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Characterization of soil fertility as influenced by age of *Eucalyptus spp* plantation and site conditions in the central highland of Eritrea

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Abstract

The present investigation was carried out to characterize the soil fertility as influenced by age and site of eucalyptus plantation enclosures in moist highland zones of Eritrea. Three sites: Serejeka, Dem-Sebai, and Emba-Dorho, and; three ages: 7, 16, and 26 years after planting were selected for the study. No significant difference was observed in bulk density with age and site. pH showed a highly significant difference with age but non-significant with the site. Soil organic carbon showed a significant difference with age. A highly significant difference in soil nitrogen content at the Serejeka site, but no significant difference at Dem-Sebai and Emba-Dorho, was observed for age. The amount of available phosphorous in the forest plantations and the non-forested control was low. There was a significant difference in available phosphorus with age only in Emba-Dorho.

Key Words: Afforestation, Enclosures, Organic carbon, Nitrogen, Phosphorus.

Introduction

Eucalyptus was introduced to Eritrea in 1922 (Berhane and Elias 2004); in which *Eucalyptus globulus*, *Eucalyptus camaldulensis, and Eucalyptus cladocalyx* were grown for fuel wood, pole wood production, and water conservation to rehabilitate degraded hillsides. The ongoing expansion of *Eucalyptus* plantations has been the focus of two major debates on the environmental impacts and the role of the species in the livelihoods of the population. The argument on the environmental influences of the species is associated to soil acidification, nutrient exhaustion, allelopathic effects, and excessive water use and hence drying up of water points, particularly in arid areas like Eritrea. But owing to its fast growth, high biomass production, and browsing resistance (Kidanu et al 2004), it is an important multipurpose species. Empirical evidence to either support or refute the supposed ecological impacts of the tree species in Eritrea is scanty, anecdotal, and poorly understood. Hence, there was a need to address the effect of *Eucalyptus* plantation enclosures on soil nutrient status and quantify the changes in soil nutrient stock and soil quality along a chronosequence of forest plantations. The total area set as permanent enclosures is 86,367.00 ha and temporary enclosures are 25,167.00 ha (FAO 2010). The effectiveness of such interventions, particularly in terms of soil amelioration, productivity, restoration of degraded vegetation, and regeneration of the indigenous species had not been systematically investigated. Hence the present investigation was carried out to characterize the conditions e.g. soil fertility of the afforested enclosures as influenced by age and site conditions in the moist highlands of Eritrea. The aim was to examine the spatial and temporal dynamics of the Eucalyptus plantations because of some soil attributes and find out if the species improves or degrades the land productivity.

Materials and Methods

Eritrea is located along the Red Sea with varied topography, rainfall, and climate. Its climate ranges from hot and semi-desert near the Red Sea to sub-humid in isolated micro catchments. The central highlands are semi-arid for most parts of the year; and the monsoon last from mid-June up to mid-September. Three sites in the central highlands of Zoba Maekel namely: Dem-Sebai located between 476000 and 484000 UTM latitude and 1704000 and 1696000 UTM longitude; Emba-Dorho and Serejeka located between 476000 and 484000 UTM latitude and 1712000 and 1704000 UTM longitude, were selected for the present investigation. The altitudes of Zoba Maekel ranged from 1,300 MAS l to 2,610 MAS l. Mean annual rainfall in the area was 400 mm with minimum and maximum temperatures of 4.3^0C and 25.5^0C, respectively. It is characterized by undulating planes with slopes ranging from below 2% to steep slopes greater than 50%, (MoA 2013).

Considering the heterogeneity of soil properties at the spatial scale of a few meters or less, particularly for soil organic matter content driven by litter inputs; a preliminary soil survey was carried out to get a general impression of the sites. To accommodate spatial variation at a plot or compartment level, due considerations were made while measuring changes in surface soil chemical and physical properties. Hence, to minimize the effect that would arise from the difference in topography and aspect, samples were strategically collected in the field from the different plantation age groups in selected forest inventory plots. A 'W' shaped sampling procedure was used to select the points for sampling which involved the use of a coordinated system where the points sampled were at the intersection of two lines of approximately 15 paces in a 'W' shape to the depth of 0-20cm. (Carter and Gregorich 2008)

Soil samples were taken for physical and chemical characteristics analysis from each of the square sample plots using a sharp-edged steel cylinder with a diameter of 5 cm (25 cm^2) for bulk density determination and composite soil samples (McFee and Stone 1965). The sampling units were then thoroughly mixed to form a composite sample. The soil was air-dried and grounded to pass through a 2 mm sieve for soil analysis at National Agricultural Research Institute (NARI) laboratory using standard procedures. Bulk density: London (1991); mechanical analysis: hydrometer method, (Ryan et al 2001; EC (DSM^{-1}) and pH were determined in a 1:5 soil suspensions deionized water solution using conductivity meter and a digital potentiometric pH-meter, respectively; organic carbon was obtained by the wet dichromate acid oxidation method; total nitrogen was determined using the Kjeldahl distillation method; available phosphorus (ppm) was determined using sodium bicarbonate extraction. Analysis of Variance (ANOVA) was used to detect any significant differences in physicochemical properties on the surface soils (0-20 cm) of different ages of forests and sites. All statistical tests were conducted with Gen Stat Discovery edition 2013.

Results and Discussion

The bulk density ranged from 1.27 Mg m^{-3} to 1.51 Mg m^{-3}, and there were no significant differences among age and site (Table 1). The average bulk density in

Emba-Dorho was the highest (1.41 Mg m^{-3}) and the average bulk densities at Dem-Sebai and Serejeka were almost similar. The smallest (1.27 Mg m^{-3}) bulk density was recorded at Serejeka at age seven.

The results, especially of Serejeka where the bulk density of the forested land was surpassed by the non-forested land, were similar to the findings of Wicharuck et al (2010). Ambachew et al (2012) also reported a considerable decrease in soil bulk density when a forest was established on cultivated soils.

Table 1: Mean values of BD (Mg m^{-3}), pH, and EC (dS m^{-1}) concerning age and site variations

Plantation Age	Serejeka			Dem_sebai			Emba-Dorho		
	BD	pH	EC	BD	pH	EC	BD	pH	EC
7 years	1.27	5.92	0.51	1.32	5.88	0.55	1.35	5.90	0.53
16 years	1.34	6.14	0.38	1.39	6.30	0.55	1.38	6.22	0.56
26 years	1.34	6.44	0.57	1.32	6.40	0.58	1.38	6.56	0.65
Control (non-forested)	1.40	6.78	0.53	1.37	6.54	0.56	1.51	6.40	0.56
G. Mean	1.34	6.32	0.50	1.35	6.28	0.56	1.41	6.27	0.58
F pr.	0.385	0.027	0.108	0.206	0.048	0.096	0.062	0.019	0.096
CV%	1.2	0.8	8.9	3.4	3.5	15.2	1.9	1.8	15.2
s.e.d. +/-	0.071	0.209	0.158	0.033	0.175	0.085	0.051	0.148	0.085
L.S.D. (5%)	NS	0.511	NS	NS	0.428	NS	NS	0.363	NS

The results (Table 1) revealed that there was a significant difference with increasing age, but no significant difference with site variations. pH ranged from moderately acidic (5.88 to 5.92) at age seven to slightly acidic (6.44 to 6.56) at age twenty-six years, similar results were reported by Hazelton and Murphy (2007). These values were lower than those reported by Atzbaha et al (1998) where they ranged from 6.69 to 7.59 for the Sesewa catchment area near the Dem-Sebai site. The decreased soil acidity at younger ages may be attributed to the higher density of trees at these ages where higher stocking density leads to higher litter fall and fresh organic matter accumulation on the forest floor, which lowers the soil pH.

The values of EC showed significant differences with age and site. EC of the control plots (non-forested land), was lower than the plantation. Maximum EC (0.65 DSM^{-1}) was recorded at age twenty-six at the Dem-Sebai site. Lowest EC (0.38 DSM^{-1}) was recorded at age sixteen in Serejeka (Table 1). Invariably, EC in all ages and sites was low suggesting that the soils of these plantations were non-saline (Landon 1991). Atzbaha et al (1998) reported an EC of 0.33 dS m^{-1} for the Sesewa catchment located nearby the Dem-Sebai site. EC is heavily dependent on climatic conditions where for instance, soils of sub-humid tropics had sufficient rainfall to flush out base-forming cations from the root zone.

SOC showed a considerable statistical difference among the different age groups (Table 2). Soil samples from seven years old plantations had higher SOC compared to the sixteen and twenty-six-year-old plantations. Comparing the SOC across age showed a highly significant difference (Fpr=0.003) for the Serejeka site and a significant difference (Fpr=0.038) for both

Dem-Sebai and Emba-Dorho sites. As age increased, the SOC content decreased up to the age of sixteen years and then started to increase towards the age of twenty-six. These results were similar to the reports of Atzbaha et al (1998).

There was a highly significant difference in soil nitrogen content for age differences within the Serejeka site but no significant difference in soil N content with age at Dem-Sebai and Emba-Dorho. There was similarity in soil nitrogen content of the older age forest plantation and the non-forested control but the N content of the soil samples taken from plots of age seven years was considerably high as compared to the non-forested control and even the older age plantations. These results are comparable with the findings of Chen et al (2004).

Table 2: Mean values of SOC%, N% and P (ppm) concerning age and site variations

Plantation Age	**Serejeka**			**Dem sebai**			Emba-Dorho		
	SOC	N	P	SOC	N	P	SOC	N	P
7 years	1.97	0.13	1.54	2.03	0.20	4.68	2.01	0.17	3.46
16 years	1.08	0.06	0.20	1.25	0.10	3.51	1.98	0.11	3.40
26 years	1.19	0.08	1.10	1.78	0.10	3.18	2.58	0.11	4.48
Control(non-forested)	0.90	0.06	1.60	0.43	0.10	2.01	1.18	0.10	2.03
G. Mean	1.29	0.08	1.11	1.37	0.13	3.34	1.94	0.12	3.34
F pr.	0.003	0.006	0.079	0.038	0.269	0.098	0.038	0.124	0.039
CV%	9.11	15.9	35.1	19.0	18.4	22.1	19.0	16.5	19.0
s.e.d. +/-	0.172	0.013	0.472	0.348	0.034	0.944	0.348	0.375	0.612
L.s.d. (5%)	0.421	0.032	NS	1.702	NS	NS	0.851	NS	1.497

There was a significant difference in available phosphorus with age only in Emba-Dorho. There was a highly significant difference in mean phosphorus availability among the sites. The average means of phosphorous at Dem-Sebai and Emba-Dorho was 3.34 ppm whereas in Serejeka it was 1.11ppm only (Table 2). These were comparable to the results reported by Atzbaha et al (1998). Phosphorus availability was affected by the pH of the soil as P is always found in a fixed form at lower pH. The pH of these forest plantations ranged from 5.88 - 6.78 (Table 1) which is moderately acidic to slightly acidic (Hazelton and Murphy 2007) which makes P to be fixed and unavailable to the plant.

Conclusions

Bulk density did not show any difference with age and site whereas EC in all ages and sites was low suggesting that the soils of these plantations were non-saline; it was further observed that the soil pH increased with increasing age of the stand in the three sites. The comparison of the soil organic carbon across age showed a different level of variations in the three sites. There was also a considerable difference observed in soil nitrogen content among the forest plantations. The amount of available phosphorous in the forest plantations and the non-forested control was low and a significant difference in available phosphorus with age was observed only in Emba-Dorho.

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