

The effect of Ensosila (*Impatiens tinctoria*) on soil physico-chemical properties across soil depth and topographic position in Northern Ethiopia

Halefom Giday

halefom.giday@mu.edu.et

Mekelle University College of Dryland Agriculture and Natural Resources <https://orcid.org/0009-0009-5796-1471>

Kassa Teka

Yemane Welday

Research Article

Keywords: Di-Ammonium Phosphate, Endamehoni district, Key soil parameters, Residual effect

Posted Date: February 17th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-8170105/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Abstract

Background and Aims

Impatiens tinctoria A. Rich, locally known as Ensosila, is a traditional cosmetic herb native to East Africa, specifically Tigray, Ethiopia. In Southern Tigray, where this study took place, Ensosila has been cultivated on small farms for its cosmetic uses for many years. However, the species is now facing the threat of extinction due to limited awareness of its additional benefits like its potential impact on soil productivity. Hence, this study was initiated to investigate the effects of Ensosila cultivation on selected soil physico-chemical properties across soil depths and topographic positions.

Methods

Soil samples were taken from two land uses, Ensosila planted and non-planted farmlands, two soil depths (0–30 cm and 30–60 cm) and three topographic positions (upper, middle and lower). Key soil parameters including texture, bulk density (BD), pH, electrical conductivity (EC), soil organic carbon (SOC), total nitrogen (TN), available phosphorus (Av.P) and exchangeable potassium (Ex.K) were taken as major indicators. Data were analyzed using ANOVA and mean comparisons were made using LSD.

Results

The results revealed that all tested soil parameters were significantly ($p < 0.05$) affected by land use. Ensosila planted soils had 1.4%, 6.3%, 31.9%, 46.2%, 27.6% and 7.4% higher pH, EC, SOC, TN, Av. P and Ex.K, respectively. Plantation of the herb also resulted 3.3% lower in BD. Furthermore, its residual effect contributed to a 15.53 kg/ha of di-ammonium phosphate (DAP) equivalent.

Conclusions

It can be concluded that Ensosila had a potential impact on enhancing soil physico-chemical properties.

Introduction

In many countries, people have been using natural substances such as *Impatiens* to increase their natural beauty for thousands of years (Akbar, 2020; Chungkrang & Bhuyan, 2020; Sripriya, 2024; Vaidya et al., 2023). Cosmetics from parts of the plant such as bark, leaf, flowers, roots, fruits and seeds are used by people to improve their natural beauty, maintaining a youthful appearance, increase their sensuality, and preserve their health and hygiene (Desam & Al-Rajab, 2021; John et al., 2014; Vaidya et al., 2023). Globally, there are more than 1000 *Impatiens* species distributed while more than 100 species have been cultivated both annually and perennially with high succulent stems in Africa (Cheek et al., 2022; Gadagkar et al., 2023; Janssens et al., 2012).

Impatiens tinctoria is one of the largest species in the genus of *Impatiens* and is dominant in East African countries such as Ethiopia, Sudan, Uganda, Zaire, Kenya, Tanzania, Malawi and Zambia (Seboka, 2017). In the regions of Ethiopia, Ensosila (*Impatiens tinctoria*) is one of the most abundant perennial herb species commonly found in East Shewa (Alemayehu et al., 2022; Burju et al., 2014; Gurmessa et al., 2013; Nune, 2008), Butajura (Degu et al., 2020), Endamohoni Tigray (Amede & Taye, 2015), South Gondar and West Gojjam (A. B. Mekonnen et al., 2022; Yayesh et al., 2015).

It is growing vertically up to 2 m tall, branching, succulent hollow stem and a smooth tuber with a large tuberous rootstock up to 30 cm × 10 cm (Fig. 1A & B) that lies below the soil surface (Chen et al., 2020; Matthews et al., 2015; Seboka, 2017). It also tends to grow in wet deep clay loam soils, gentle slope, usually at an altitude ranging from 750 to 3630 m above sea level with about 10–27 °C preferable temperature interval (Hailesilassie, 2016; Matthews et al., 2015; Seboka, 2017). It propagates easily by cutting (Favi et al., 2021; Jansen, 2005; Kaviani et al., 2021).

Traditionally, Ensosila is used to treat various diseases such as bacterial and fungal infections (Gidamo, 2023; Li et al., 2024; Yang et al., 2001), cough medicine with phlegm, skin inflammation, and healing burns (Hedberg, 1996; Pimple et al., 2023). Ethiopian women also use Ensosila (*Impatiens tinctoria*) as beautifying agent (Amede & Taye, 2015). They chop the inner part of the tubers into a paste to dye the palm hands (Fig. 1C & D) and nails and making complicated patterns on the hands and feet even during festivity (Hedberg, 1996). Furthermore, Ensosila is grown as a cash herb in both rain-fed and supplementary irrigation systems that has been cultivated in small farmlands by smallholder farmers (Zuberi et al., 2014).

However, the herb is currently in a threat of extinction as farmers have a limited knowledge of the multifunctional benefits of the plant species (e.g. effect on soil productivity) other than its cosmetic and medicinal uses. In this case, a critical study that deals on planting Ensosila species and its effect on soil physico-chemical properties is scant. Hence, this study was conducted with the aim of evaluating the effect of Ensosila on selected soil physical and chemical properties in Endamehoni district, Southern Tigray (northern Ethiopia).

Materials and Methods

Description of the study area

The study was carried out at the Embahasti kebele of Endamehoni district, Southern Tigray (Northern Ethiopia). It is geographically located at 39°31' – 39°35' E and 12°48' – 12°53' N (Fig. 2) at about 121 km south of Mekelle city (the Tigray capital) with an average elevation of about 2,875 m.a.s.l (AREP,

2015).

Embahasti Kebelle represents the highlands cool sub-moist to moist and partially the mid-highland areas of the district. It has erratic, unevenly distributed and bimodal rainfall. The short rainy season locally known as “Belgi” occurs usually from mid-January to March (15%) and the main rain season is locally described as “Kiremti” that comes during mid June to mid-September (85%). The annual mean rainfall ranges from 600 to 950 mm. The annual temperature ranges between 12 °C and 18 °C (Hagos & Girma, 2018; Van Beek et al., 2016). The area is dominated by basalt parent materials and the geological formation was Alaje formation and Ashnge formation (FAO & ISRIC, 2012). In addition, the soil types in the study area were grouped into chromic Vertisols and eutric Cambisols (AREP, 2015; Van Beek et al., 2016). From the total cultivated area, about 26 hectare (3.26%) was planted with Ensosila (*Impatiens tinctoria*) in the year 2024.

Data collection method

Study site selection criteria and reconnaissance survey

The study site, Embahasti Kebelle, was selected due to the dominant presence of *Ensosila* tuber plant. About ten trips of reconnaissance field survey were carried out in order to identify the two land use types (Ensosila planted and never planted areas), and characterize and take soil samples (Figs. 3 and 4).

With these adjacent representative land uses, two soil depths (0–30 and 30–60 cm) and three topographic positions that have different elevation ranges (upper topographic position = > 2900 m, middle topographic position = 2850–2900 m and lower topographic position = 2,800–2,850 m) were used for the study (Fig. 4). This classification helps to characterize the soil parameters and nutrient availability under the three elevation classes (Seifu et al., 2020).

Soil sampling and analysis method

A total of 72 soil samples (36 undisturbed and 36 disturbed) were taken from the two land use types, two soil depths and three topographic locations replicated three times before the tillage operations. The disturbed soil samples were collected and thoroughly mixed, transported to the laboratory, air-dried, crushed and made to pass through a 2 mm sieve. These samples were used for soil chemical properties (pH, EC, SOC, TN, Av.P and Ex.K) analysis using standard laboratory methods (Table 1). Laboratory work was done at Mekelle Soil Research Center, Tigray Agricultural Research Institute, Mekelle, Ethiopia. The undisturbed soil samples were collected using core sampler for bulk density and coarse fragment determination. Soil moisture content was determined gravimetrically by oven drying the whole soil at 105 °C for 24 hours to calculate the dry fine BD (Blake & Hartge, 2018). An adjustment for pure fine bulk density was made by identifying and measuring coarse fragment proportion because it affects the soil carbon estimation (Ellert et al., 2001).

Table 1
Selected soil properties and their method of analysis

Parameters	Method of analysis	Sources
Soil Texture	Hydrometer	(Bouyoucos, 1962)
BD	Excavation/Core method	(Blake & Hartge, 2018)
pH	Soil: Water ratio 1: 2.5	(Jackson, 1967)
EC	Soil: Water ratio 1: 2.5	(Corwin & Rhoades, 1984)
SOC	Walkley and Black method	(Walkley & Black, 1934)
Total N	Kjeldahl method	(Bremner & Mulvaney, 1982)
Av. P	Extraction method	(Olsen, 1954)
Ex. K	Neutral ammonium acetate	(Jackson, 1958)

Statistical analysis

Data were tested for normal distribution before analysis. Then, all the collected data were subjected to analysis using GenStat software version 18th (Goedhart & Thissen, 2018). For the quantitative variables, analysis of variance (ANOVA) and Pearson correlation were used within the general linear model (GML) to compare the significance change in soil physicochemical properties and significances differences were compared using the least significance difference (LSD) comparison method at 5% probability (0.05 significance level).

Results

Effect of Ensosila on soil physical properties

Soil particle content was significantly ($p < 0.05$) affected by land use (Table 2). The proportion of sand, silt and clay in percent was increased by 13.7%, decreased by 1.4% and decreased by12.3% respectively in non-planted areas. The soil particle size distribution on different land uses along soil depth and elevation difference was significantly different. Along the topographic position, the lowest sand content was also recorded in the lower topographic position (Table 2).

Table 2. Effect of Ensosila along soil depth and topographic position on means of particle size distribution and BD

SD and EA	Sand (%)				Silt (%)				Clay (%)				Textural class		Bulk density (g/cm ³)			
	NP	P	LSD _{0.05}	CV (%)	NP	P	LSD _{0.05}	CV (%)	NP	P	LSD _{0.05}	CV (%)	NP	P	NP	P	LSD _{0.05}	CV (%)
0 – 30 cm	46.17 ^a	32.9 ^b	7.8 ^{**}	8.7	26.13	27.6	2.79 ^{ns}	4.6	27.7 ^b	39.5 ^a	7.01 ^{**}	9.2	Sandy clay loam	Clay loam	1.20 ^a	1.12 ^b	0.072 [*]	6.2
30 – 60 cm	43.23 ^a	29.1 ^b	9.32 [*]	11.4	26.47	27.8	3.14 ^{ns}	5.1	30.3 ^b	43.1 ^a	7.85 [*]	9.4	Clay loam	Clay	1.28	1.26	0.068 ^{ns}	5.4
Upper	47.15 ^a	30.5 ^b	9.32 [*]	5.6	25.2 ^b	28.9 ^a	2.75 [*]	2.1	27.65 ^b	40.6 ^a	11.74 [*]	8.0	Sandy clay loam	Clay	1.30	1.27	0.084 ^{ns}	5.1
Middle	47.45 ^a	33.7 ^b	7.83 [*]	4.5	26.85	26.2	1.16 ^{ns}	1.0	25.7 ^b	40.1 ^a	7.1 [*]	5.0	Sandy clay loam	Clay	1.22	1.20	0.078 ^{ns}	5.0
Lower	39.5	28.8	15.97 ^{ns}	10.9	26.85	28.0	4.11 ^{ns}	3.5	33.65	43.2	12.06 ^{ns}	7.3	Clay loam	Clay	1.16	1.10	0.077 ^{ns}	5.3
Grand mean	44.7 ^a	31.0 ^b	3.82 ^{**}	25.62	26.3	27.7	4.10 ^{ns}	3.26	29.0 ^b	41.3 ^a	1.27 ^{**}	25.15	Clay loam	Clay	1.23	1.19	0.016 ^{***}	7.26

***, ** and * indicate significant different at 0.1% ($p < 0.001$), 1% ($p < 0.01$) and 5% ($p < 0.05$) level of significance respectively; ns: non-significant with means followed by different letters in the same row showed significantly different on LSD test; NP: non-planted area; P: planted area; SD: Soil depth; EA: Elevation Aspect

Soil bulk density was significantly ($p < 0.05$) affected by land use. The bulk density in both land uses has increased in magnitude with soil depth. The lowest value was recorded on soils in planted areas, with 6.67% and 1.56% reduction at the top and lower depths, respectively.

Effect of Ensosila on soil chemical properties

Comprehensively, pH has shown a 1.36% increase on planted areas compared to the non-planted areas. The mean pH (H₂O) value was found to be neutral (7.35) on the non-planted area and mildly alkaline (7.45) on the *Ensosila* planted area (Table 3) as per the rating of (Beyene et al., 2023) and (Wogi et al., 2021). *Ensosila* plantation had significant ($p < 0.05$) effect on soil pH, with the lowest value on non-planted areas. The result revealed that Ensosila along soil depth has resulted in a 2.2% and 0.54% increase in pH at both topsoil and subsurface layer, respectively. In relation to topographic position, the planted area has increased by 1.6%, 1.1% and 1.2% in upper, middle and lower, respectively (Table 3). There was statistically ($p < 0.05$) significant difference in EC content between land uses and soil depths with the highest value in the lower depth and in the planted areas.

There was a significant difference ($p < 0.05$) in soil organic carbon content among land use types (Table 3). The mean Soil Organic Carbon (SOC) concentration varied from 14.4 g/kg (*Ensosila* non-planted area) to 19 g/kg (*Ensosila* planted area), which was in the range of moderate to high according to the classification made in (Hazelton & Murphy, 2007). According to Hazelton and Murphy, OC is classified as very low (< 6 g/kg), low (6 – 9.9 g/kg), moderate (10 – 15.9 g/kg), high (16 – 19.9 g/kg) and very high (> 19.9 g/kg). The findings showed that *Ensosila* plantation has increased SOC content by 31.9%. The mean value of organic carbon has also shown a decreasing trend across depth with a statistically significant difference ($p < 0.05$). This is related to a decrease in faunal activities in the underlying horizons as reported in (Lawal et al., 2014). The soil organic carbon (SOC) was significantly ($p < 0.05$) higher in the lower topographic position (16.12 g/kg) followed by middle (14.5 g/kg) and upper (13.25 g/kg) in the area of non-planted. This trend was also confirmed in the other land use type with lowest value recorded at the upper topographic position (16.87 g/kg) followed by middle (18.95 g/kg) and lower (21.3 g/kg).

Table 3. Effect of Ensosila along soil depth and topographic position on means of soil pH, EC, SOC and TN

SD and EA	pH H2O (1:2.5)				EC H2O (1:2.5) (dS/m)				SOC (g/kg)				TN (g/kg)		
	NP	P	LSD _{0.05}	CV (%)	NP	P	LSD _{0.05}	CV (%)	NP	P	LSD _{0.05}	CV (%)	NP	P	LSD _{0.05}
0 – 30 cm	7.3 ^b	7.46 ^a	0.112 ^{**}	1.5	0.079	0.083	0.004 ^{ns}	5.2	15.36 ^b	20.80 ^a	0.937 ^{***}	11.0	1.57 ^b	2.11 ^a	0.256 ^{***}
30 – 60 cm	7.4	7.44	0.108 ^{ns}	1.5	0.082 ^b	0.088 ^a	0.003 ^{**}	4.0	13.47 ^b	17.28 ^a	1.619 ^{***}	10.5	1.56 ^b	1.80 ^a	0.257 ^{***}
Upper	7.36	7.48	0.153 ^{ns}	1.6	0.078	0.083	0.006 ^{ns}	5.4	13.25 ^b	16.87 ^a	2.019 ^{***}	10.6	1.22 ^b	1.67 ^a	0.315 ^{**}
Middle	7.35	7.43	0.156 ^{ns}	1.6	0.081	0.085	0.005 ^{ns}	4.4	14.5 ^b	18.95 ^a	1.834 ^{***}	8.50	1.30 ^b	1.97 ^a	0.318 ^{***}
Lower	7.35	7.44	0.148 ^{ns}	1.6	0.083	0.087	0.005 ^{ns}	4.6	16.12 ^b	21.3 ^a	2.449 ^{***}	10.2	1.57 ^b	2.23 ^a	0.347 ^{**}
Grand mean	7.35 ^b	7.45 ^a	0.07 ^{**}	1.64	0.08 ^b	0.085 ^a	0.002 ^{***}	5.8	14.4 ^b	19 ^a	0.37 ^{***}	19.44	1.30 ^b	1.90 ^a	0.12 ^{***}

***, ** and * indicate significant different at 0.1% ($p < 0.001$), 1% ($p < 0.01$) and 5% ($p < 0.05$) level of significance respectively; ns: non-significant with means followed by different letters in the same row showed significantly different on LSD test; NP: non-planted area; P: planted area; SD: Soil depth; EA: Elevation Aspect

Total nitrogen had shown a significant variation among land uses ($p < 0.001$). The average value of total nitrogen (TN) content was higher on *Ensosila* planted areas (1.9 g/kg) as compared to the other land use type (1.3 g/kg). These values are classified as low to medium following Havlin *et al.* (1999) classification guideline. Havlin and others classified total N as very low (< 0.5 g/kg), low (1.0 – 1.5 g/kg), medium (1.5 – 2.5 g/kg), and high (> 2.5 g/kg). The result showed that the average value of total nitrogen decreased with an increase in soil depth on both land uses (Table 3). It is 34.4% and 15.4% higher in the planted topsoil layer (0 – 30 cm) and subsurface layer (30 – 60 cm), respectively, compared to its corresponding non-planted one. Total nitrogen value under

different land uses along soil depth had also shown a significant difference ($p < 0.05$). The total nitrogen content showed a decreasing trend with elevation: upper topographic position (1.22 g/kg) < middle (1.30 g/kg) < lower (1.57 g/kg) at non-planted area while 1.67 g/kg < 1.97 g/kg < 2.23 g/kg, respectively at planted area.

The Av.P recorded in the planted area was 20.13 mg/kg while 15.78 mg/kg was in the non-planted area (Table 4). These were, respectively, categorized as high and medium following to the (Wogi et al., 2021) classification guide that categorized Av.P values as very low (< 5 mg/kg), low (6 – 9), medium (10 – 17), high (18 – 25 mg/kg) and very high (> 25 mg/kg). It was statistically different ($p < 0.05$) between the land uses, with a 27.6% increase in the planted area. Available phosphorus (Av.P) was significantly ($p < 0.05$) different along soil depth. A higher value was recorded at the top soil layer (22.42 mg/kg) than that of the subsurface layer (17.85 mg/kg). The available phosphorus content was also statistically significantly ($p < 0.005$) different in the upper topographic position but not significant different in the middle and lower topographic positions. However, the trend was inversely related to topographic position that showed an increase in available phosphorus with a decrease in elevation. For instance, Av.P was higher (20.75 mg/kg) at the lower position as compared to the upper position (19.61 mg/kg) (Table 4), which is, respectively, classified as high and lower following (Wogi et al., 2021) classification guide.

Table 4. Effect of Ensosila along soil depth and topographic position on means of Av.P and Ex. K

SD and EA	Av.P (mg/kg)					Ex. K (cmol(+)/kg)				
	NP	P	LSD _{0.05}	CV (%)	Pvalue	NP	P	LSD _{0.05}	CV (%)	Pvalue
0 – 30 cm	18.11 ^b	22.42 ^a	3.40 ^{**}	16.8	0.016	0.7	0.72	0.052 ^{ns}	7.5	0.064
30 – 60 cm	13.45 ^b	17.85 ^a	3.74 [*]	23.9	0.024	0.66 ^b	0.73 ^a	0.043 [*]	5.9	0.047
Upper	12.37 ^b	20.04 ^a	5.74 ^{**}	27.6	0.014	0.67 ^b	0.70 ^a	0.025 [*]	2.9	0.043
Middle	16.62	19.61	5.37 ^{ns}	23	0.243	0.67	0.71	0.046 ^{ns}	5.1	0.053
Lower	18.35	20.75	4.26 ^{ns}	16.9	0.237	0.71	0.77	0.082 ^{ns}	8.6	0.191
Grand mean	15.78 ^b	20.13 ^a	2.207 ^{***}	26.14	< 0.001	0.68 ^b	0.73 ^a	0.029 ^{**}	7.34	0.008

***, ** and * indicate significant different at 0.1% ($p < 0.001$), 1% ($p < 0.01$) and 5% ($p < 0.05$) level of significance respectively; ns: non-significant with means followed by different letters in the same row showed significantly different on LSD test; NP: non-planted area; P: planted area; SD: Soil depth; EA: Elevation Aspect

Exchangeable Potassium (Ex. K) ranged from 0.68 to 0.73 cmol (+)/kg (Table 4) and its rating was high at both land uses (planted and non-planted areas) following (Wogi et al., 2021) classification guideline. Wogi and others classified exchangeable Potassium as Very low (< 0.2 cmol (+)/kg), Low (0.2 – 0.3 cmol (+)/kg), Medium (0.3 – 0.6 cmol (+)/kg), High (0.6 – 1.2 cmol (+)/kg) and Very high (> 1.2 cmol (+)/kg). Potassium (K) was observed in a 7.35% higher amount in planted area (0.73 Cmol (+)/kg) than in the remaining non-planted area.

Regarding to soil depth, the mean exchangeable potassium (Ex. K) content of the soil across the non-planted and planted study area was 0.70 cmol (+)/kg and 0.72 cmol (+)/kg at the topsoil surface while 0.66 cmol (+)/kg and 0.73 cmol (+)/kg at subsurface layer which was decreasing and increasing to down as soil depth increased, respectively (Table 4). The result showed that potassium on planted area has increased by 2.86% at topsoil (0 – 30 cm) and 10.6% at the subsurface layer (30 – 60 cm). Exchangeable potassium did not show a statistically significant difference ($p > 0.05$) across the topsoil soil layers but significantly different ($p < 0.05$) on the subsurface layer.

Exchangeable potassium was statistically significantly different ($p < 0.05$) at upper topographic position but not significantly different ($p > 0.05$) in the middle and lower positions. The highest exchangeable potassium was recorded at the lower topographic position compared to the middle and upper (Table 4) at both land uses. It was recorded 0.67 cmol (+)/kg, 0.67 cmol (+)/kg and 0.71 cmol (+)/kg at the upper, middle and lower topographic position, respectively in the non-planted area; while 0.70 cmol (+)/kg, 0.71 cmol (+)/kg and 0.77 cmol (+)/kg at the planted area.

Discussion

Effect of Ensosila on soil physical properties

The proportion of silt and clay was higher in the *Ensosila* planted areas than their corresponding non-planted ones but sand fraction was lower at the *Ensosila* planted areas. These findings are consistent with Merga et al., (2023) that reported there was low clay content in surface layers of cultivated lands as a result of the removal of particles through erosion (both water and wind). The high clay fraction in the *Ensosila* planted area might also be due to the high organic matter added by the herb. Having these organic matter, clay particles stick-up with the tuberous plants of *Ensosila* (Ufot et al., 2016). In addition, the residual decayed leaves and stems of organic matter contributes to soil aggregation that enhances soil structure, improves water retention and stability of clay particles (Li et al., 2024). This finding aligns with the findings stated in Gadana (2021) that reported clay content remained stable (35–40%) in tuber crop fields, while adjacent wheat plots lost 10% clay due to erosion and Microbial biomass (linked to clay-SOM bonding). The average sand content of soils on Ensosila planted area decreases with depth, while an increase in sand content was observed on the non-planted soils. This corresponds with the findings of Asmare et al., (2023), Assefa et al., (2020), Fetene & Amara, (2018) Kebebew et al., (2022) and Masha et al., (2023) that reveals sand content is higher in cereal cultivated land than Agroforestry, grass land, Enset cultivated land and shrub land. This could be related to the organic matter addition from Ensosila

that enhances soil structure and water retention as well as less erosion prone to loss fine particles. The decreasing fraction from upper to lower topographic position agrees with the findings of (Haile et al., 2024). This was mainly related to a low erosion rate as well as higher material deposition at the lower position, while high erosion which migrates fine materials selectively away and leaves coarse particles in the upper position (Bufebo et al., 2021; Endrias et al., 2024; Jaleta Negasa, 2020; Seifu et al., 2020). In addition, mulch straw obtained from vegetable residues conserve fine soil particles from vulnerability of erosion by reducing runoff (El-Beltagi et al., 2022). Cumulatively, mean soil bulk density in *Ensosila* planted area has shown a 3.25% reduction as compared to its corresponding non-planted one. The decrease in bulk density in the planted area could be due to higher organic matter addition by the *Ensosila* herb. In this regard, (Mebrate et al., 2022) and (Sun et al., 2018) reported that crop residues addition and reduced tillage increased soil organic matter content, resulted in less soil disturbance and reduced soil bulk density. Similarly, this result is in agreement with the findings of (Seifu et al., 2021) that reported low and high bulk density values due to variation in contents of clay fraction and organic matter. However, soil bulk density was not significantly affected by topography but numerical value was recorded as order as upper position > middle position > lower position in both land uses. This result is in line with the findings of (Seifu et al., 2021) that reported mean value of bulk density in Lower elevation (2722–2800 m) < Middle elevation (2800–3100 m) < upper elevation (3100–3944 m) and statistically significant ($p < 0.05$).

Effect of *Ensosila* on soil chemical properties

This lower value can be the result of removal of basic cations due to erosion (Amusan, et al., 2006; Fentie et al., 2020; Selassie et al., 2015). The increment in pH values along the soil depth has been existed. This result could be associated with a higher organic matter content from *Ensosila* as it can bind tightly or traps basic cations, this may lead to decreased H^+ concentration and increased pH of the soil (Assefa et al., 2020; Bahilu et al., 2016; Bufoebo et al., 2021; Seifu et al., 2020). A similar result was recorded in (Azeez et al., 2018) that showed pH has decreased as soil depth increased in plantation while (Dhaliwal et al., 2023) and (Kaur et al., 2020) increased as soil depth increased due to leaching effect of the basic cations. The mean value of soil pH along elevation was statistically ($p > 0.05$) different.

In the planted areas, the EC content was significantly difference with highest result in the subsurface soil depth. The reason is might due to soluble salts of anions and cations move downward with leaching runoff, accumulating toward subsurface soil depth. In addition, since *Ensosila* tuber root is fleshy, it has the capacity to hold water having soluble salts (Gidamo, 2023; Seboka, 2017). This, in turn, might have caused an increase in EC values down the depth (Assefa et al., 2020; Dhaliwal et al., 2023). Similar studies such as (Dong et al., 2017) and (Ibrahim et al., 2022) stated that the highest accumulation of base forming cations like Ca^{+2} , Mg^{+2} , K^{+2} and high accumulation of $CaCO_3$ leads to increased EC. However, topographic position had no significant effect on EC. This result is in par with (Hailemariam et al., 2023) and (Kamal et al., 2023) that explained EC had no major difference along altitude.

The soil organic content along the land use type, there was high SOC content in the *Ensosila* plantation areas than non-planted areas. This is related to the high addition of organic materials through leaf fall or crop residues of the herb (Tsui et al., 2004). On the other hand, *Ensosila* plant has fat and fleshy tuber that regulates the runoff and soil loss; penetrates the soil depth that enhances the soil aeration and captures water and plant nutrients; boosts soil microbial activity that decomposes and incorporates the organic matter (Fentie et al., 2020; Sun et al., 2018; Tesemma, 2013). Likewise, (Lal, 2001) and (Abera & Belachew, 2011) stated that most cultivated land soils of Ethiopia are poor in their SOC content due to the low amount of organic materials applied to the soil and complete removal of the biomass from the field. Regarding to soil depth and topographic position, SOC content becomes decreasing as soil depth increase but increasing at lower topographic position. This is related to a decrease in faunal activities in the underlying horizons as reported in (Lawal et al., 2014) while high deposition of organic and fine materials at the lower topographic position (M. Mekonnen & Getahun, 2020). (Qiu et al., 2021) also highlighted a significant reduction of SOC mineralization at erodible sites. The practices of ex-situ organic materials in lower topographic position protects the long term fertility of the soils by maintaining a high level of OM content and increasing soil biological activities (Negash et al., 2012).

The highest total nitrogen content observed in the planted area may be attributed to the continuous input of organic matter, such as leaf litter and stems, from *Ensosila*. As these materials decompose, microbial activity facilitates their conversion into nitrogenous compounds (Birhane et al., 2020; Fahad et al., 2022; Kebede, 2021; Okolo et al., 2022; Song et al., 2023). Similar findings have been reported in Ethiopian agroecosystems, where organic amendments significantly enhance soil nitrogen levels (Aytenew & Bore, 2020; Bufoebo et al., 2021; Tesfay et al., 2020; Weldewahid et al., 2023). Even the amount of TN across the individual soil depth was high at planted areas than compared to the non-planted areas. In agreement with this result, (Anwanane et al., 2017) and (Manojlović et al., 2011) have reported that total nitrogen was high at the topsoil layer (0–30 cm) than subsurface (30–60 cm). The trend for total nitrogen through the topographic position was increasing to down position. This remarkable difference might be attributed to the removal of organic matter connecting to the displacing of total nitrogen from upper to middle and lasting at lower topographic position tended by water erosion (Bufoebo et al., 2021).

The available phosphorus was significantly difference with high existence value in the *Ensosila* planted areas. This could be attributed to the continuous organic matter addition from *Ensosila*, which can keep phosphorus from becoming bound to aluminum and other ions, thus making it more available (Condon & Tiessen, 2005; Jemaludin, 2020; Mebrate et al., 2022; Regassa et al., 2023). Similar findings were reported in (Anwanane et al., 2017), (Manojlović et al., 2011) and (Mebrate et al., 2022) in that available phosphorus was found to decrease across soil depth. The increase in available phosphorus in the planted land used could be attributed to the *Ensosila*'s ability to reduce nutrient displacement caused by surface erosion, thereby enhancing in-situ infiltration and leaching rather than ex-situ losses. Similar findings have been reported in Northern Ethiopia, where vegetation cover significantly reduced soil erosion and nutrient depletion (VandenBygaart et al., 2021). Additionally, the substantial increase in available phosphorus in the subsurface layer (30–60 cm) may be linked to the decomposition of *Ensosila*'s tuberous biomass deposited at deeper soil depths, which can contribute to subsurface nutrient enrichment (Geleta Likasa et al., 2024). The loss of phosphorus via erosion might be also high on the upper position and more deposition at the lower position. Findings in (Lawal et al., 2014), (Bufoebo et al., 2021), (Buraka et al., 2023) and (Hailemariam et al., 2023) also showed that Av. P decreases with an increase in elevation due to nutrient displacement by erosion.

In different land uses, exchangeable potassium content has been come high in the plantation areas than the non-planted areas. This might be due to the *Ensosila* that conserves the weathered potassium from erosion risks along the farmland. In the other way, it might be decomposition of the plant species

that could increase the exchangeable potassium in the soil. The report was supported by (Gidamo, 2023) that investigated the concentration of macro-nutrients found in the Ensosila plant was orderly potassium (K) > calcium (Ca) > magnesium (Mg) > sodium (Na). Other findings of Anwanane et al. (2017) revealed that the higher potassium content on the upper layer (0–30 cm) than the subsurface (30–60 cm). The result also agreed with in non-planted area but disagreed in planting area having 0.72 cmol (+)/kg in topsoil layer and 0.73 cmol (+)/kg in subsurface layer. The reason could be due to high clay content and organic matter in the subsurface layer particularly Ensosila stock zone increases the retention of cations. In addition, Tumayro and Tesgaye (2021), reported that the exchangeable bases (Ca, Mg, K and Na) increases from surface (0–15 cm) to sub- surface (15–30 cm) soil depths. It might be due to translocation of basic cations as truncating soil horizon subsurface to surface and vice versa by digging hoe for planting case. Along the topographic position, the exchangeable potassium was significantly difference at all classes between the land uses and inceasing from upper to lower position. This corresponds with the findings of (Mekuria et al., 2007), (Amare et al., 2013), (Bufebo et al., 2021) and (Buraka et al., 2023) that stated the highest exchangeable potassium in the lower position. This is might be due to the plant tuberous stock allows breaking the parent material as biological weathering (Babur, 2024; Dontsova et al., 2020) and the transportation of potassium reach materials from the upper & middle into the lower topographic position through erosion agents (Bufebo et al., 2021; Buraka et al., 2023).

Conclusions

This study indicated that the Ensosilatuber plant species is important to enhance both soil physicochemical properties and soil fertility. The soil pH, EC, SOC, TN, Av. P and Ex.K, respectively, increased by 1.4%, 6.3%, 31.9%, 46.2%, 27.6% and 7.4% but decreased its bulk density by 3.3% in soils under Ensosilaplanted farms. This is due to completely falling of leaf litter and decomposition of dead tuberous stocks. Furthermore, Ensosilahad prospecting potential on moisture conservation, source of nutrients and improving soil fertility due to its residual effect that contributes to a 15.53 kg/ha of DAP fertilizer equivalent. It can be concluded that Ensosila is key rotational strategic cash crop for improving soil fertility. Based on the findings, Ensosilais a contributor for selected important soil parameters and uses for improvement of soil fertility. Hence, it would advantage to use this crop as alternative rotational organic input to improve soil productivity and crop production.

Abbreivations

ANOVA	Analysis of variance
Av. P	Available Phosphorus
BD	Bulk density
CV	Coefficient variance
DAP	Di-ammonium Phosphate
EA	Elevation Aspect
EC	Electrical conductivity
Ex. K	Exchangeable Potassium
LSD	Least significant difference
NP	Non-Planting Area
P	Planting Area
pH	Power of Hydrogen
SD	Soil depth
SOC	Soil Organic Carbon
TN	Total nitrogen

Declarations

Data Availability

Data used in this manuscript are available upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest or personal relationships that could have influenced the work reported in this paper.

Authors' Contributions

Halefom Giday was involved in conceptualization, literature review, methodology, formal analysis, investigation, data curation and recordation, writing original draft, writing review and editing, and visualization. Kassa Teka was involved in conceptualization, methodology, supervision, writing, and review and editing. Yemane Welday was involved in conceptualization, reconnaissance survey, supervision, writing, and editing. All authors have read and approved the manuscript.

Acknowledgments

The authors thank Mekelle University for funding this study. The authors are also very grateful to all farmers for allowing us to take soil samples and equipping up with valuable information.

References

1. Abera Y, Belachew T (2011) *Effects of Landuse on Soil Organic Carbon and Nitrogen In Soils Of Bale, Southeastern Ethiopia*
2. Akbar S (2020) Handbook of 200 Medicinal Plants: A Comprehensive Review of Their Traditional Medical Uses and Scientific Justifications. Springer International Publishing. <https://doi.org/10.1007/978-3-030-16807-0>
3. Alemayehu K, Sara S, Addisie G (2022) Ethnoecological knowledge allied to the management of wild medicinal plants in Adaa District, East Shewa Zone of Oromia Regional State, Ethiopia. *Int J Biodivers Conserv* 14(1):35–52. <https://doi.org/10.5897/IJBC2019.1311>
4. Amare T, Terefe A, Selassie G, Yitafaru Y, Wolfgramm B, B., Hurni H (2013) Soil Properties and Crop Yields along the Terraces and Toposequence of Anjeni Watershed, Central Highlands of Ethiopia. *J Agric Sci* 5(2):p134. <https://doi.org/10.5539/jas.v5n2p134>
5. Amede T, Taye M (2015) Home garden assessment report: System niches, production and marketing constraints and intensification barriers in the Ethiopian highlands. International Crops Research Institute for Semi-arid Tropics
6. Amusan AA, Shitu AK, Makinde WO, Orewole O (2006) *Assessment of Changes In Selected Soil Properties Under Different Land Use In Obafemi Awolowo University Community, Ile-Ife, Nigeria*. 5(1), 1178–1184
7. Anwanane NB, Affinnih KO, Olaniyan JO (2017) Effect of slope and depth on soil chemical properties of a typical alfisol. *Poljoprivreda* 23(2):3–9. <https://doi.org/10.18047/poljo.23.2.1>
8. AREP (2015) *Africa RISING Ethiopia project in Tigray region*
9. Asmare TK, Abayneh B, Yigzaw M, Birhan TA (2023) The effect of land use type on selected soil physicochemical properties in Shihatig watershed, Dabat district, Northwest Ethiopia. *Heliyon* 9(5):e16038. <https://doi.org/10.1016/j.heliyon.2023.e16038>
10. Assefa F, Elias E, Soromessa T, Ayele GT (2020) Effect of Changes in Land-Use Management Practices on Soil Physicochemical Properties in Kabe Watershed, Ethiopia. *Air Soil Water Res* 13:1178622120939587. <https://doi.org/10.1177/1178622120939587>
11. Aytenew M, Bore G (2020) Effects of Organic Amendments on Soil Fertility and Environmental Quality: A Review. *J Plant Sci* 8(5):112. <https://doi.org/10.11648/j.jps.20200805.12>
12. Azeze JO, Ojewande BO, Olayinka OO, Adesodun JK (2018) Impact Assessment of Organic Farming on Soil Nutrients and Heavy Metal Content. *Trop AGRICULTURAL Sci*, 41(4)
13. Babur E (2024) Significant Differences in Microbial Soil Properties, Stoichiometry and Tree Growth Occurred within 15 Years after Afforestation on Different Parent Material. *Life* 14(9):1139. <https://doi.org/10.3390/life14091139>
14. Bahilu B, Abeyayehu A, Tadesse M, Bayu D (2016) The effect of land management practices on soil physical and chemical properties in Gojeb Sub-river Basin of Dedo District, Southwest Ethiopia. *J Soil Sci Environ Manage* 7(10):154–165. <https://doi.org/10.5897/JSSSEM2016.0574>
15. Beyene S, Regassa A, Mishra BB, Haile M (eds) (2023) *The Soils of Ethiopia*. Springer International Publishing. <https://doi.org/10.1007/978-3-031-17012-6>
16. Bihane E, Hailemariam M, Gebresamuel G, Araya T, Hadgu KM, Norgrove L (2020) Source of mycorrhizal inoculum influences growth of *Faidherbia albida* seedlings. *J Forestry Res* 31(1):313–323. <https://doi.org/10.1007/s11676-018-0810-7>
17. Blake GR, Hartge KH (2018) Bulk Density. In: Klute A (ed) *SSSA Book Series*. American Society of Agronomy. Soil Science Society of America, pp 363–375. <https://doi.org/10.2136/sssabookser5.1.2ed.c13>
18. Bouyoucos GJ (1962) Hydrometer Method Improved for Making Particle Size Analyses of Soils¹. *Agron J* 54(5):464–465. <https://doi.org/10.2134/agronj1962.00021962005400050028x>
19. Bremner JM, Mulvaney CS (1982) Nitrogen—Total. In A. L. Page (Ed.), *Agronomy Monographs* (1st ed., Vol. 9, pp. 595–624). Wiley. <https://doi.org/10.2134/agronmonogr9.2.2ed.c31>
20. Bufebo B, Elias E, Agegnehu G (2021) Effects of landscape positions on soil physicochemical properties at Shenkolla Watershed, South Central Ethiopia. *Environ Syst Res* 10(1):14. <https://doi.org/10.1186/s40068-021-00222-8>
21. Buraka T, Elias E, Lelago A (2023) Effects of land-use-cover-changes on selected soil physicochemical properties along slope position, Coka watershed, Southern Ethiopia. *Heliyon* 9(5):e16142. <https://doi.org/10.1016/j.heliyon.2023.e16142>
22. Burju T, Hundera K, Kelbessa E (2014) Floristic Composition and Structural Analysis of Jibat Humid Afromontane Forest, West Shewa Zone, Oromia National Regional State, Ethiopia. *Ethiop J Educ Sci* 8(2):11–34. <https://doi.org/10.4314/ejesc.v8i2>
23. Cheek M, Darbyshire I, Onana JM (2022) *Impatiens banen sp. Nov. & I. etugei sp. Nov. (Balsaminaceae), threatened lowland species of the Cross-Sanaga Interval, Cameroon*. *Plant Biol*. <https://doi.org/10.1101/2022.05.01.490166>

24. Chen M, Vial ML, Gee L, Davis RA, John S, J. A., Ekberg JAK (2020) The plant natural product 2-methoxy-1,4-naphthoquinone stimulates therapeutic neural repair properties of olfactory ensheathing cells. *Sci Rep* 10(1):951. <https://doi.org/10.1038/s41598-020-57793-2>
25. Chungkrang L, Bhuyan S (2020) Natural Dye Sources and its Applications in Textiles: A Brief Review. *Int J Curr Microbiol Appl Sci* 9(10):261–269. <https://doi.org/10.20546/ijcmas.2020.910.034>
26. Condrón LM, Tiessen H (2005) Interactions of organic phosphorus in terrestrial ecosystems. In B. L. Turner, E. Frossard, & D. S. Baldwin (Eds.), *Organic phosphorus in the environment* (1st ed., pp. 295–307). CABI Publishing. <https://doi.org/10.1079/9780851998220.0295>
27. Corwin DL, Rhoades JD (1984) Measurement of Inverted Electrical Conductivity Profiles Using Electromagnetic Induction. *Soil Sci Soc Am J* 48(2):288–291. <https://doi.org/10.2136/sssaj1984.03615995004800020011x>
28. Degu S, Gemeda N, Abebe A, Berihun A, Debebe E, Sisay B, Gemeda H, Ashebir R, Amano A, Fekadu N, Kasahun T, Taye S, Bitew A (2020) *In vitro* antifungal activity, phytochemical screening and thin layer chromatography profiling of *Impatiens tinctoria* A. Rich root extracts. 8(5), 189–196
29. Desam NR, Al-Rajab AJ (2021) The Importance of Natural Products in Cosmetics. In D. Pal & A. K. Nayak (Eds.), *Bioactive Natural Products for Pharmaceutical Applications* (Vol. 140, pp. 643–685). Springer International Publishing. https://doi.org/10.1007/978-3-030-54027-2_19
30. Dhaliwal SS, Sharma V, Shukla AK, Kaur J, Gupta RK, Verma V, Kaur M, Singh VK, Singh P (2023) Interactive effect of land use systems on depth-wise soil properties and micronutrients minerals in North-Western, India. *Heliyon* 9(2):e13591. <https://doi.org/10.1016/j.heliyon.2023.e13591>
31. Dong Z, Hu G, Qian G, Lu J, Zhang Z, Luo W, Lyu P (2017) High-Altitude Aeolian Research on the Tibetan Plateau. *Rev Geophys* 55(4):864–901. <https://doi.org/10.1002/2017RG000585>
32. Dontsova K, Balogh-Brunstad Z, Chorover J (2020) Plants as Drivers of Rock Weathering. In K. Dontsova, Z. Balogh-Brunstad, & G. Le Roux (Eds.), *Geophysical Monograph Series* (1st ed., pp. 33–58). Wiley. <https://doi.org/10.1002/9781119413332.ch2>
33. El-Beltagi HS, Basit A, Mohamed HI, Ali I, Ullah S, Kamel EAR, Shalaby TA, Ramadan KMA, Alkhateeb AA, Ghazzawy HS (2022) Mulching as a Sustainable Water and Soil Saving Practice in Agriculture: A Review. *Agronomy* 12(8):1881. <https://doi.org/10.3390/agronomy12081881>
34. Ellert B, Janzen H, Mcconkey BG (2001) *Measuring and comparing soil carbon storage* (pp. 131–146)
35. Endrias M, Assen M, Legass A (2024) Effect of land-use types and topographic positions on soil physico-chemical properties in urago and mendi micro-watersheds, Becho District, Central Highlands of Ethiopia. *Cogent Food Agric* 10(1):2356933. <https://doi.org/10.1080/23311932.2024.2356933>
36. Fahad S, Chavan SB, Chichaghare AR, Uthappa AR, Kumar M, Kakade V, Pradhan A, Jinger D, Rawale G, Yadav DK, Kumar V, Farooq TH, Ali B, Sawant AV, Saud S, Chen S, Poccai P (2022) Agroforestry Systems for Soil Health Improvement and Maintenance. *Sustainability* 14(22):14877. <https://doi.org/10.3390/su142214877>
37. FAO I, ISRIC I (2012) *Harmonized world soil database v1.2 | FAO SOILS PORTAL | Food and Agriculture Organization of the United Nations*. <https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en/>
38. Favi GA, Dassou GH, Adomou AC, Fandohan AB, Sogbohossou EOD, Yedomonhan H, Tossou MG, Akoègninou A (2021) *Cochlospermum planchonii* Hook.f. ex Planch. and *Cochlospermum tinctorium* Perrier ex A. Rich.: Extent of knowledge and prospects for sustainable use in West Africa. *Genet Resour Crop Evol* 68(1):25–44. <https://doi.org/10.1007/s10722-020-01062-8>
39. Fentie SF, Jembere K, Fekadu E, Wasie D (2020) Land Use and Land Cover Dynamics and Properties of Soils under Different Land Uses in the Tejjibara Watershed, Ethiopia. *The Scientific World Journal*, 2020, 1–12. <https://doi.org/10.1155/2020/1479460>
40. Fetene EM, Amara MY (2018) The effects of land use types and soil depth on soil properties of Agedit watershed, Northwest Ethiopia. *Ethiop J Sci Technol* 11(1):39. <https://doi.org/10.4314/ejst.v11i1.4>
41. Gadagkar SR, Baeza JA, Buss K, Johnson N (2023) *De-novo* whole genome assembly of the orange jewelweed, *Impatiens capensis* Meerb. (Balsaminaceae) using nanopore long-read sequencing. *PeerJ* 11:e16328. <https://doi.org/10.7717/peerj.16328>
42. Geleta Likasa W, Fufa Feyessa F, Bekele Sima A (2024) Exploring the Influence of Land Use Types on Soil Properties at Arjo-Dhidhessa Sugar Estate, Western Ethiopia. *Appl Environ Soil Sci* 2024(1):6949296. <https://doi.org/10.1155/aess/6949296>
43. Gidamo GH (2023) Antioxidant activity and mineral content of *Impatiens tinctoria* A. Rich (Ensosila) tuber, an Ethiopian medicinal plant. *Sci Rep* 13(1):14998. <https://doi.org/10.1038/s41598-023-41824-9>
44. Goedhart PW, Thissen JTNM (2018) *Biometris GenStat Procedure Library Manual 19th Edition*
45. Gurmesssa F, Soromessa T, Kelbessa E (2013) Floristic Composition and Community Analysis of Komto Afromontane Moist Forest, East Wollega Zone, West Ethiopia. *Sci Technol Arts Res J* 2(2):58. <https://doi.org/10.4314/star.v2i2.98887>
46. Hagos KM, Girma T (2018) Determinants of the adoption of improved faba bean varieties in Enda-Mehoni district, South Tigray, Northern Ethiopia. *J Dev Agricultural Econ* 10(10):352–358. <https://doi.org/10.5897/JDAE2018.0927>
47. Haile G, Gebre C, Lemenih M, Agegnehu G (2024) Soil property and crop yield responses to variation in land use and topographic position: Case study from southern highland of Ethiopia. *Heliyon* 10(3):e25098. <https://doi.org/10.1016/j.heliyon.2024.e25098>
48. Hailemariam MB, Woldu Z, Asfaw Z, Lulekal E (2023) Impact of Elevation Change on the Physicochemical Properties of Forest Soil in South Omo Zone, Southern Ethiopia. *Applied and Environmental Soil Science*, 2023, 1–17. <https://doi.org/10.1155/2023/7305618>
49. Hailesilassie H (2016) *The effect of improved fodder production on livestock productivity in Endamehoni District, southern Tigray Ethiopia* [Mekelle University]. <https://hdl.handle.net/10568/81207>
50. Hazelton P, Murphy B (2007) Interpreting Soil Test Results: What Do All the Numbers Mean? *CSIRO*, 1–152. <https://doi.org/10.1071/9780643094680>
51. Hedberg I (1996) Flora of Ethiopia and Eritrea. In L. J. G. Van Der Maesen, X. M. Van Der Burgt, & J. M. Van Medenbach De Rooy (Eds.), *The Biodiversity of African Plants* (pp. 802–804). Springer Netherlands. https://doi.org/10.1007/978-94-009-0285-5_104

52. Ibrahim IA, Jabbour AA, Abdulmajeed AM, Elhady ME, Almaroai YA, Hashim AM (2022) Adaptive Responses of Four Medicinal Plants to High Altitude Oxidative Stresses through the Regulation of Antioxidants and Secondary Metabolites. *Agronomy* 12(12):3032. <https://doi.org/10.3390/agronomy12123032>
53. Jackson ML (1958) *Soil Chemical Analysis*. Prentice-Hall Inc., Englewood Cliffs. <https://www.scirp.org/reference/referencespapers?referenceid=2049089>
54. Jackson ML (1967) *Soil Chemical Analysis*. Prentice-Hall of India Pvt. Ltd., New Delhi. <https://www.scirp.org/reference/referencespapers?referenceid=105097>
55. Jaleta Negasa D (2020) Effects of Land Use Types on Selected Soil Properties in Central Highlands of Ethiopia. *Appl Environ Soil Sci* 2020:1–9. <https://doi.org/10.1155/2020/7026929>
56. Jansen PCM (2005) Dyes and Tannins. PROTA
57. Janssens SB, Smets EF, Vrijdaghs A (2012) Floral development of Hydrocera and Impatiens reveals evolutionary trends in the earliest diverged lineages of the Balsaminaceae. *Ann Botany* 109(7):1285–1296. <https://doi.org/10.1093/aob/mcs065>
58. Jemaludin Akemal (2020) The effect of Enset management practices on soil fertility (Ensete ventricosum): The case of Enemorna Ener wereda, Gurage zone, SNNPR. Ethiopia. *Global Sci J*, 8(3).
59. John SK, Beegum SSU, Ravi V (2014) Management of the Waste Lands by Exploiting the Carbon Sequestration Potential and Climate Resilience of Cassava. *J ROOT CROPS* 40(2):28–32
60. Kamal A, Mian IA, Akbar WA, Rahim HU, Irfan M, Ali S, Alrefael AF, Zaman W (2023) Effects of Soil Depth and Altitude On Soil Texture And Soil Quality Index. *Appl Ecol Environ Res* 21(5):4135–4154. https://doi.org/10.15666/aeer/2105_41354154
61. Kaur R, Singh B, Dhaliwal SS (2020) Dynamics of Soil Cationic Micronutrients in a Chronosequence of Poplar (*Populus deltoides* Bartr.)-Based Agroforestry System in India. *J Soil Sci Plant Nutr* 20(4):2025–2041. <https://doi.org/10.1007/s42729-020-00272-4>
62. Kaviani B, Almasi A, Sedaghatthoor S, Khoddamazadeh AA (2021) A protocol for fast in vitro propagation of Impatiens hawkeri cv. Sweeties Blue Star, an important ornamental-cover species. *Rodriguésia* 72:e02562019. <https://doi.org/10.1590/2175-7860202172053>
63. Kebebew S, Bedadi B, Erkossa T, Yimer F, Wogi L (2022) Effect of Different Land-Use Types on Soil Properties in Cheha District, South-Central Ethiopia. *Sustainability* 14(3):1323. <https://doi.org/10.3390/su14031323>
64. Kebede E (2021) Contribution, Utilization, and Improvement of Legumes-Driven Biological Nitrogen Fixation in Agricultural Systems. *Frontiers in Sustainable Food Systems, Volume 5-2021*. <https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2021.767998>
65. Lal R (2001) World cropland soils as a source or sink for atmospheric carbon. In *Advances in Agronomy* (Vol. 71, pp. 145–191). Elsevier. [https://doi.org/10.1016/S0065-2113\(01\)71014-0](https://doi.org/10.1016/S0065-2113(01)71014-0)
66. Lawal BA, Tsado PA, Eze PC, Idefoh KK, Zaki AA, Kolawole S (2014) Effect of Slope Positions on some Properties of Soils under a Tectona grandis Plantation in Minna, Southern Guinea Savanna of Nigeria. *Int J Res Agric Forestry* 1(2):37–43
67. Li X, Li J, Zhao Z, Zhou K, Zhan X, Wang Y, Liu N, Han X, Li X (2024) Soil Organic Carbon and Humus Characteristics: Response and Evolution to Long-Term Direct/Carbonized Straw Return to Field. *Agronomy* 14(10):2400. <https://doi.org/10.3390/agronomy14102400>
68. Manojlović M, Čabilovski R, Sitaula B (2011) Soil Organic Carbon in Serbian Mountain Soils: Effects of Land Use and Altitude. *J Environ Stud* 20(4):977–986
69. Masha M, Belayneh M, Bojago E, Tadiwos S, Dessalegn A (2023) Impacts of land-use and topography on soil physicochemical properties in the Wamancho watershed, Southern Ethiopia. *J Agric Food Res* 14:100854. <https://doi.org/10.1016/j.jafr.2023.100854>
70. Matthews J, Beringen R, Boer E, Duistermaat H, Odé B (2015) *Risks and management of non-native Impatiens species in the Netherlands*
71. Mebrate A, Kippie T, Zeray N, Haile G (2022) Selected physical and chemical properties of soil under different agroecological zone in Gedeo Zone, Southern Ethiopia. *Heliyon* 8(12):e12011. <https://doi.org/10.1016/j.heliyon.2022.e12011>
72. Mekonnen AB, Mohammed AS, Tefera AK (2022) Ethnobotanical Study of Traditional Medicinal Plants Used to Treat Human and Animal Diseases in Sedie Muja District, South Gondar, Ethiopia. *Evidence-Based Complementary and Alternative Medicine*, 2022, 1–22. <https://doi.org/10.1155/2022/7328613>
73. Mekonnen M, Getahun M (2020) Soil conservation practices contribution in trapping sediment and soil organic carbon, Minizir watershed, northwest highlands of Ethiopia. *J Soils Sediments* 20(5):2484–2494. <https://doi.org/10.1007/s11368-020-02611-5>
74. Mekuria W, Veldkamp E, Haile M, Nyssen J, Muys B, Gebrehiwot K (2007) Effectiveness of exclosures to restore degraded soils as a result of overgrazing in Tigray, Ethiopia. *J Arid Environ* 69(2):270–284. <https://doi.org/10.1016/j.jaridenv.2006.10.009>
75. Merga K, Gidago G, Laekemariam F (2023) Soil Fertility Status as Influenced by Slope Gradient and Land Use Types in Southern Ethiopia. *Applied and Environmental Soil Science*, 2023, 1–13. <https://doi.org/10.1155/2023/8583671>
76. Negash M, Yirdaw E, Luukkanen O (2012) Potential of indigenous multistrata agroforests for maintaining native floristic diversity in the south-eastern Rift Valley escarpment, Ethiopia. *Agroforest Syst* 85(1):9–28. <https://doi.org/10.1007/s10457-011-9408-1>
77. Nune S (2008) *Flora Biodiversity Assessment in Bonga, Boginda and Mankira Forest, Kafa, Ethiopia*
78. Okolo CC, Bore E, Gebresamuel G, Zenebe A, Haile M, Nwite JN, Dippold MA (2022) Priming effect in semi-arid soils of northern Ethiopia under different land use types. *Biogeochemistry* 158(3):383–403. <https://doi.org/10.1007/s10533-022-00905-z>
79. Olsen SR (1954) Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. U.S. Department of Agriculture
80. Pimple B, Vadje S, Kuchekar M, Chumbhale D, Tare M, Baheti D (2023) Pharmacognostic Investigations of Impatiens balsamina Linn. *Int J Experimental Res Rev* 30:119–126. <https://doi.org/10.52756/ijerr.2023.v30.013>

81. Qiu L, Zhu H, Liu J, Yao Y, Wang X, Rong G, Zhao X, Shao M, Wei X (2021) Soil erosion significantly reduces organic carbon and nitrogen mineralization in a simulated experiment. *Agric Ecosyst Environ* 307:107232. <https://doi.org/10.1016/j.agee.2020.107232>
82. Regassa A, Kibret K, Selassie YG, Kiflu A, Tena W (2023) Soil Properties. In S. Beyene, A. Regassa, B. B. Mishra, & M. Haile (Eds.), *The Soils of Ethiopia* (pp. 111–156). Springer International Publishing. https://doi.org/10.1007/978-3-031-17012-6_7
83. Seboka N (2017) *Bioprospecting Potential of Impatiens tinctoria for Access and Benefit Sharing*
84. Seifu W, Elias E, Gebresamuel G (2020) The Effects of Land Use and Landscape Position on Soil Physicochemical Properties in a Semiarid Watershed, Northern Ethiopia. *Applied and Environmental Soil Science*, 2020, 1–20. <https://doi.org/10.1155/2020/8816248>
85. Seifu W, Elias E, Gebresamuel G, Khanal S (2021) Impact of land use type and altitudinal gradient on topsoil organic carbon and nitrogen stocks in the semi-arid watershed of northern Ethiopia. *Heliyon* 7(4):e06770. <https://doi.org/10.1016/j.heliyon.2021.e06770>
86. Selassie YG, Anemut F, Addisu S (2015) The effects of land use types, management practices and slope classes on selected soil physico-chemical properties in Zikre watershed, North-Western Ethiopia. *Environ Syst Res* 4(1):3. <https://doi.org/10.1186/s40068-015-0027-0>
87. Song Y, Yu Y, Li Y, Du M (2023) Leaf litter chemistry and its effects on soil microorganisms in different ages of *Zanthoxylum planispinum* var. *Dintanensis*. *BMC Plant Biol* 23(1):262. <https://doi.org/10.1186/s12870-023-04274-z>
88. Sriprya D (2024) The Ingenuous Evaluation on Herbal Cosmetics. *World J Pharm Res* 13(13):1437–1448. <https://doi.org/10.20959/wjpr202413-33098>
89. Sun D, Yang H, Guan D, Yang M, Wu J, Yuan F, Jin C, Wang A, Zhang Y (2018) The effects of land use change on soil infiltration capacity in China: A meta-analysis. *Sci Total Environ* 626:1394–1401. <https://doi.org/10.1016/j.scitotenv.2018.01.104>
90. Tesemma MN (2013), November 22 *The indigenous agroforestry systems of the south-eastern Rift Valley escarpment, Ethiopia: Their biodiversity, carbon stocks, and litterfall*. <https://helda.helsinki.fi/items/853e0bde-6ab3-4f81-868c-84ef5d3f902e>
91. Tesfay F, Kibret K, Gebrekirstos A, Hadgu KM (2020) Litterfall production and associated carbon and nitrogen flux along exclosure chronosequence at Kewet district, central lowland of Ethiopia. *Environ Syst Res* 9(1):11. <https://doi.org/10.1186/s40068-020-00172-7>
92. Tsui C-C, Chen Z-S, Hsieh C-F (2004) Relationships between soil properties and slope position in a lowland rain forest of southern Taiwan. *Geoderma* 123(1–2):131–142. <https://doi.org/10.1016/j.geoderma.2004.01.031>
93. Ufot UO, Iren OB, Chikere Njoku CU (2016) Effects of Land Use on Soil Physical and Chemical Properties in Akokwa Area of Imo State, Nigeria. *Int J Life-Sciences Sci Res* 2(3). <https://doi.org/10.21276/ijlssr.2016.2.3.14>
94. Vaidya SN, Agrawal S, Telrandhe UB, Pimpale A (2023) A review on recent scenario of herbal cosmetics. *Annals Phytomedicine Int J* 12(1). <https://doi.org/10.54085/ap.2023.12.1.17>
95. Van Beek CL, Elias E, Yihenew GS, Heesmans H, Tsegaye A, Feyisa H, Tolla M, Melmuye M, Gebremeskel Y, Mengist S (2016) Soil nutrient balances under diverse agro-ecological settings in Ethiopia. *Nutr Cycl Agrosyst* 106(3):257–274. <https://doi.org/10.1007/s10705-016-9803-0>
96. VandenBygaart AJ, Geng X, He J (2021) Spatial decoupling of legacy phosphorus in cropland: Soil erosion and deposition as a mechanism for storage. *Soil Tillage Res* 211:105050. <https://doi.org/10.1016/j.still.2021.105050>
97. WALKLEY A, BLACK IA (1934) An Examination Of The Degtjareff Method For Determining Soil Organic Matter, And A Proposed Modification Of The Chromic Acid Titration Method. *Soil Sci* 37(1):29–38
98. Weldewahid Y, Habtu S, Taye G, Teka K, Gessesse TA (2023) Effects of long-term irrigation practice on soil quality, organic carbon and total nitrogen stocks in the drylands of Ethiopia. *J Arid Environ* 214:104982. <https://doi.org/10.1016/j.jaridenv.2023.104982>
99. Wogi L, Dechassa N, Haileselassie B, Mekuria F, Abebe A, Tamene LD (2021) *A guide to standardized methods of analysis for soil, water, plant, and fertilizer resources for data documentation and sharing in Ethiopia*. <https://hdl.handle.net/10568/115840>
100. Yang X, Summerhurst DK, Koval SF, Ficker C, Smith ML, Bernards MA (2001) Isolation of an antimicrobial compound from *Impatiens balsamina* L. using bioassay-guided fractionation. *Phytother Res* 15(8):676–680. <https://doi.org/10.1002/ptr.906>
101. Yayesh L, Shemsu U, Messay W-M (2015) Ethnobotanical study on traditional medicinal plants in Dega Damot Woreda, Amhara Region, North Ethiopia. *Int J Res Pharm Chem* 5(2):258–273
102. Zuberi MI, Kebede B, Gosaye T, Belachew O (2014) *Species of herbal spices grown in the poor farmers' home gardens of West Shoa, Highlands of Ethiopia: An Ethnobotanical account*

Figures

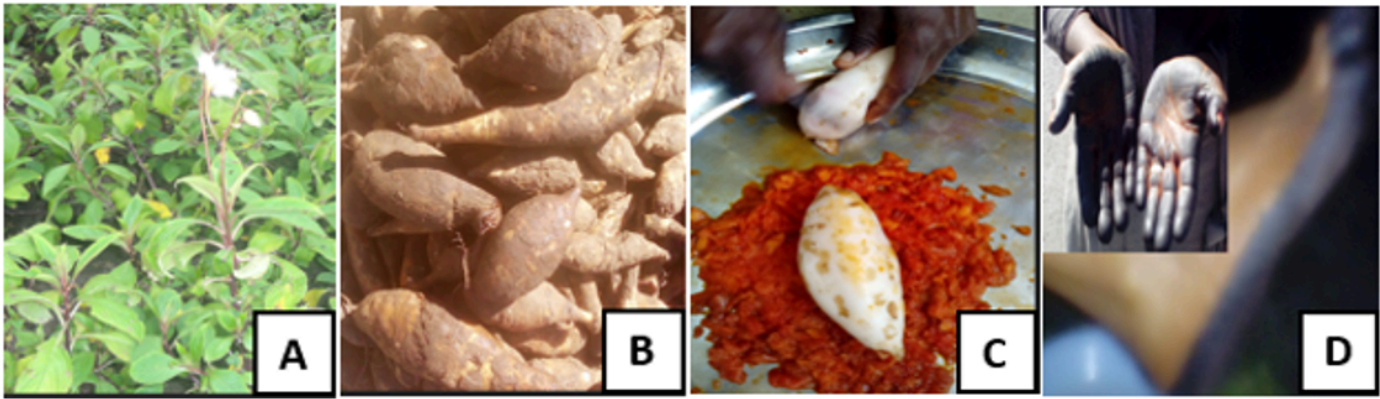


Figure 1

The *Impatiens tinctoria* A) Shoots B) Tuber roots C) Chopping D) Pasted on palm and feet

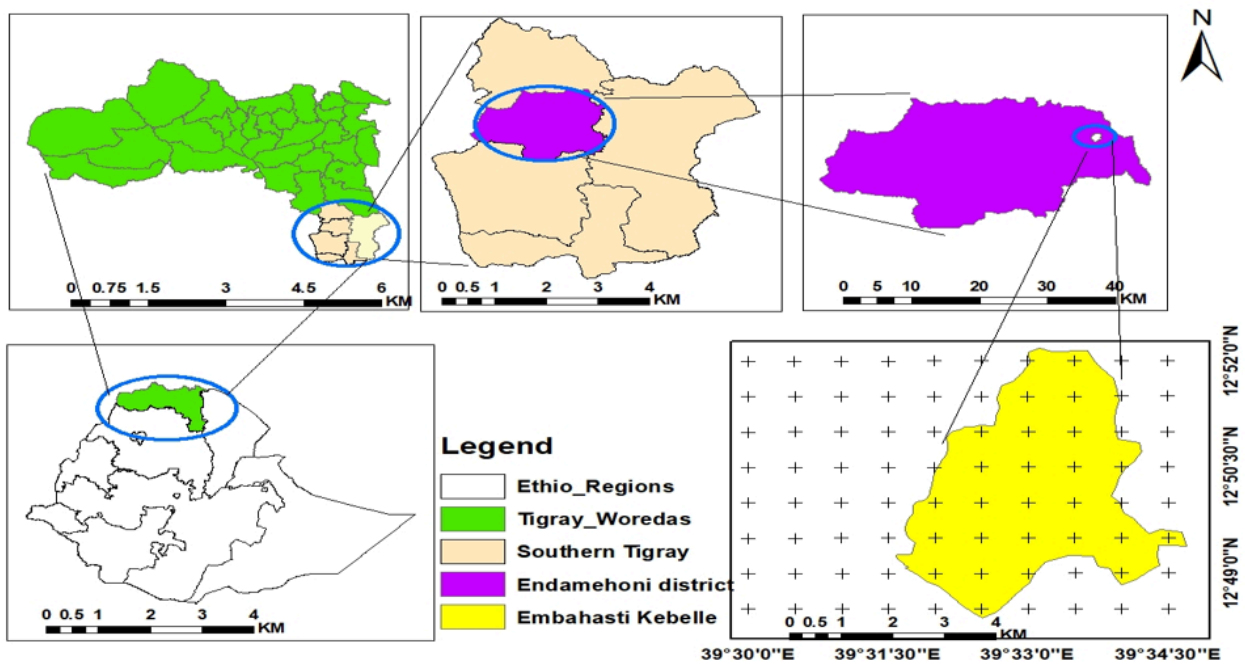


Figure 2

Location map of the study



Figure 3

land use types as planted (a) and non-planted (b) areas

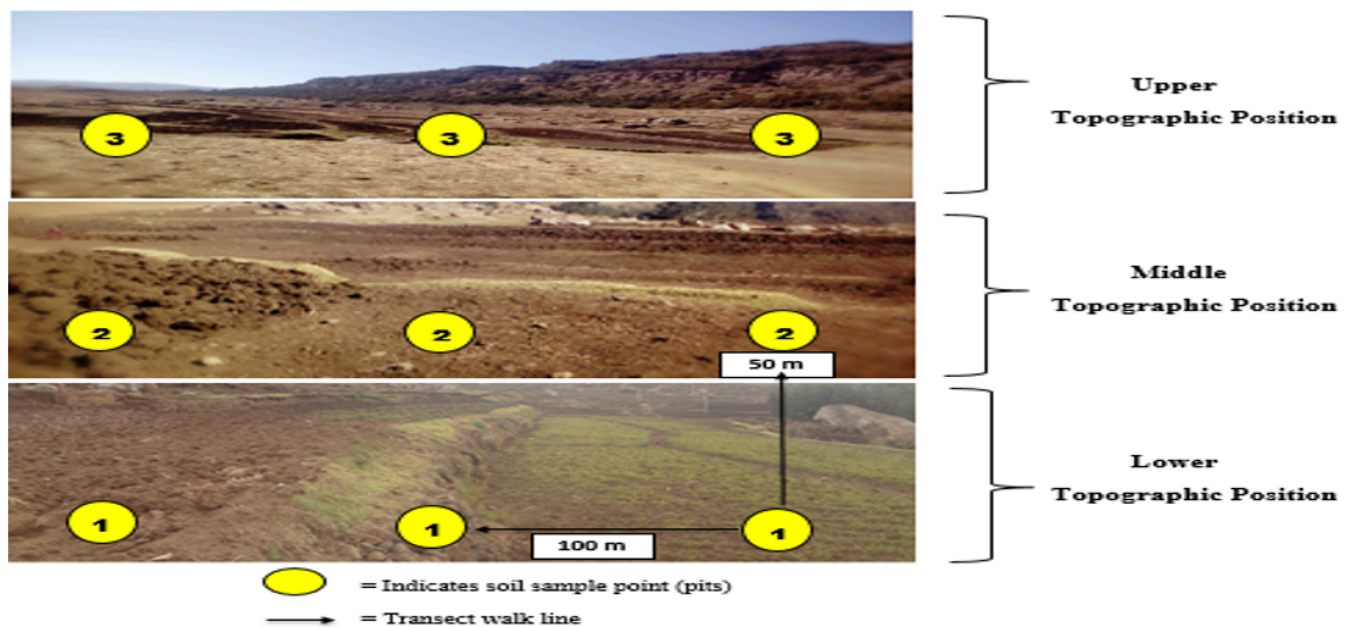


Figure 4

Site design and sampling points for a single land use type