficus sur* and *Cordia africana* showed a similar pattern with higher soil pH values, demonstrating that the species' influence on the soil chemical characteristics is more pronounced than the influence of elevation. On the other hand, all elevations showed statistically equivalent effects of *Ficus sur*, *Cordia africana*, and *Manihot esculenata* on the percentage of organic carbon, total nitrogen, and available phosphorus. The soil cation exchange capacity was found to be much higher under *Ficus sur* and *Cordia Africana* in the higher elevation range. Comparatively to *Manihot esculenata*, CEC under *Ficus sur* was found to be substantially greater in the medium elevation. In agricultural land, *Manihot esculenata* management would result in poorer cation exchange capacity than *Ficus sur* and *Cordia Africana* management, regardless of the elevation range.

4.4 Soil chemical properties variation of the agroforestry species at various elevations

When comparing the role of each of the agroforestry species on the soil chemical properties at different elevations(Table 5), available potassium, pH, percent organic carbon, total nitrogen, and available phosphorus were not significantly different for *Cordia Africana, Ficus sur* and *Manihot esculenata*. Hence, the influence of agroforestry species on soil properties is not affected by the elevation. In the same talk, the soil Cation exchange capacity (CEC) which was not different under *Cordia Africana* and *Ficus sur* in all elevations showed variation along the elevation gradient in case for *Manihot esculenata. Consequently*, the highest value of soil CEC was found in the lower elevation, and the lowest in higher elevation. This suggests that to minimize the detrimental effect on the soil CEC, *Manihot esculenata* should only be used in the lower elevation zone of the agroforestry system. If the crop is not managed effectively, the production of cassava (*Manihot esculenata*) on sloping terrain can lead to significant erosion (Howeler, 1991), which increases the loss of basic cations by run-off and weakens the soil's cation exchange capacity.

Conclusion

The soil under the agroforestry species has significantly better chemical characteristics as compared to soil without a cover of woody species. However, depending on the species maintained in the agroforestry system or practice, the extent to which agroforestry species influence soil chemical characteristics varies. As a result, *Cordia africana* comes in second place behind *Ficus sur* in terms of enhancing the majority of the chemical properties of the soil. *Manihot esculenata*, on the other hand, has the least favorable effects on several soil chemical characteristics.

For the majority of the parameters included in the current study, the impact of agroforestry species on the soil chemical properties is not exacerbated by differences in elevation. However, *Manihot esculenata* harvesting in the upper elevations poses the risk of weak soil functionality over the long term due to the lowest soil cation exchange capacity. In the agroforestry system, the sustainability of the soil property is generally discriminated against due to the persistent shortage of farmland and the paradigm shift from short-term economically attractive "*Manihot esculenata*" to ecologically significant species like *Ficus sur* and *Cordia Africana*. We strongly suggest that *Ficus sur* and *Cordia africana* are much better at improving the soil chemical properties to ensure the sustainable soil productivity in the agroforestry system than cassava crop (*Manihot esculenata*). Indeed, more investigation is required to clarify the rate at which the litter decomposes in agroforestry species in order to confirm the impact of these species on the chemical composition of the soil. To assist land users in choosing an appropriate agroforestry species, it is also important to assess the trade-offs between economic valuation and ecological function of the contesting agroforestry species.

Declarations

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Figures

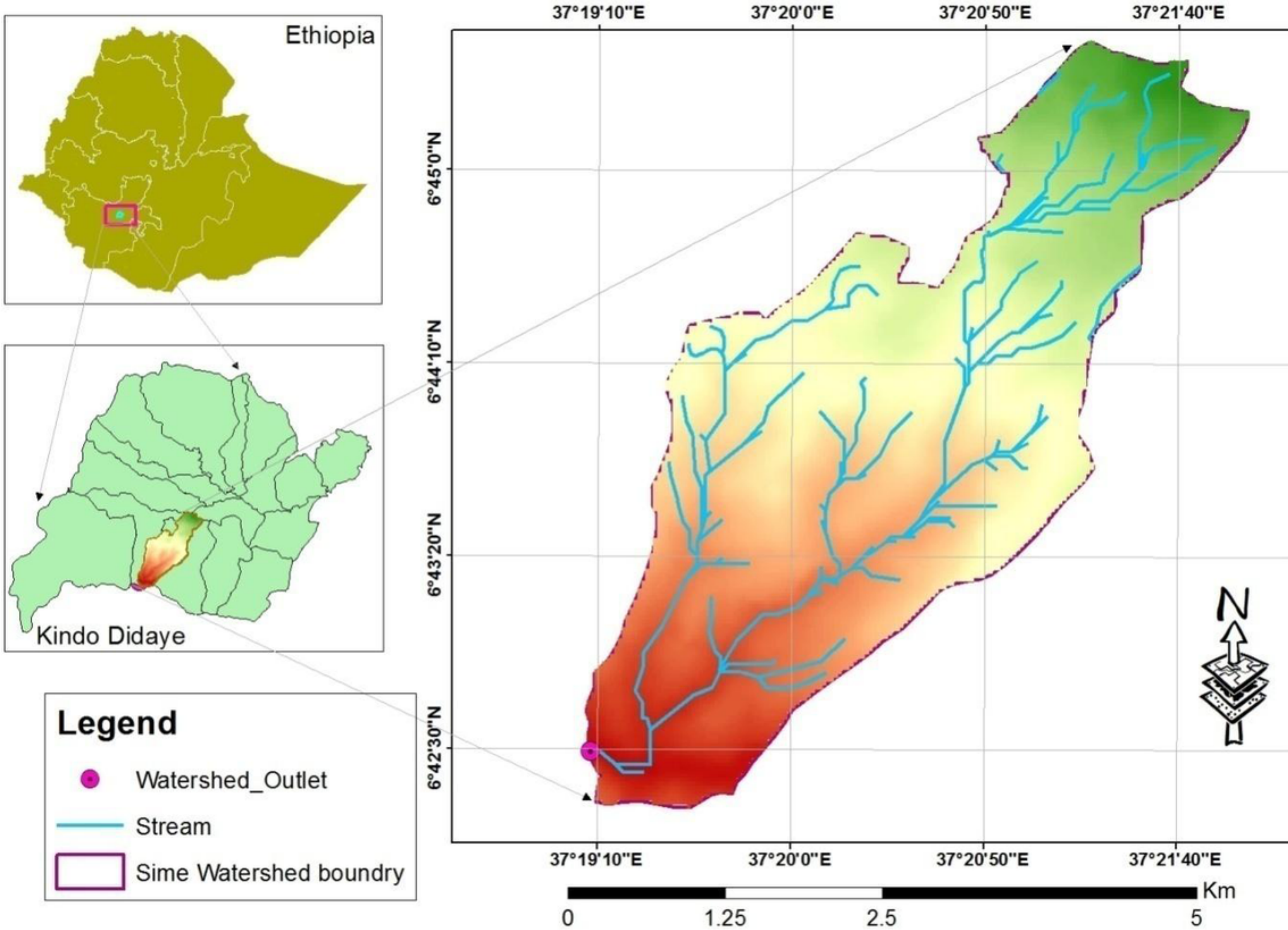
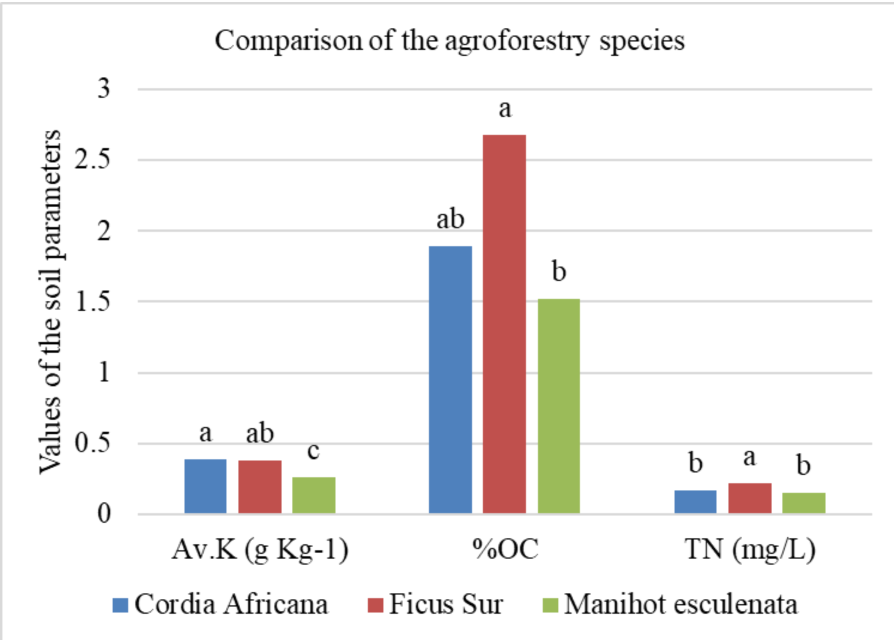
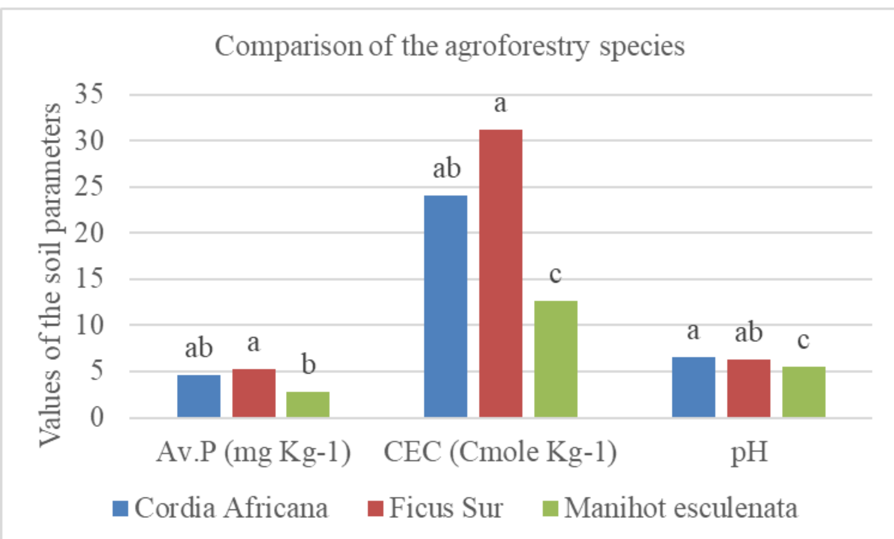


Figure 1

Watershed map of the study area



A



B

Figure 2

(A): Comparisons of agroforestry species for their influence on some soil chemical properties under the canopy cover. Note: Av. K for (available potassium), %OC for (percent organic carbon), and TN for (total nitrogen). (B): Comparisons of agroforestry species for their influence on some soil chemical properties under the canopy cover. Note: Av. P for (available phosphorus), CEC for (Cation exchange capacity), and pH for (soil pH),