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Research Article

Measuring Soil Fertility under *Hagenia abyssinica* (Bruce) J. F. Gmel by the Biotest Method

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The experiment was conducted at the Forestry Research Center, Ethiopia in 2008. Soil was sampled under the canopy of *Hagenia abyssinica* and from farmland area adjacent to the forest to measure fertility of soils by using the biotest with linseed (*Linum usitatissimum* L.), barley (*Hordeum vulgare* L.), and wheat (*Triticum aestivum* L.) as indicators. The experimental design was a completely randomized design comprising of 20 seedlings per study site. Seeds were seeded into polythene plastic bags. Seedling emergence, germination, and survival rate were recorded. Plant height and root collar diameter were measured. Final weight of fresh biomass was measured, and each component was oven-dried at 70°C. Dry weight was recorded at constant weight. Significant differences ($P < .05$) were observed between soil treatments. Plants grown on *Hagenia*-influenced soils attained better performance, suggesting the beneficial role of *Hagenia abyssinica* in enhancing soil fertility status which in turn results in higher productivity.

1. Introduction

In Ethiopia, land degradation in the form of soil erosion and declining soil fertility is a serious constraint to agricultural productivity as well as economic development [1–3]. Land cover change triggered by agricultural land expansion and heavy livestock pressure are the proximate causes for degradation [4–6]. Some of the noticeable problems of soil fertility loss in the highlands include using dung and crop residues as household fuels and animal feeds, declining fallow periods, soil and organic matter burning (*guie*), and low use of chemical fertilizers [7]. Though the farming system in most part is mixed crop-livestock, nutrient flows between the two are predominantly one sided, with feeding of crop residues to livestock but little or no dung being returned to the soil [7].

Fertility replenishment can only be sustained if the nutrients removed are returned to the soil through addition. Trees on crop land have potential to improve soil fertility due to their organic inputs with nutrient recycling through mineralization [8–12]. Because soils in many parts of Ethiopia have low fertility, farmers are trying to apply inorganic fertilizers to replenish plant nutrients in their crop land. However, with the rising costs of farm inputs, this is becoming less of an option for the majority who do not have enough cash to purchase fertilizers. Therefore, it is critical to look for an option by examining trees that can improve top soil fertility through addition of litter.

Hagenia abyssinica (Bruce) J. F. Gmel is an indigenous broad-leaved dioecious tree species belonging to a monotypic genus in the Rosaceae family [13, 14]. The species is a multipurpose tree with a broad range of economic and ecological values [13, 15–17]. *Hagenia* is one of the species that contribute tremendously valuable biological attributes in fertile soil formation and conservation [14]. Moreover, it has a wide range of products and environmental functions such as medicine, timber, firewood, fodder, and mulch. In this study, the contribution of *Hagenia abyssinica* for soil fertility improvement was assessed. Planting some indicator plants and measuring their growth and production is one way to measure fertility of soils in an indirect way

[18]. Therefore, the study examines growth and biomass production of indicator plants grown under two different growing conditions (soil treatments).

2. Materials and Methods

2.1. Study Sites. Three study sites (Kofele, Bale, and Debark) were chosen for the study. "Deyu" (hereafter described as Kofele) is found in the Oromiya National Regional State, southeastern Ethiopia. It is located in 7°11′ N and 38°52′ E. The area lies between 2600 and 2750 m a.s.l. Annual average rainfall is about 1232 mm. Mean monthly minimum and maximum temperatures are about 5.4°C and 19.8°C, respectively [19]. Luvisols are the dominant soil types in the studied plots. Vegetation is mostly composed of trees (e.g., *Hagenia abyssinica*) and shrubs (e.g., *Acanthus arboreus*). The pasture composition is mainly represented by tufted grass varieties of *Pennisetum schimperi* and *Trifolium* spp. Bale site is located in the Bale Mountains National Park, Oromiya National Regional State, southeastern Ethiopia. It lies between 6°05′–7°54′ N and 39°33′–39°59′ E. The altitude ranges between 2400 and 3600 m a.s.l. The area has a bimodal rainfall. Mean annual rainfall is 1218 mm. The mean annual minimum and maximum temperatures are 2.4°C and 15.5°C, respectively. The present topography is a reflection of long-term weathering processes originating from Oligocene lava outflows [20]. Vegetation formations belong mainly to the afromontane and afroalpine [21]. "Wuraba" (hereafter described as Debark) is located in Amhara Regional State, northern Ethiopia. The geographic location is 13°11′ N and 37°58′ E. The altitude ranges between 2800 and 3175 m a.s.l. Similar to Bale site, this area is also formed as a result of Oligocene lava outflows [20]. Mean annual rainfall ranges between 900 and 1550 mm. The minimum temperature usually drops to −3°C and −5°C at night. Vegetation is dominated by *Erica arborea* trees. Trees such as *Hagenia abyssinica*, *Myrsine melanophloeos,* and *Juniperus procera* are some of the sparsely distributed tree species in the area.

2.2. Soil Sampling. Soil representing "forest soil" was sampled under the canopy of *Hagenia abyssinica* trees. Similar type of soil from farmland area adjacent to the forest was also collected. Soil from farmland did not have any history of chemical fertilizer application. Soil was sampled from the upper most 15 cm, thoroughly mixed and passed through a 2 mm sieve to remove some gravel fragments before pot experiment.

3. Seedling Production and Growth Measurement

Seedlings were raised in the nursery located at the Forestry Research Center (9°02′ N and 38°45′ E), Addis Ababa, Ethiopia. In this experiment, the most commonly grown cereal crops in the study sites were chosen as biotest indicator plants. These are linseed (*Linum usitatissimum* L.), barley (*Hordeum vulgare* L.), and wheat (*Triticum aestivum* L.). Linseed and barley seeds were sown in April 2008 while wheat seeds were sown in June 2008. Polythene plastic bags (20 × 20 cm when flat) were filled with soils, and seeds were directly seeded into the soil with five seeds per plastic bag. The seedlings were reduced to one per pot after germination. For the first 30 days, the seedling bed was covered with grass straw in order to protect seedlings from direct sunlight and wind; hence seedlings were grown under partial shade (50% full sunlight). The shade was gradually reduced and removed as seedlings grow. To maintain soil moisture, seedlings were watered twice a day. No fertilizer or mycorrhizal inoculation was applied. Weeding was performed manually. The experimental design used was a completely randomized design (CRD) comprising of 20 seedlings per study site (1 crop type × 2 treatments × 10 replicates). In order to evaluate the seedling growth nondestructive measures (shoot length and root collar diameter) were recorded every 15 days. Shoot length was measured with a ruler while root collar diameter was measured with a digital caliper.

4. Biomass Measurement

At the end of the experiment, a destructive harvest of seedlings was made by splitting the aerial part into leaves, stems, and fruits. The root part was carefully cut using a sharp blade and washed out with gently applied water until the attached soil was completely removed. Each part of the aboveground biomass was freshly weighed using analytical scale. Similarly, root length was measured and its fresh biomass was weighed. To determine the dry biomass production each component was oven-dried at 70°C until the weight remained constant. Dry weight was recorded at constant weight. The hypothesis of differing biomass production was tested by evaluating the total biomass (above and below ground) recorded for individual seedlings grown on both growing conditions (soils treatments). Data were computed using SPSS for Windows Version 15.0. One-way analysis of variance (ANOVA) was performed on each parameter to test whether the differences investigated were statistically significant. Mean values were compared using least significant difference (LSD).

5. Results

5.1. Seedling Emergence, Germination, and Survival Rate. Linseed seedlings emerged six and seven days after sowing while barley seedlings emerged on the 6th, 7th, and 10th days. Wheat seedlings emerged five and seven days after sowing. On the whole, seedlings of each indicator plant had an overall survival percentage of 100.

5.2. Plant Height. Linseed plants survived up to 120 days while barley and wheat plants stayed up to 105 days in the nursery. Continuous incremental growth was observed as days after planting increased (Table 1). Mean plant height in all plants showed differences at the time of harvest ($P < .05$). On the whole, relatively higher plant height growth was recorded in plants grown on *Hagenia*-influenced soils (hereafter described as T1 (treatment 1)) than those grown

Table 1: Plant height (cm) of indicator plants.

Site	Crop type	Treatment	Time after planting (day)							
			15	30	45	60	75	90	105	120
Kofele	Linseed	T1	4a	7b	18b	43b	51a	53a	57a	62a
		T2	4a	7a	15a	34a	42b	44b	50b	50b
		SD	0.4	1.7	2.8	9.3	8.4	8.6	7.7	8.5
Bale	Barley	T1	3a	4a	11a	29a	34a	63a	71a	—
		T2	3a	4a	10a	23a	33a	56a	60b	—
		SD	1.8	2.7	2.5	6.5	7.9	12.3	11.5	—
Debark	Wheat	T1	1a	5a	11a	34a	39a	53a	61a	—
		T2	1a	4b	10a	25b	32b	42a	49b	—
		SD	0.3	1.7	2.4	6.8	6.5	10.8	9.8	—

Means with different letters within a column are significantly different ($P < .05$).
T1: forest soil (*Hagenia*-influenced soil); T2: farmland soil; SD: standard deviation.

Table 2: Whole plant height (cm) of indicator plants.

Plant height	Forest soil	Farmland soil	SD	ANOVA
		Linseed (*Linum usitatissimum* L.)		
Root	29	28	3.7	ns
Shoot	62	50	8.5	**
Total	91	78	10.2	*
		Barley (*Hordeum vulgare* L.)		
Root	25	20	3.7	**
Shoot	71	60	11.5	*
Total	96	80	13.3	*
		Wheat (*Triticum aestivum* L.)		
Root	22	20	1.3	**
Shoot	60	49	9.3	*
Total	82	69	10.5	*

** Significant ($P < .01$); *significant ($P < .05$); ns: nonsignificant ($P > .05$).

on farmland soils (hereafter described as T2 (treatment 2)). During final record, plant height of linseed, wheat, and barley plants grown on T1 condition surpassed the rest with values of 12.5, 11.2, and 10.9 cm, respectively (Table 1).

5.3. Root Collar Diameter (RCD). Mean root collar diameter showed significant variation among seedlings ($P < .05$). At the time of final record mean RCD of linseed plants grown on T1 and T2 was 6.05 and 4.75 mm, respectively. Barley plants attained mean RCD of 0.38 mm (T1) and 0.36 mm (T2). On the other hand, wheat plants grown on T1 and T2 had mean RCD of 0.5 and 0.42 mm, respectively. By and large, seedlings grown on T1 attained relatively higher RCD than those grown on T2.

5.4. Whole Plant Height (Shoot + Root). Following the termination of experiment whole plant height (shoot + root) was measured. The value showed significant difference in all crop types ($P < .05$). Plants grown on T1 condition showed relatively higher mean whole plant height over those planted on T2 condition (Table 2).

6. Biomass

Mean fresh biomass showed significant variations among plant types ($P < .05$). Plants grown on T2 condition had relatively less fresh biomass (Table 3). Likewise, mean dry matter yield (g seedling^{-1}) varied between all types of plants ($P < .05$). Plants grown on T1 attained comparatively higher dry matter yield (both aboveground and root biomass) than those grown on T2 (Table 3). Dry matter yield among plant organs also exhibited statistically significant difference ($P < .05$). Noticeably, seedlings grown under T1 attained comparatively higher DM content. On the whole, in all types of crops the dry matter content of root was the least among all plant organs (Table 4).

7. Relative Dry Matter (RDM) Accumulation

In both types of linseed plants, dry matter content accumulation followed a trend stem > fruit > leaf > root. Linseed plants grown on T1 and T2, respectively, attained RDM content in stem (61%; 63%), fruit (17%; 16%), leaf (16%; 15%), and root (6%; 6%). In barley plants, dry matter content in T1

Table 3: Mean (±SEM) dry matter yield of indicator plants (g seedling^{-1}).

Crop	Treatment	Aboveground biomass		Belowground biomass (g)		Total biomass (g)		ANOVA
		Fresh wt (g)	Dry wt (g)	Fresh wt (g)	Dry wt (g)	Fresh wt (g)	Dry wt (g)	
Linseed	T1	102 ± 5.6	24 ± 1.7	8 ± 0.5	2 ± 0.1	110 ± 6	26 ± 1.7	*
	T2	72 ± 4.5	17 ± 1.7	6 ± 0.2	1 ± 0.1	78 ± 4.6	18 ± 1.7	*
Barley	T1	369 ± 49	73 ± 8.9	33 ± 6	5 ± 1.1	402 ± 53	78 ± 9.6	*
	T2	197 ± 20	33 ± 2.6	15 ± 2.2	2 ± 0.2	212 ± 21	35 ± 2.8	*
Wheat	T1	195 ± 15	72 ± 6.3	10 ± 0.9	2 ± 0.2	205 ± 16	74 ± 6.3	*
	T2	133 ± 17	44 ± 6.3	7 ± 0.7	1 ± 0.1	140 ± 17	46 ± 6.3	*

Table 4: Mean (±SEM) dry matter of plant organs (g seedling^{-1}).

Plant organ	Linseed		Barley		Wheat		ANOVA
	T1	T2	T1	T2	T1	T2	
Fruit	4 ± 0.5	2 ± 0.2	6 ± 1	2 ± 0.4	15 ± 2.1	8 ± 0.9	*
Leaves	4 ± 0.3	3 ± 0.2	32 ± 3.6	19 ± 1.6	12 ± 0.9	9 ± 1.4	*
Stem	16 ± 1.1	12 ± 1.4	35 ± 5.6	11 ± 1.1	45 ± 3.9	31 ± 5.2	*
Root	2 ± 0.1	1 ± 0.1	5 ± 1.1	2 ± 0.2	2 ± 0.2	1 ± 0.1	*

T1: forest soil (*Hagenia*-influenced soil); T2: farmland soil; *significant ($P < .05$).

followed a trend of stem (45%) > leaf (41%) > fruit (8%) > root (6%) while barley plants grown on T2 followed a trend of leaf (55%) > stem (33%) > fruit (6%) > root (6%). Wheat seedlings grown on T1 attained a relative dry matter content in stem (61%) > fruit (19%) > leaf (17%) > root (3%); yet, wheat plants grown on T2 followed a trend of stem (63%) > leaf (18%) > fruit (16%) > root (3%). In general, the contribution of root biomass to total dry matter was the lowest in all plants. Moreover, the dry matter content in plant organs observed among indicator plants grown differently remained significant ($P < .05$).

8. Discussion

Contribution of *Hagenia abyssinica* for soil fertility management using biotest method showed significant differences between treatments. Morphological features and dry matter accumulation varied among the studied plants. In this regard, plants grown on *Hagenia*-influenced soil attained enhanced performance than those grown on farmland soil. The reason could be due to high organic matter and nutrient content in the soil which resulted from substantial amount of leaf litter under *Hagenia abyssinica* trees. Dense litter cover under *Hagenia* trees possibly enriches the soil with nitrogen, organic carbon, and basic cations and adds more organic matter especially on upper soil horizon. It has been reported that *Hagenia abyssinica* has great amount of litter production per unit time and fast decomposition rates which makes it an effective nutrient pump [14, 22]. Litter falling to the soil surface has a tremendous impact on the composition of the soil C and N pools [23].

9. Conclusion

The higher biomass and growth performance observed in plants grown on *Hagenia*-influenced soils noticeably shows the beneficial role of this species in enhancing soil fertility status which in turn results in higher productivity. This indicates that it would be possible to achieve better performance in field conditions by combining *H. abyssinica* with agricultural crops, if specificities of shading and competition for water are considered too. Given the low soil fertility status of the farms in the Ethiopian highlands associating, indigenous trees such as *H. abyssinica*, as an agroforestry tree, would contribute much for soil fertility improvement. The study also points out that studies attempting to examine role of indigenous tree species in growth and yield promotion through biotest method are a simple, practical and low-cost procedure in providing information on soil fertility especially for those who do not have access to well-equipped laboratory facilities.

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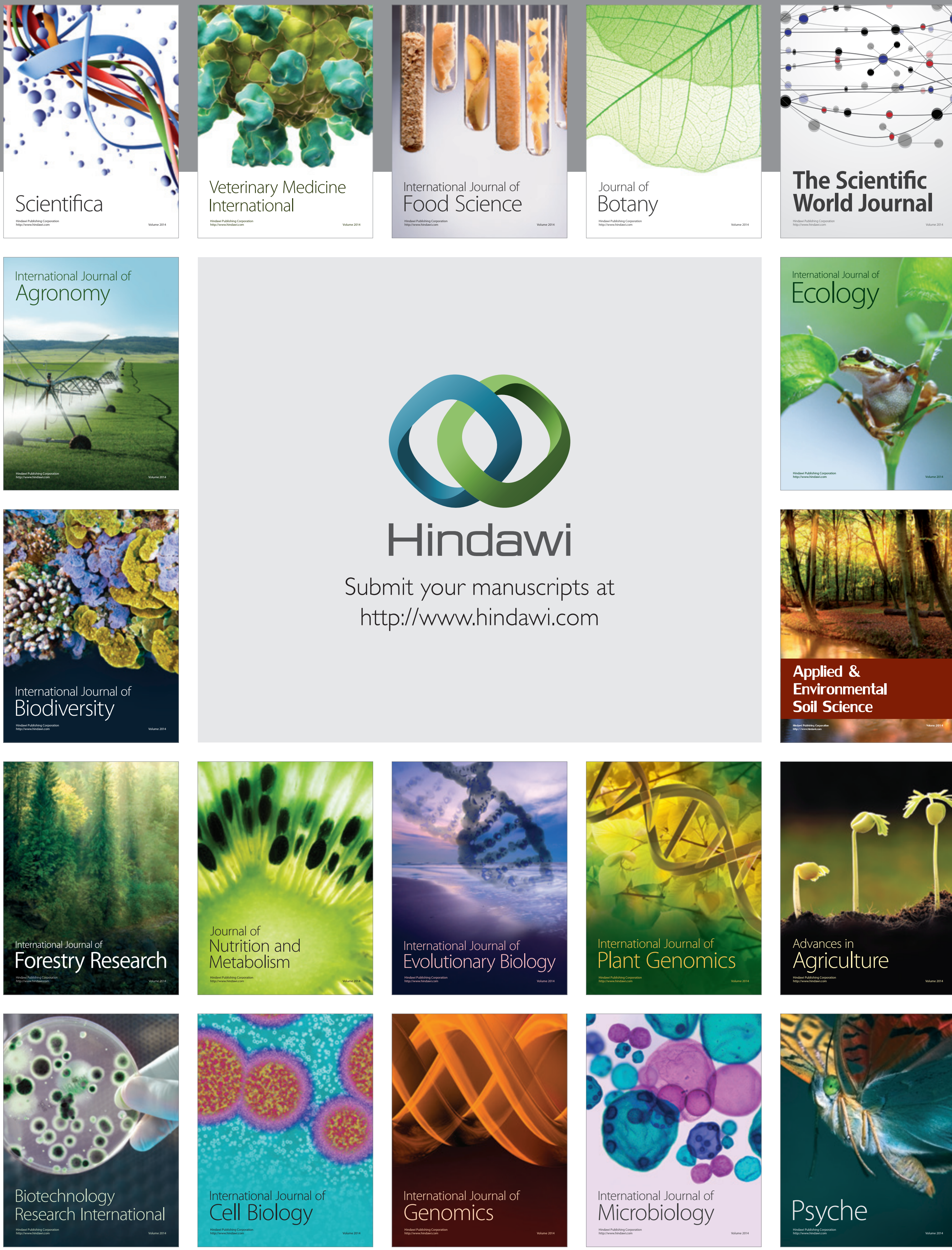
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