Assessing available soil nitrogen under different land use types in Fagita Lekoma district, northwest Ethiopia

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# ***ABSTRACT***

*There has been a notable shift in land use from annual crop cultivation to short-rotation A. mearnsii woodlots in the Fagita Lekoma district in northwest Ethiopia. It was primarily driven by market demand for charcoal production. This study was intended at analyzing the effects of* A.mearnsii woodlots*in relation to other land use types. A total of 60 samples were collected from five land uses at 0–15 cm and 15–30 cm soil depth. Soil moisture, soil bulk density, pH, soil active carbon, and soil available nitrogen (Ammonium and Nitrate) were analyzed by the standard procedures. Soil moisture, soil bulk density, soil pH, soil active carbon, and available soil nitrogen had significant differences (*p < *0.05) among land use type. This suggests, cultivation of A. mearnsii woodlots should be practice in rotation as it improves soil carbon and available soil nitrogen for sustainable cropping systems. Variation of soil active carbon and available soil nitrogen among different land use types were minimal on the lower soil depth as compared to the surface soil layer, implying that the surface soil layer was most affected by different management practices. On the basis of the above findings, there is a need to develop sustainable soil management and cropping practices to combat the ongoing soil degradation and improve soil fertility.*

***Keywords:*** A. mearnsii, *available soil nitrogen, Fagita-Lekoma, land use type, woodlot*

# **INTRODUCTION**

In Ethiopia's highlands, land use change, deforestation, and soil erosion are the most serious environmental issues that lead to a deterioration in soil quality (Gashaw et al. 2014; Asmame and Abegaz, 2018). Furthermore, Eyayu et al. (2009) stated soil fertility reduction, and loss of soil quality (Asmamaw and Mohammed, 2013) in Ethiopia are caused by the conversion of forest area into agriculture or rangeland. As a result, there was a notable reduction in forest cover (Wassie et al. 2010; Eshete et al. 2011). This led to soil erosion, which is the primary cause of the deterioration in soil fertility caused by the conversion of forests into agriculture and grazing land (Asmame and Abegaz, 2018; Bazie et al. 2020). Land use conversion also had a significant impact on soil quality, according to Zobeck et al. (2015). A significant environmental issue is the decrease in soil quality brought on by improper land use and inadequate soil management, which was again the outcome of clearing forests for cereal cultivation (Gebreyesus, 2013). Reduced soil fertility has an impact on soil quality (Lemenih et al. 2005) and the terrestrial ecosystem's nutrient cycles (Sukumar et al. 2000), and soil quality (Lemenih et al. 2005), as well as soil physicochemical characteristics (Valentine et al. 2018). Due to frequent farming and forest clearing, the Fagita Lekoma district in Ethiopia's highlands faced major soil problems (Abiot and Ewketu, 2017; Bazie et al. 2020). In the Fagita Lekoma district's Amesha watershed, forest clearance for crop production caused to soil erosion (Wondie and Mekuria, 2018). However, the A. mearnsii tree has caused a notable alteration in the watershed, and has become a new land use system for farmers in the Awi zone.

Therefore, A. mearnsii trees based farming is thought to improve soil fertility and crop yield by restoring soil quality. Farmers in the Fagita Lekoma district assert that A. mearnsii trees offer extra benefits in enhancing soil fertility and reclaiming damaged land, even though the main driver of the growth of A. mearnsii woodlots is economic gain. The impact of changing land use on soil quality is site-specific and heavily influenced by the kind of soil. Therefore, it is imperative to evaluate how various land use transitions affect indices of soil quality. Soil nitrogen availability in Fagita Lekoma, Awi zone, specifically in the Amesha watershed, was therefore evaluated in relation to land use type and land use conversion from cropland to short-term rotation of A. mearnsii woodlot.

**MATERIALS AND METHODS**

**Description of the study site**

The study was held in 2023 at Amesha watershed, Fagita Lekoma district, Amhara region, Ethiopia, covering 4810.49ha with altitude ranges of 1800-2900 m.a.s.l. and located between 10056’–11012’ N latitude and 36040’–37006’ E. The rainfall pattern of the area is bimodal, with mean annual rainfall of 1500 mm to 2500 mm. The mean annual temperature ranges from 12°C to 22°C. Most of the rainfall occurs from June to August (Wondie and Mekuria, 2018). Subsistence agriculture is the major economic activity in the study area (Tesfaye et al. 2014). The major crops were maize, teff, wheat, finguremillet. The main land cover types (LCTs) are cropland, forestland, and grassland, settlements, and A.mearnsii woodlot. The major soil types in the study site are Acrisols and Nitosols (Nigussie et al. 2016). The smallholder farmers in the study area predominantly practice cereal-based production, tree-based farming, livestock rising, or a combination of these practices (Abegaz, 2005). The species A.mearnsii is the principal exotic tree species that local farmers cultivate and utilize for fuel and other wood-related products is A.mearnsii in Fagita Lekoma.

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Figure 1: Map of the study area

Table 1: Basic soil sample characteristics for different land use type

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| --- | --- | --- | --- | --- | --- | --- |
| ***LUT*** | ***Area covered in (ha)*** | ***Area proportion (%)*** | ***Number of sample*** | ***Sample proportion (%)*** | ***Species density (100m2)*** | ***Land use history/vegetation type*** |
| *OADCL* | *1.59* | *10.6* | *12* | *20* | *None* | *Teff (Eragrostis tef), Wheat (Triticum aestivum), Maize (Zea mays),* |
| *CL* | *0.91* | *6.05* | *12* | *20* | *None* | *Teff (Eragrostis tef), Wheat (Triticum aestivum), Maize (Zea mays),* |
| *GL* | *3.8* | *25.3* | *12* | *20* | *7* | *Grass, Abalo (Terminalia schimperiana)* |
| *1AD6* | *2.92* | *19.4* | *12* | *20* | *84* | *A. mearnsii* |
| *NF* | *5.8* | *38.6* | *12* | *20* | *53* | *Abalo (Terminalia schimperiana), Bisana (Croton macrostachyus), Keret (Osyris quadripartite), Koba /kumel (Mimusops kummel), Lankuso (Chiliocephalum schimperi), Bazira girar (Acacia abyssinica), Donga (Apodytes dimidiate), Dokma (Syzygium guineense),* |

*Note: from vegetation type, name in bracket is scientific name for every local name of plant species. LUT: land use type; GL: grazing land; NF: natural forest; CL: cropland; OADCL: cropland that previously A.mearnsii woodlot before two years; 1AD6: six years with 1st rotation cultivation of A.mearnsii woodlot.*

**Experimental Design and Soil Sampling Method**

The selected watershed was divided into six sampling locations with a 6 km × 6 km grid size. The center of the six sampling locations was marked and subsequently uploaded to Google Earth for navigation purposes in the field. Then, five land use types (grazing land; natural forest; cropland; cropland that previously A.mearnsii woodlot before two years; six years with 1st rotation cultivation of A.mearnsii woodlot) were used for this study. After selecting the land uses purposively, soil samples were collected at two soil depths (0–15 cm and 15–30 cm) in 10 m ×10 m plots using a hand-driven auger. In each plot, soil samples were collected at the center and four corners. Soil samples from similar layers were mixed to make a composite soil sample. A total of 60 samples were collected for this study. In addition, 60 undisturbed samples were collected using a core sampler (c.a. 10 cm and 14 cm, diameter and height, respectively) in each plot for soil bulk density analysis. Soil samples were air-dried sieved with 2 mm sieve size prior to soil chemical and physical analysis. All soil samples were analyzed at Agri-Ceft soil and water laboratory, Addis Ababa, Ethiopia.

**Soil analysis**

Soil pH was measured in 1:2.5 soils to 0.01M CaCl2 ratio using a digital pH meter (McLean, 1982). Soil ammonium (NH+4) was determined using the indophenol blue method (Carter and Gregorich, 2007). Soil nitrate (NO-3) was measured according to Kachurina et al. (2000) and Nesterenko et al. (2016) methods. The concentration of soil active carbon was determined using the method of KMnO4 oxidation protocol (Weil et al. 2003). The soil bulk density (BD) was measured oven-dried weight (105 oC for 24 hours) divided by the core volume.

$V=πr^{2}h (cm3)$ …………………………………………………… (Eq. 1)

Where, V = the volume of the core in (cm3), r = radius of the core in (cm), and h = height of the core in (cm).

$BD=\frac{Ms (g)}{V (cm3) }$ ………………………………………………..….……. (Eq. 2)

Where, BD = soil bulk density in ($\frac{ g}{cm3 }$), Ms = soil oven-dry weight (g), and V = bulk volume of the soil in (cm3).

The soil moisture content was determined by the gravimetric method described by Kolay (2000).

$SMC\left(\%\right)=100\*(\frac{Wwet-Wdry}{Wdry})$ ………………………….………… (Eq. 3)

Where SMC: soil moisture content (%), W (wet) = weight of soil before oven-dry (g), W (dry) = weight of soil after oven-dry (g).

**Statistical analysis**

Before any statistical analysis, the data were checked for normality and homogeneity of variance. Data that violate the normality and homogeneity of variance were transformed using log. To identify the effect of different land use type on available soil nitrogen, soil moisture, soil bulk density, soil pH, and soil active carbon One-way and two-way analyses of variance (ANOVA) were performed to test the effect of age and rotation cultivation of soil parameters. The least significant difference (LSD) was used for mean separation at the alpha=5% level. Correlation test were carried out using Pearson method. All statistical analysis was performed using R (Version, 4.4.2) software.

# **RESULT AND DISCUSION**

**Soil physical properties under different land use types**

Soil moisture and bulk density were significantly (*p* < 0.05) affected by land use change. The highest soil moisture content was found in natural forest (NF) (29.1±3.1) and the lowest soil moisture content was found on cropland that was previously A. mearnsii woodlot (OADCL) (17.1±4.8). The result was similar with the finding of Bazie et al. (2020) revealed that higher soil moisture in natural forests. The highest moisture content in natural forests is attributed to trees and shrub covers, which protect soil from direct sunlight and maintain a cool environment. Whereas the lower soil moisture content was recorded under cropland that previously A.mearnsii woodlots before two years (OADCL), cropland (CL), and grazing land (GL) possibly due to the removal of crop residues.

Similarly, bulk density was higher (**1.26±0.06**) in the first rotational cultivation of A. mearnsii woodlot (1AD6), while the lowest was found in natural forests (1.09±0.06). This is largely due to the presence of organic matter in forest soils, which enhances soil structure and porosity. Higher organic matter content helps to create more pore spaces, leading to lower bulk density. This was consistent with previous studies of Eyayu et al. (2009 and Bazie et al. (2020), which found lower bulk density in natural forests due to increased soil organic residues and low soil compaction. However, the higher bulk density in the first rotational cultivation of A. mearnsii woodlot (1AD6) was due to farmers' grazing practice until the clear-cutting, that increased soil compaction.



Figure 2: Soil moisture content and soil bulk density

**Soil chemical properties under different land use types**

Soil active carbon, soil pH, and soil available nitrogen (ammonium and nitrate) were significantly (*p* < 0.05) affected by land use type. Natural forests (NF) had the highest active carbon level (586.4±76.2), while cropland that had previously developed A. mearnsii woodlots before two years (OADCL) had the lowest levels (368.7±76.5). The result was in line with those of (Aumtong et al. (2009); Nega and Heluf (2009); conversions of forest to other land use types have led to increases in soil carbon loss (Darge et al. 2022); higher soil carbon in forest land (Yihenew et al. 2015); lowest soil carbon in crop land and higher in natural forest land (Bazie et al. 2020) showed that soil organic carbon level was higher in natural forest and A. mearnsii tree farmlands. In comparison to other land uses, the increased soil active carbon in natural forests (NF) and six years with first rotation cultivation of A. mearnsii woodlot (1AD6) is probably caused by biomass transfer from natural forests to the soil. This result was also consistent with the finding of Kassie et al. (2015) and Abiot and Ewuketu, (2017), reported that crop land containing A. mearnsii produced more soil organic carbon than cropland. Additionally, Baker et al. (2003) found that continual tillage practice, crop residue removal, and a lack of biomass addition aggravate crop land carbon losses. The highest soil pH (4.3±0.1) was found in a six-year-old stand that was the first to be rotated in the cultivation of the A. mearnsii woodlot (1AD6) whereas cropland that had previously been an A. mearnsii woodlot (OADCL) had the lowest soil pH (4.1 ± 0.1). This was in line with the findings of Birhanu et al. (2014), who reported a similar outcome in Fagita Lekoma. The depletion or removal of basic cations as a result of ongoing soil tillage and soil erosion, which add surplus H+ ions to the soil and raise acidity, may be the cause of the comparatively lower soil pH beneath the cornfield. Soil pH has been significantly impacted by land use change and soil management techniques, according to Kassie et al. (2015) and Yihenew et al. (2015). Soil ammonium (14.7±2.2) and soil nitrate (14.9±1.7) were higher under six-year with 1st rotation cultivation of A.mearnsii woodlot (1AD6) compared to cropland (NH4+ and NO3-) (6.7±3.5 and 6.5± 3.5). The result was consistent with the findings of Yihenew and Getachew (2013), and Bazie et al. (2020) who found low nitrogen content in soils of croplands as compared to A.mearnsii and natural forest lands. This could be the loss of available soil nitrogen (NH4+ and NO3-) that already formed by leaching, converted to gases like ammonia, or the NH4+ that oxidized to NO3- and then lost as N2 gas through denitrification because of a lack of plants or microbes that take up nitrogen that was available.

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Figure 3: Soil active carbon (SAC); soil pH; Ammonium; nitrate

**Effects of soil depth on Soil pH, NH4+, NO3-, active carbon, soil moisture and bulk density**

Soil depth significantly *(*p *< 0.05)* affected soil moisture, bulk density, active carbon, pH, and nitrogen availability. Lower soil depths (15–30 cm) have higher moisture content (25.1±5.9) compared to the upper soil depth (20.8±6.0) due to high evaporation rate on the upper soil depth, while upper soil depths have higher bulk density. The lower soil depth (15–30 cm) had the highest soil bulk density (1.22±0.06), while the upper soil depth (0–15 cm) had the lowest bulk density (1.12±0.06). Similar results showed that soil bulk density rose with soil depth in many regions of Ethiopia (Getahun et al. 2014; Berhanu, 2016; Tariku et al. 2017). This is because the upper layers of soil are often more disturbed and have higher organic matter content, which helps to maintain lower bulk density. As moved deeper into the soil profile, the organic matter decreases, and the soil becomes more compacted due to the weight of the overlying soil layers. According to Eyayu et al. (2009), the compaction brought on by the weight of the upper soil layer may also be the cause of the higher soil bulk density in the lower layer. The upper soil profile depths (0–15 cm) had the higher active carbon (498.3±89.9), whereas the lower soil depth (15–30 cm) had the lowest (389.4±94.9). This may have been caused by the occurrence of organic matter, which decreased with increasing depth.

The higher soil depths (0–15 cm) have the lowest soil pH. This result is consistent with finding of Tariku et al. (2017), which showed that soil pH increased as soil depth increased. This might be due to the addition of basic cations in the lower soil depths. The addition of more soil organic matter (SOM) to the surface soil was directly linked to the higher levels of available soil nitrogen (NH4+ and NO3-) in the top soil depths (0–15 cm) (11.9±3.6 and 10.6±3.5). At lower soil depths (15–30 cm), however, the lower levels of NH4+ and NO3- were detected (7.7±3.6 and 7.5±4.3). This was consistent with Yihenew and Getachew, (2013) findings that the upper soil layer had a higher intake of organic materials.

Table 2: Statistical analysis of soil properties in relation to land use type, and profile depths

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| LUT | SMC (%) | SBD (g/cm3) | NH4+(g/k.g) | NO3-(g/k.g) | SAC(mg C/k.g) | pH (CaCl2.2H2O) |
| 1AD6 | 29.1±3.1a | 1.26 ±0.06a | 14.7±2.2a | 14.9±1.7a | 446.1±85.9b | 4.3 ±0.1a |
| CL | 17.3±2.8c | 1.13 ±0.05c | 6.7±3.5c | 6.5± 3.5c | 403.1±87.6cd | 4.2±0.2bc |
| GL | 22.1±1.9b | 1.21±0.06b | 7.9±2.8c | 6.6±3.4c | 415.0±58.9bc | 4.0±0.1c |
| NF | 29.1±3.4a | 1.09±0.06d | 11.6±3.5b | 10.3± 2.2b | 586.4 ±76.2a | 4.2±0.1ab |
| OADCL | 17.1±4.8c | 1.16±0.05c | 8.0±2.8 c | 6.9± 2.4c | 368.7±76.5c | 4.1 ±0.1c |
| Mean | 22.9 | 1.17 | 9.8 | 9.0 | 443.9 | 4.2 |
| CV (%) | 23.3 | 5.1 | 30.2 | 36.0 | 17.0 | 2.5 |
| LSD | 2.7 | 0.04 | 2.5 | 2.2 | 63.6 | 0.1 |
| Soil depth |  |  |  |  |  |  |
| 0-15 cm | 20.8±6.0b | 1.12±0.06b | 11.9±3.6a | 10.6±3.5a | 498.3 ±89.9a | 4.1±0.1b |
| 15-30 cm | 25.1±5.9a | 1.22±0.06a | 7.7±3.6b | 7.5±4.3b | 389.4 ±94.9b | 4.3 ±0.1a |
| Mean | 22.9 | 1.17 | 9.8 | 9.05 | 443.7 | 4.2 |
| CV (%) | 13.2 | 6.0 | 30.3 | 24.2 | 17.3 | 3.4 |
| LSD | 3.08 | 0.03 | 1.1 | 2.03 | 47.7 | 0.06 |

*Note:* 1AD6: six-year A.mearnsii woodlot with 1st rotation cultivation, CL: cropland, GL: grazing land, NF: natural forest, OADCL: that previously *A.mearnsii* woodlot before 2-years but now cropland. *SMC:* soil moisture content; SBD: soil bulk density; NH4+: soil ammonium; NO3-: soil nitrate; SAC: soil active carbon; CV: coefficient of variation; Treatments in a column with similar letters are not significantly different (p< 0.05). Values are mean ± SD (standard deviation).

## A relationship between soil properties under different land uses across soil depths

Soil pH was positively and strongly correlated with both soil available nitrogen (1M KCl extractable NH4+ and NO3-) and soil active carbon (SAC). This result was supported by the findings of Bazie et al. (2020), who found a substantial positive correlation between soil pH and both total nitrogen and soil organic carbon. This showed a notable increase in nutrient availability in soils with a higher pH. Additionally, there was a positive and significant correlation between the nitrogen available in the soil (NH4+ and NO3-). A positive correlation among soil nitrogen forms can either increase soil nitrogen immobilization or increase transformed available soil nitrogen concentrations (NH4+ and NO3-). Soil active carbon was significantly related to nitrogen forms in the upper soil depth (0-15 cm), as per Xue et al., 2013 and Asmamaw and Mohammed (2013) reported a significant relationship between soil nitrogen and soil organic carbon. This could possibly due to higher organic matter input and biomass transfer in the upper soil depth (0-15 cm).  The finding was further supported by Bazie et al. (2020), who showed a direct correlation between the addition of more SOM to the surface soil and the higher total nitrogen on the topsoil layer. The correlation analysis between soil physicochemical parameters and nitrogen mineralization in the soil validated this finding (Xue et al., 2013).

Table 3: Pearson’s correlation matrix between selected soil properties

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Soil depth (cm)** | **SMC**  | **SBD**  | **SAC** | **NH4+**  | **NO3-**  | **pH** |
| 0-15 | SMC | 1 |  |  |  |  |  |
| SBD | .134 | 1 |  |  |  |  |
| SAC | .684\*\* | -.407\* | 1 |  |  |  |
| NH4+  | .683\*\* | .193 | .604\*\* | 1 |  |  |
| NO3-  | .623\*\* | .306 | .554\*\* | .852\*\* | 1 |  |
| pH | .492\*\* | -.148 | .627\*\* | .727\*\* | .647\*\* | 1 |
| 15-30 | SMC | 1 |  |  |  |  |  |
| SBD | .140 | 1 |  |  |  |  |
| SAC | .514\*\* | -.440\* | 1 |  |  |  |
| NH4+  | .540\*\* | .396\* | .181 | 1 |  |  |
| NO3-  | .586\*\* | .512\*\* | .054 | .708\*\* | 1 |  |
| pH | .420\* | -.116 | .216 | .294 | .425\* | 1 |

Note: Numbers are Pearson correlation coefficients (r); \*: significant difference at p < 0.05; \*\*: significant difference at p < 0.01, ns: non-significant at p > 0.5; SMC: soil moisture content; SBD: soil bulk density; SAC: soil active carbon; NH4+: soil ammonium; NO3-: soil nitrate; pH: potential of hydrogen

**CONCLUSION AND RECOMMENDATION**

The findings demonstrated that land use type affected soil active carbon and soil available nitrogen. As a result, cultivated lands had lower levels of soil active carbon and available soil nitrogen than A.mearnsii plantation and natural forest. This suggests that, in addition to crop rotation, crop residues, and organic matter addition, cultivation of A. mearnsii woodlots should be practice in rotation as it improves soil carbon and available soil nitrogen for sustainable cropping systems. Variation of soil active carbon and available soil nitrogen among different land use types were minimal on the lower soil depth as compared to the surface soil layer, implying that the surface soil layer was most affected by different management practices. On the basis of the above findings, there is a need to develop sustainable soil management and cropping practices to combat the ongoing soil degradation and improve soil fertility. The impact of A.mearnsii plantation on biodiversity and species composition needs to be studied on the future.

**Conflict of interest**

The authors declared that no conflict of interest.

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