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Soil fertility augmentation through indigenous tree species in Gummara-Maksegnit watershed, North Ethiopia

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ORIGINAL RESEARCH ARTICLE

ABSTRACT

Soil fertility improvement using sole application of artificial fertilizer is not commendable due to inaccessibility and financial stress for a farmer living in developing countries. Thus, the objective of this study was to evaluate ability of locally available tree species for soil fertility maintenance in Gummara-maksegnit watershed, Ethiopia. Questionnaires were administered to a total of 385 respondents with aim to determine three topmost preferred tree species for soil fertility enhancement. Leaf litter from the selected tree species and soil samples from both under the canopy of the selected tree species and open (controlled) area was collected for soil chemical properties analysis. *Croton macrostachyus*, *Cordia africana* and *Olea europaea* was perceived as to be the best by 42%, 32% and 26% of the respondents respectively. Leaf litter of *C. macrostachyus*, *C. africana*, and *O. europaea* had significantly different ($P < 0.05$) nitrogen value. In addition, leaf litter of *C. macrostachyus* and *C. africana* also showed higher concentration of P and K than *O. europaea*. Soil properties under the canopy of all the selected tree species significantly differ ($P<0.05$) from the open (controlled) sampling point mainly because of nutrient addition from the fallen leaf litter to the underneath soil. Therefore, it is necessary to advise farmers to let these tree species grow on their farms and improve soil condition to achieve maximum production.

KEYWORDS
Cordia africana; *Croton macrostachyus*; *Olea europaea*; Soil fertility

1. INTRODUCTION

The history of humankind shows that the civilizations that have flourished have always intensively used soils for food production. However, in recent years, soil degradation has become a major environmental concern and threat for prosperity (İmamoglu et al., 2014; Rompaey and Govers 2015; Sun et al., 2014; Zhu 2014). The most important problem of economic development of countries in Africa is loss of soil fertility because of erosion caused by forest destruction and nutrient depletion due to extensive cultivation without fertilizer inputs (Mehari 2005; Getachew et al., 2015; Adugna et al., 2015; Mushir and Kedru 2012). Thus, ensuring the presence of a healthy and fertile soil is an essential global issue as reflected in the world development agenda because of its high linkage to food insecurity, climate change mitigation, carbon sequestration and economic wellbeing of the population (Adugna et al., 2015; Pimentel and Burgess 2013).

Soils of tropical region including Ethiopian soils are naturally poor in nitrogen and phosphorus. In addition to this natural challenge human induced soil fertility loss are significantly threaten crop productivity. Apparently commercial fertilizer application is widely known strategy for alleviating nutrient depletion and increasing crop yields in many nations. However, most farmers living either in poor or developing countries are unable to afford fertilizers due to financial stress or limited access to fertilizers (Getachew et al., 2015). In addition, artificial fertilizers alone cannot guarantee

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sustainable long-term productivity on many soils hence input of organic materials are in need to maintain soil organic matter levels.

Therefore, the option farmers have is to use indigenous tress which are available around their homestead (Rosenstock et al., 2014). There are numerous as well as very complex relationships and processes between the soil and the plant and in recent years, plant scientists and soil scientists have made effort to identify the rules governing this complex system. In this way, many achievements has been gained but still a long way is ahead to understand all aspects of this complex system (Jahed et al., 2014). Tress can affect soil properties including quantity and quality of soil organic matter reserves which is depended on complex climatic responses, soil type, management and tree species in soil nutrient cycling between trees and soil (Rosenstock et al., 2014).

Integration of soil fertility improving trees in farming systems which is referred to as agro-forestry is a critical option for enhancement of crop production in degraded soils (Ståhl 2005; Jahed et al., 2014; Etuk and Edem 2014; Getachew et al., 2015). Because, nutrient release from the tree/shrub litter fall is perceived to be the major factor for transferring of nutrients and energy from living biological components to the soil and contribute to the soil fertility and its associated productivity. Different tree species through their various characteristics in litter production, nutrient release and having specific chemical compounds in their litter play a major role in the nutrient cycling (Tanga et al., 2014). Nitrogen (N), phosphorus (P) and potassium (K) reserves are among the important indicators for evaluation the effect of tree species on ecosystem function (Tanga et al., 2014; Jahed et al., 2014).

In Ethiopia, native trees such as *Acacia tortilis*, *Acacia nilotica*, *Cordia africana* and exotic ones like *Casuarina cunninghamiana*, *Eucalyptus globulus* and *Leucaena leucocephala* are planted for economic and environmental conservation purposes (Mehari 2005). Numerous studies have been conducted on the effects of tree species on soil properties indicating a significant effect of over story tree species on soil (Tanga et al., 2014; Jahed et al.,, 2014; Ali 2018; Etuk and Edem 2014; Fritzsche et al., 2018; Kacálek et al., 2013; Luca et al., 2018; Rosenstock et al., 2014; Ståhl 2005; Rhoades, 1997; Getachew et al., 2015; Kanmegne et al., 1999; Frost, 1994; Tesfaye et al., 2015). Nevertheless, the capacity of all these trees species are different. Therefore, any decision made on what species to plant must get answer carefully. The objective of this study was to assess farmers' perception about locally available tree species that improve soil fertility and back it up with scientific evidence. It is also aim at evaluating the capacity of selected indigenous trees for soil fertility improvement by analyzing some selected soil chemical properties.

2. MATERIALS AND METHODS

2.1. Study site description

The study area is Gumara-Maksegnit watershed, which is located in the northern part of Amhara Region, Ethiopia. The watershed is located in north Gondar zone and it is far at about 45 km southwest of Gondar town. The geographical location is lied between 120 23' 53'' to 120 30' 49'' latitude and 370 33' 39'' to 37037' 14'' longitude. This mountainous agricultural watershed, which covers an area of 53.7 km^2, is one of the most severely eroded parts of the Ethiopian highlands (Addis et al., 2015). The study watershed has a very rugged mountainous topography, with an average slope of 22.1% and most the study watershed (more than 90% of the area) is composed of gullies and ridges. The elevations of the watershed range from 1920 to 2850 m above sea level (Addis et al., 2015). The area geology is predominated by Trapp series of Tertiary volcanic eruptions (Addis et al., 2015). The soil types of the watershed are predominately classified as Cambisols and Leptosols, which covered in the upper and central part of the area, while Vertisols in the lower parts of the watershed near the outlet. There are five different soil textural classes within the Gumara-Maksegnit watershed namely: sandy clay loam, sandy loam, clay loam, loam, and clay (Addis et al., 2015). The land use types of the watershed are mainly agricultural land (63.5%) followed by mixed forest (24.3%) and grazing land (12.2%) (Kendie and Klik 2015). The study area is characterized by a bi-modal rainfall distribution with annual mean value of 1170 mm. The mean minimum and maximum temperatures are 13.3 and 28.5°C, respectively. The most common tree/shrub species are *Croton macrostachyus, Cordia africana, Olea europae, Acacia saligna, Gravellia robusta, Sesbania sesban* and *Leucina leucocephala*.

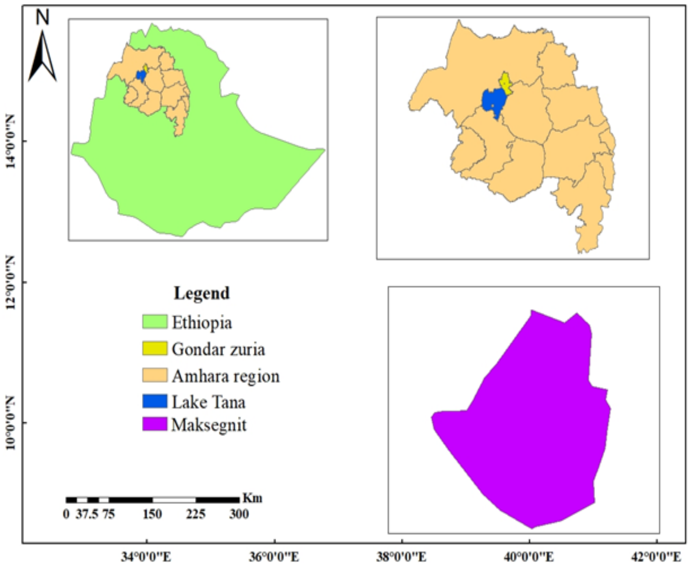

Figure 1. Overview of the study site

2.2. Sampling procedure and data collection

A systematic sample of 385 household were selected from the three villages for personal interviews. The sampling was done using a list obtained from the respective village administrations. Every twenty fifth household on the list was included in the sample. A household in this case consists of a family having the following member; a husband, a wife, and children with other dependents if any living in the same house and depending on the same farm land and farm resources. The head of the household was considered to be the unit of analyses because she/he was the ultimate decision-maker with respect to tree planting on farm land. Well-trained interviewers who could understand the local language administered the questionnaire, and the head of the household was interviewed. When the head of a selected sample household was unavailable (after repeated visits); interviewers went to the next household on the list.

This study was carried out in three consecutive phases. In the first phase, questionnaires were administered to 385 farmers to determine their perception on indigenous tree species found around their locality in relation to enhance soil fertility and their tree management strategies. Since it is difficult to consider all trees growing on farmer's cropland, questionnaires were used to identify first three trees species that are associated with enhancement of soil fertility. Trees that were ranked as the three top most were used for further analysis in the second and third phases. In the second phase, under canopy soils from the selected tree species and from the nearby open land were sampled for further soil chemical properties analysis. In the third phase, leaf litters were collected from selected species for selected essential elements analysis.

2.3. Vegetation survey, soil sampling and chemical analyses

The experiment was conducted in randomize complete block design with three replication. Nine sampling trees, three from each species were randomly selected in blocked area based on similarity in diameter at breast height (DBH) and total height (TH) so as enable comparison among tree species. Three concentric circles were drawn under each tree crown and one out of tree effect in the block. This means, soil samples were taken from four horizontal sampling distances of each sampling tree: rizosphere (just near tree root), mid of canopy, edge of canopy, and the open area (control) at 0-20cm depth. Aiming for representative soil sample, four sub composites from each direction under nine trees and four distances including open controlled area were collected. Hence, 36 soil samples and which consists of 144 sub-composites were collected.

Soil samples were then taken to laboratory to be analyzed for soil pH, Total nitrogen (TN), available Phosphorus (Ava.P), exchangeable potassium (Ex.K) and organic carbon (OC). The soil samples were air dried, crushed and passed through 2 mm sieve for laboratory analyses. Soil properties were analyzed using the following analyses methods: pH was determined using a pH meter (1:2.5 ratio of soil: water suspension). OC, TN, Ex.K, Ava.P was determined using the wet oxidation method (Nelson and Sommers 1982), Kjeldahl methods (Jackson 1967), flame photometric method (Jackson 1967) and Olson method (Olsen and Sommers 1982) respectively.

2.4. Leaf sampling and chemical analyses

Leaves of the first three selected tree species were collected from all canopy positions on the trees. After air-dried, leaf samples were oven dried at 65°C for 24 hours, and grounded into powdered form to pass through the mesh screen for chemical analysis. N was determined by the micro-Kjeldahl method by digesting 0.5g samples in 10ml concentrated H_2SO_4, using a catalyst mixture ($CuSO_4$, K_2SO_4 and selenium powder) and distillation (Olsen and Sommers 1982). P was determined in digested samples colorimetrically using the ammonium molybdate stannous chloride method

(Olsen and Sommers 1982) and K was analyzed by a flame photometric method (Jackson 1967).

2.5. Statistical analyses

Descriptive statistics was used to determine the selected species both their leaf litter nutrient content and the soil nutrient status under their canopy and open (controlled) area. One-way analysis of variance (ANOVA) procedure was performed to see the effect of the selected tree species on the soil fertility properties, and nutrient contents in litter of each of the species. Mean comparisons were made at 0.05 significant levels. The Microsoft excel was used to perform all the statistical analysis.

3. RESULTS AND DISCUSSION

Based on results obtained from questionnaire, among many indigenous tree species found in the study area, *C. macrostachyus* was perceived best for improving soil fertility by 42% of the respondents; 32% of the respondents noted that *C. africana* as the best; 26% of the respondents acknowledge that *O. europae* is most importantly preferred tree for soil fertility improvement. These three tree species were taken as sampling tree to further study for soil nutrient status under their canopy and leaf litter content.

Evaluating the leaf litter nutrient content is important to understand the underneath soil condition. This is because litter-fall is a major pathway for the return of dead organic matter and nutrients held in it from the aerial parts of the plant communities to the surface of the soil (Getachew et al., 2015). The results obtained for the leaf litter nutrient composition revealed that there were significant ($p < 0.05$) differences between the treatments. Comparisons of potential leaf litter nutrient content (C, N, P, and K) returning from each selected species showed that leaf of *C. macrostachyus* and *C. africana* had significantly higher ($P < 0.05$) N compared with the leaf of *O.europae*. *C. macrostachyus* and *C.africana* also showed higher concentration of P and K than *O. europae* (Table 1) may be due to the inherent characteristics of the species. The result is in agreement with earlier study reported by Getachew and his colleagues (Getachew et al., 2015).

The result of this study also showed that P content was low (Table 1) in leaf of the three tree species as compared to C, N and K nutrients which could be mainly because it is not so readily cycled from plant surfaces to the soil. This result is also in agreement with the observations of other study (Getachew et al., 2015); which described that P is one of the most tightly cycled major plant nutrients. The P content may re-translocate to other plant body before leave abscission or serve for construction of new tissues.

Although the variations of soil properties may be the outcome of several physical, chemical, or biological processes, soils are mainly affected by vegetation cover and as an inherent factor of soil formation has potential for modifying soil properties (Getachew et al., 2015). Structural differences in leaves of plants present a possible source of variability in the amount of leaves reaching to the soil under plant canopies and the amount of nutrients in the soil (Getachew et al., 2015). Litter production also varies according to habit of the tree species, its age and local environmental condition (Rhoades 1997; Getachew et al., 2015). Results on previous study of Getachew (Getachew et al., 2015) do agree with the findings of this study that *C. macrostachyus*, increases soil nitrogen, which was attributed to tree leaf and root litter. Since *C. macrostachyus* is not nitrogen-fixing plant, the only way it could have improved soil nitrogen is by absorbing N from the subsoil and depositing through litter fall.

The increase in soil Ec, Ex.K, TN, Ava.P, and OC of the under canopy soil are indicators of increased fertility (Table 2, Table 3 and Table 4) whereas soil pH had lower value under the canopy of the selected tree species compared to the open (controlled) area which is mainly attributed to the chemical composition

Table 1. Major nutrients in leaves of *C. macrostachyus*, *C. africana*, and *O. europae* tree species.

Tree species	Nutrients			
	%C	**%N**	**%P**	**%K**
Croton macrostachyus	49.70	3.59	0.843	20.94
Cordia africana	48.00	2.43	0.61	20.00
Olea europae	52.10	1.03	0.44	9.00
LSD (5%)	NS	0.67	0.25	11.54

Table 2. Soil nutrient status of different sampling points of *Croton macrostachyus*.

Tree species	Sampling points	Selected soil chemical properties					
		pH (H_2O) (1:2.5)	E_c (dS/m)	Ex.K (cmol(+)/kg)	OC (%)	TN (%)	Ava.P (mg/L)
Croton macrostachyus	rhizosphere	6.77	0.15	3.54	1.3	0.1	47.83
	mid crown	6.72	0.15	3.2	1.48	0.12	35.13
	edge crown	6.75	0.11	2.71	1.36	0.11	32.33
	control	6.75	0.08	2.3	0.95	0.07	29.25
	LSD (5%)	NS	0.01	0.33	0.4	0.01	2.31

Table 3. Soil nutrient status of different sampling points of *Cordia africana*.

Tree species	Sampling points	Selected soil chemical properties					
		pH (H_2O) (1:2.5)	E_c (dS/m)	Ex.K (cmol(+)/kg)	OC (%)	TN (%)	Ava.P (mg/L)
Cordia africana	rhizosphere	6.56	0.15	4.06	1.61	0.13	31.17
	mid crown	6.72	0.11	3.92	1.34	0.44	32.63
	edge crown	6.73	0.09	2.64	1.44	0.11	31.17
	control	6.91	0.1	2.85	1.54	0.12	29.08
	LSD (5%)	0.34	NS	1.02	0.05	0.03	2.03

Table 4. Soil nutrient status of different sampling points of *Olea europae*.

Tree species	Sampling points	Selected soil chemical properties					
		pH (H_2O) (1:2.5)	E_c (dS/m)	Ex.K (cmol(+)/kg)	OC (%)	TN (%)	Ava.P (mg/L)
Olea europae	rhizosphere	6.65	0.08	1.18	1.65	0.13	4.21
	mid crown	6.64	0.1	1.06	1.3	0.1	3.75
	edge crown	6.7	0.09	1.12	1.53	0.12	2.63
	control	6.76	0.07	1.36	0.94	0.07	2.88
	LSD (5%)	NS	NS	0.22	0.32	0.001	0.79

of the leaves. Similar to this finding, Getachew reported significant difference ($P<0.05$) in pH between the soils within and outside the canopies of both trees, with a higher pH in the open cultivated land than under the canopy areas (Getachew et al., 2015). Several other studies have also reported that soil fertility under tree situation is improved due to increased input of organic matter through litter (Getachew et al., 2015; Ståhl 2005; Jahed et al., 2014; Rhoades 1997; Etuk and Edem 2014; Kacálek et al., 2013; Kanmegne et al., 1999; Frost 1994). Therefore, it is quite necessary to increase trees density on farmland for replenishing nutrients in the soil.

4. CONCLUSIONS

In the study area, farmers perceived that some selected indigenous trees species (*C. macrostachyus, O. europae* and *C. africana*) are relevant for soil fertility enhancement and let these tree species to grow in their farm. This study was therefore intended to evaluate the effect of these tree species on the quality of the soil. Soil properties under the canopy of all the selected tree species are in better status compared with open (controlled) sampling point mainly as a result of nutrient addition from litters fall to the underneath soil. The research revealed that *C. macrostachyus* and *C. africana* are amongst the most productive soil fertility improving tree species in the study area. Therefore, it is highly recommended for farmers to let these tree species grow on their farm, manage properly and improve their growth to enhance soil fertility and crop production as well.

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