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Status of Native Woody Species Diversity and Soil Characteristics in an Exclosure and in Plantations of *Eucalyptus globulus* and *Cupressus lusitanica* in Northern Ethiopia

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Exclusion of grazing animals and tree plantations are 2 methods that have been used for restoration of degraded lands in tropical semiarid areas. These 2 options can foster secondary forest succession by improving

soil conditions, attracting seed-dispersal agents, and modifying microclimate for understory growth. We compared native woody plant diversity and soil chemical and physical attributes under exclosure and on *Eucalyptus globulus* (EGP) and *Cupressus lusitanica* (CLP) plantations. Vegetation data were collected by an inventory of stands with circular plots of 5.64 m radius, and soil samples were collected from the 4 corners and center of 20 × 20 m plots. As a result, 15 native woody plant species belonging to 13 families were recorded. Importance value index (IVI), Shannon-Wiener, Simpson's diversity, and species richness were higher in the exclosure, followed by EGP and CLP. Contents of soil

organic carbon and total nitrogen showed significance difference and were highest in the exclosure, followed by CLP, EGP, and grazing land. Although the difference was not significant, an increasing trend was observed for cation exchange capacity and K^+ . Bulk density was highest on the grazing land, followed by EGP, CLP, and exclosure. Our results suggest that degraded land reclamation can be achieved with plantation of rapidly growing tree species as well as exclosure. However, native woody species diversity and improved soil attributes are better achieved with exclosure. Exclosures can be established interspersed strategically with single- or mixed-species plantations to facilitate restoration of native vegetation. However, it is important to conduct further research on the comparative advantage of enrichment planting of exclosures with preferred tree species or exclosures interspersed within blocks of plantation.

Keywords: Restoration; regeneration; succession; woody species; soil attributes; Afromontane; Ethiopia.

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Introduction

Land degradation, which impairs land productivity in the Ethiopian Highlands, may lead to desertification if unabated. Especially in northern Ethiopia, land degradation has been accelerated by long-standing human impact through changing land use and deforestation (Hurni 1988; Nyssen et al 2009) and strong biomass demand for the still-increasing human and livestock populations (Tekle 1999). The most important countermeasures taken to halt this process have been plantation of trees and assisted natural regeneration by excluding human and animal interference (exclosure) (Pohjonen and Pukkala 1990; Tekle 2001).

Plantations of rapidly growing exotic tree species are good options for increased biomass productivity per

given time and area (Pohjonen and Pukkala 1990). However, in terms of restoration of degraded lands, this option may fail to address the concerns of productivity and diversity, and it may not be feasible and compatible with specific local environmental, socioeconomic, and technological realities, which all may force tree plantations to be replaced or augmented with different restoration strategies, such as exclosure. Exclosures have been reported to be effective for native plant restoration (Mengistu et al 2005; Aerts et al 2007), improving soil attributes, and reducing soil erosion (Descheemaeker et al 2006a, 2006b). Similarly, plantations have been used to catalyze forest succession in the understory to restore native vegetation (Parrotta 1999; Lee et al 2005; Brockerhoff et al 2008) and improve soil physical and chemical attributes (Mishra et al 2003).

The 2 options considered here can foster secondary forest succession by improving soil conditions, attracting seed-dispersal agents, and modifying microclimate for understory growth; however, there might be differences with regard to speed in restoring native vegetation and soil close to their original condition. Findings show that seedlings of late successional tree species are especially impacted by environmental modifications following restoration (Farwig et al 2009). Thus, the diversity and density of late successional species can be used as proxies for the potential of different reclamation techniques to develop into more natural forests (Babaasa et al 2004).

Several studies have been conducted that compare pure and mixed-species plantation and natural forest (Lisanework and Michelsen 1994; Lugo 1997; Lemenih et al 2004a; Piotto et al 2004; Zamora and Montagnini 2007) to determine their impact on naturally regenerated native woody species (NRNWS) and soil. Few studies, however, have compared enclosure and plantation of exotic species on degraded lands in the dry Afromontane forests of Ethiopia. In this study, we compared enclosure, *Cupressus lusitanica* (CLP), and *Eucalyptus globulus* (EGP) plantations with respect to their impact on naturally regenerated native woody species (NRNWS) as well as on soil attributes.

Material and methods

Study area

The study area is located in Tehuledere district, South Wello, on the eastern edge of the northeastern highlands of Ethiopia (11°12'30.56"N; 39°40'44.51"E). The great Ethiopian Rift system is found within an ~25 km radius. The topography is rugged, with a dissected and degraded plateau. The average altitude is 2350 m, mean annual temperature is 21°C, and the average annual precipitation is 1030 mm. The potential natural vegetation of the area is dry Afromontane forest dominated by *Juniperus procera* and *Olea europaea* ssp *cuspidata*. Broad-leaved species are dominant (Aalbaek 1993). The valley floors are settled by subsistence farmers engaged in mixed-crop production and livestock rearing. The average population density is estimated to be 285 persons per km² (Tesfahun et al 2002). The study plots were established on the east-facing slope (20–45%) of a ridge that stretches through the political boundary of the district and that was rehabilitated by the efforts of donors and local partners following the Sahel drought of the 1970s (some of the reports related to the rehabilitation efforts are: Tekle et al 1997; Tekle 1999, 2001; Tekle and Bekele 2000; Tekle and Hedlund 2000). On this ridge, we purposely selected an area where an enclosure had been established between a block of *E. globulus* and *C. lusitanica* plantations on former grazing land. According to reports, it has been protected since establishment from human and domestic animal interference by paid guards as well as by the local

population (Tesfahun et al 2002). This area was selected because it is one of the few forests that survived destruction in 1991 during the change of government. The enclosure and plantations were established in close proximity, creating a good opportunity to compare their effects, and they were also easily accessible.

Data collection

Vegetation sampling was done on transect lines perpendicular to the contours. The spacing between transects was 100 m. Circular sampling plots with a 5.64 m radius (~100 m²) at 75 m intervals (adjusted for slope) were used on a transect. The maximum number of plots per transect was 3 in the enclosure and 2 in the plantations. The total number of plots per habitat was 6. Inside each plot, every woody plant greater than 3 cm diameter at breast height (DBH) was identified and measured. Identification of species and nomenclature follow *Flora of Ethiopia and Eritrea* (Edwards et al 1995; Hedberg and Edwards 1995; Edwards et al 1997).

Little is known about soil conditions before intervention; therefore, the grazing land was used as a reference. Sampling plots were located based on their representativeness by using available field methods such as similarity in soil color, structure, and cohesiveness when wet, developed by the first and second authors. Soil samples were then collected in 5 replicates per habitat from a pit dug from the 4 corners and center of square 20 m × 20 m plots, including on the grazing land. Samples were obtained from depths of 0–10 and 10–20 cm.

Soil analysis was carried out at the soil laboratory at the Sirinka Agricultural Research Center (Ethiopia). Soil pH was measured in water and 1 M KCl suspension at 1:2.5 soil:liquid ratio potentiometrically using glass-calomel combination electrodes. Soil organic C (SOC) and total N were determined using a LECO-1000 CHN analyzer. Available P was analyzed according to standard methods (Olsen et al 1954). Potassium was analyzed by flame photometer (Black et al 1965). Cation exchange capacity (CEC) was determined following Chapman (1965). Bulk density was determined following Brady and Weil (2002).

Data analysis

The relative dominance or importance of a species in a given habitat can be expressed by the Importance value index (IVI). IVI is calculated as the sum of relative dominance, relative abundance, and relative frequency of species. Dominance is calculated as the sum of basal area (BA) in square meters per hectare of each species (BA = $\pi[\text{DBH}^2/4]$). Relative dominance is the percentage of the total basal area of a given species out of the total measured stem basal areas for all species, relative abundance is the percentage of the abundance (the number of stems of individuals of a species per ha) of each species compared to the total stem numbers for all species

per hectare, and relative frequency is the percentage of frequency (the percentage of the total number of plots containing the species to all plots) of a species compared to the total frequencies of all the species added up. Plot-level species diversity statistics were calculated using the Shannon-Wiener index and Simpson's diversity index. The effects of habitats (created by each intervention) on the diversity statistics were determined with 1-way analysis of variance (ANOVA). The frequency of DBH (cm) size classes was used to compare population structure. The data obtained from the soil analyses were subjected to 1-way ANOVA for each sample depth separately.

Results

Woody species diversity

In total, 15 NRNWS from 13 families were recorded. All NRNWS were represented in the enclosure, but only 2 were found in CLP and 4 in EGP. About 75% of the species had more than 50% frequency in the enclosure. The most dominant species were *Juniperus procera* Hochst. ex Endl., *Acacia abyssinica* Hochst. ex Benth., *Olea europaea* ssp. *cuspidata*, *Carissa edulis* (Forssk.) Vahl, *Nuxia congesta* R.Br. ex Fresen., and *Maytenus senegalensis* (Lam.) Excell. The dominance, density, and frequency values for each species were higher in the enclosure than the plantation (Table 1). The IVI values for *J. procera*, *A. abyssinica*, and *O. europaea* in the enclosure were higher than the 2 plantations (Table 1).

Species richness was significantly higher in the enclosure than in the 2 plantations ($p < 0.001$). There was no significant difference in species richness between the 2 plantations, although EGP had greater mean species richness value than CLP. Shannon-Wiener and Simpson's diversity indices also showed significant differences, where the enclosure was more diverse than the 2 plantations (Table 2). Stem diameter size distribution for the most dominant NRNWS was higher in the enclosure (Figure 1A) than in CLP (Figure 1B) and EGP (Figure 1C) for all size classes. Rather, smaller-sized individuals dominated in the plantations.

Soil physical and chemical attributes

Significant ($p < 0.05$) differences in soil pH were found at the lower (10–20 cm) soil depth among habitats. In the case of SOC and N, the enclosure exhibited significantly higher ($p < 0.001$) values, and the order was enclosure $>$ CLP $>$ EGP $>$ grazing land, except for EGP $>$ CLP in SOC for the lower layer (Table 3). Mean values of CEC, K, and P were not significantly different ($p > 0.05$).

Bulk density (g cm^{-3}) was also significantly ($p < 0.001$) different. The grazing land exhibited significantly ($p < 0.001$) higher mean value of soil bulk density, followed by EGP, CLP, and the enclosure (Table 3).

Discussion

Our results show, 30 years after establishment, that enclosure increased diversity of NRNWS more than the plantations. DBH for most of the encountered NRNWS was less than 15 cm, except in the population of *A. abyssinica* and *J. procera*, where 99% are less than 30 cm DBH, and more than 95% are less than 19 cm DBH. This difference may be explained by the regeneration strategy of NRNWS and can be discussed in relation to the facilitative or inhibitive processes created by postintervention environmental conditions (Connell and Slatyer 1977).

Reports have shown that succession achieves successful seedling recruitment in dry Afrotropical forests either from seed rain or advance regeneration (Teketay 1997a, 1997b, 1997c, 2005). However, these regeneration pathways are reportedly impeded by several limitations. Seed limitation has been reported due to diminished natural vegetation from long-standing deforestation and the confinement of mother trees in churches and remote groves (Wassie and Teketay 2006; Wassie et al 2009), absence of soil seed banks and their depletion by cultivation (Teketay and Granström 1995; Teketay and Granström 1997a, 1997b; Teketay 1998; Lemenih and Teketay 2005), and insufficient disperser activity because the seeds of late successional native plants are large, short-lived, and dependent on frugivorous animals for dispersal (Aerts et al 2006, 2008a). Similar studies also have shown that light, moisture, seed dormancy, and other biotic and abiotic factors limit establishment of late successional tree species.

Our results showed higher frequency of NRNWS for all stem diameter size classes in the enclosure than on the plantations (Figure 1A, B, and C). This suggests that the enclosure created a postintervention environment that facilitated succession, either from seed rain or advance regeneration. Regeneration from seed rain might have been facilitated in the enclosure by increased seed influx, forest structural diversity, attraction of animal seed dispersers (Zanne and Chapman 2001), and creation of light, moisture, and other resource gradients favorable for germination and establishment of diverse NRNWS (Yirdaw 2001; Yirdaw and Leinonen 2002; Yirdaw and Luukkanen 2004).

The positive role of soil seed bank (SSB) against establishment and seed limitations might have contributed to the observed differences. Although we did not measure SSB, and there have been reports of little similarity between SSB and standing flora, and SSB mostly composed of annual plants (Teketay and Granström 1995), pioneer plants from the SSB have strong effects in modifying the environment to facilitate secondary succession (Tekle and Bekele 2000). In addition, some light-demanding trees that have a strong effect on secondary succession might originate from the SSB. For

TABLE 1 Frequency, abundance, dominance, relative dominance (%), and Importance value index (IVI) of the main naturally regenerated native woody species (NRNWS) under enclosure, *C. lusitanica* plantation (CLP), and *E. globulus* plantation (EGP). (Table extended on next page.)

Family	Tree species	Frequency			Abundance		
		Excl	CLP	EGP	Excl	CLP	EGP
Cupressaceae	<i>Juniperus procera</i> Hochst. ex Endl.	100.00	66.67	83.33	1896.00	84.00	495.83
Fabaceae	<i>Acacia abyssinica</i> Hochst. ex Benth.	83.33	16.67	83.33	75.00	4.00	29.17
Oleaceae	<i>Olea europaea</i> L. ssp. <i>cuspidata</i> (Wall. ex G. Don) Cif.	100.00	0.00	33.33	104.17	0.00	16.67
Apocynaceae	<i>Carissa edulis</i> (Forssk.) Vahl	83.33	0.00	0.00	583.33	0.00	0.00
Loganiaceae	<i>Nuxia congesta</i> R.Br. ex Fresen.	83.33	0.00	0.00	91.67	0.00	0.00
Celastraceae	<i>Maytenus</i> <i>senegalensis</i> (Lam.) Excell.	83.33	0.00	16.67	316.67	0.00	4.17
Oleaceae	<i>Jasminum</i> <i>abyssinicum</i> Hochst. ex DC.	50.00	0.00	0.00	37.50	0.00	0.00
Melanthaceae	<i>Bersama abyssinica</i> Fresen.	16.67	0.00	0.00	8.33	0.00	0.00
Sterculiaceae	<i>Dombeya torrida</i> (J.F. Gmel) P. Bamps	50.00	0.00	0.00	25.00	0.00	0.00
Fabaceae	<i>Calpurnia aurea</i> (Ait.) Benth.	50.00	0.00	0.00	25.00	0.00	0.00
Anacardiaceae	<i>Rhus glutinosa</i> A. Rich.	16.67	0.00	0.00	8.33	0.00	0.00
Sapindaceae	<i>Allophylus abyssinicus</i> (Hochst.) Radlkofer	50.00	0.00	0.00	16.67	0.00	0.00
Apiaceae	<i>Heteromorpha</i> <i>trifoliata</i> (Wendel) Eckl. & Zeyher	66.67	0.00	0.00	45.83	0.00	0.00
Pittosporaceae	<i>Pittosporum</i> <i>viridiflorum</i> Sims	16.67	0.00	0.00	4.17	0.00	0.00
Santalaceae	<i>Osyris quadripartita</i> Decn.	16.67	0.00	0.00	8.33	0.00	0.00

instance, *A. abyssinica* and *J. procera* are represented by larger-sized individuals in irregular patterns in the plantations and in almost every size class in the enclosure (Figure 1A–C). Although some of the extremely large trees (<2%; not shown in Figure 1A–C) may be remnants of the original vegetation, the majority are likely to have established from the SSB before the habitat changed much in the plantations. Previous studies have shown that seeds from these 2 species have longer viability and different dormancy mechanisms (Teketay 1998; Wassie et al 2009). Disturbance during plantation-site preparation may break dormancy and trigger germination, and

protection from human and livestock would ensure successful recruitment. However, this recruitment does not seem to have occurred continuously; rather, it likely fluctuated with time and affected canopy characteristics, which would have indirectly determined germination (Yirdaw and Leinonen 2002; Yirdaw and Luukkanen 2004).

Succession through the pathway of advance regeneration might have improved NRNWS diversity under enclosure. Site clearance and weeding, which are important activities in plantation forest management, especially impede advance regeneration, as noted by

TABLE 1 Extended. (First part of Table 1 on previous page.)

Family	Tree species (short name)	Dominance			Relative dominance (%)			IVI		
		Excl	CLP	EGP	Excl	CLP	EGP	Excl	CLP	EGP
Cupressaceae	<i>Juniperus</i>	17.12	0.07	2.80	59.08	0.31	9.67	110.54	8.19	27.58
Fabaceae	<i>Acacia</i>	1.38	0.10	1.00	4.75	0.41	3.47	12.97	1.95	10.63
Oleaceae	<i>Olea</i>	0.36	0.00	0.00	1.23	0.00	0.01	11.42	0.00	2.99
Apocynaceae	<i>Carissa</i>	0.23	0.00	0.00	0.80	0.00	0.00	20.73	0.00	0.00
Loganiaceae	<i>Nuxia</i>	0.12	0.00	0.00	0.41	0.00	0.00	9.01	0.00	0.00
Celastraceae	<i>Maytenus</i>	0.12	0.00	0.00	0.40	0.00	0.01	14.19	0.00	1.40
Oleaceae	<i>Jasminum</i>	0.04	0.00	0.00	0.15	0.00	0.00	4.91	0.00	0.00
Melanthaceae	<i>Bersama</i>	0.03	0.00	0.00	0.11	0.00	0.00	1.60	0.00	0.00
Sterculiaceae	<i>Dombeya</i>	0.03	0.00	0.00	0.09	0.00	0.00	4.57	0.00	0.00
Fabaceae	<i>Calpurnia</i>	0.02	0.00	0.00	0.07	0.00	0.00	4.54	0.00	0.00
Anacardiaceae	<i>Rhus</i>	0.02	0.00	0.00	0.06	0.00	0.00	1.55	0.00	0.00
Sapindaceae	<i>Allophylus</i>	0.02	0.00	0.00	0.06	0.00	0.00	4.34	0.00	0.00
Apiaceae	<i>Heteromorpha</i>	0.01	0.00	0.00	0.03	0.00	0.00	6.28	0.00	0.00
Pittosporaceae	<i>Pittosporum</i>	0.00	0.00	0.00	0.01	0.00	0.00	1.40	0.00	0.00
Santalaceae	<i>Osyris</i>	0.00	0.00	0.00	0.01	0.00	0.00	1.50	0.00	0.00

TABLE 2 Mean \pm SE for species richness, Shannon-Wiener, and Simpson's diversity values under exclosure, *C. lusitanica* plantation (CLP), and *E. globulus* plantation (EGP).

Index	Exclosure	CLP	EGP	F	P
Shannon-Wiener	1.13 \pm 0.17 ^{a)}	0.12 \pm 0.11 ^{b)}	0.39 \pm 0.11 ^{b)}	14.84	0.00
Simpson's	0.51 \pm 0.19 ^{a)}	0.08 \pm 0.20 ^{b)}	0.22 \pm 0.18 ^{b)}	7.44	0.01
Species richness	9.00 \pm 2.81 ^{a)}	1 \pm 0.75 ^{b)}	2 \pm 1.33 ^{b)}	31.00	0.00

^{a)}Different letters indicate significant differences between groups according to Tukey's honestly significant difference (HSD) test.

FIGURE 1 Frequency of the number of trees per ha according to stem diameter size. (A) Exclosure; (B) *C. lusitanica* plantation (CLP); (C) *E. globulus* plantation (EGP). Note: for reasons of scale, the number of trees per ha has been log transformed.

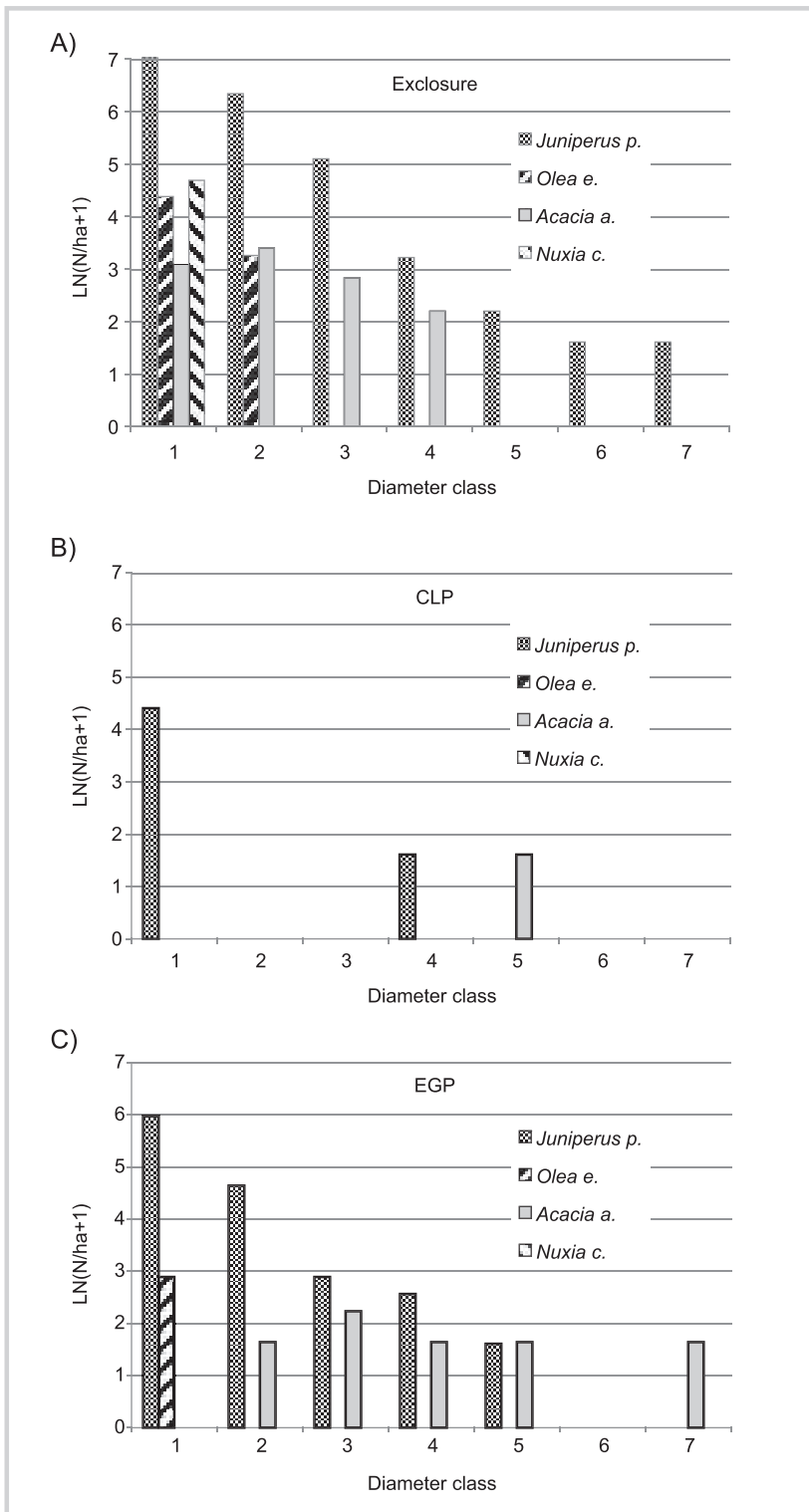


TABLE 3 Mean \pm SE result of soil pH, soil organic carbon (SOC), total nitrogen (N), available potassium (K), available phosphorus (P), and bulk density (BD) for depths of 0–10 cm and 10–20 cm for the enclosure, *C. lusitanica* plantation (CLP), grazing land (GL), and *E. globulus* plantation (EGP), and corresponding F and P values from ANOVA.

Soil properties	Depth (cm)	Enclosure	CLP	GL	EGP	F	P
pH	0–10	5.9 \pm 0.1	5.8 \pm 0.1	5.9 \pm 0.02	5.6 \pm 0.2	1.96	0.16
	10–20	5.8 \pm 0.1 ^{a(b)}	5.8 \pm 0.1 ^{a(b)}	5.9 \pm 0.04 ^{a)}	5.6 \pm 0.02 ^{b)}	4.05*	0.03
SOC (g kg ⁻¹)	0–10	36.0 \pm 3.2 ^{a)}	25.5 \pm 1.9 ^{b)}	11.9 \pm 1.5 ^{c)}	23.7 \pm 2.7 ^{b)}	16.57	0.00
	10–20	27.1 \pm 1.2 ^{a)}	18.7 \pm 2.8 ^{b(c)}	11.7 \pm 1.2 ^{c)}	19.5 \pm 1.5 ^{b)}	12.52	0.00
N (g kg ⁻¹)	0–10	3.9 \pm 0.6 ^{a)}	2.9 \pm 0.6 ^{a)}	0.8 \pm 0.2 ^{b)}	2.7 \pm 0.3 ^{a)}	8.59	0.00
	10–20	3.8 \pm 0.8 ^{a)}	2.0 \pm 0.3 ^{b)}	0.9 \pm 0.1 ^{b(c)}	1.9 \pm 0.2 ^{b)}	7.41	0.00
K (g kg ⁻¹)	0–10	700.2 \pm 63.9	571.6 \pm 67.7	414.3 \pm 114.3	539.6 \pm 109	2.84	0.22
	10–20	413.6 \pm 55.3	411.5 \pm 33.7	327.2 \pm 14.4	431.3 \pm 56.2	2.49	0.36
P (mg kg ⁻¹)	0–10	8.0 \pm 0.4	7.8 \pm 0.9	6.9 \pm 0.7	8.2 \pm 0.6	1.64	0.58
	10–20	9.6 \pm 1.2	7.2 \pm 0.1	9.2 \pm 0.3	8.1 \pm 0.5	1.15	0.07
Clay (%)	0–10	31.8 \pm 2.4	32.3 \pm 3.1	26.3 \pm 1.7	33.3 \pm 1.7	1.89	0.17
	10–20	32.3 \pm 2.5 ^{a(b)}	34.3 \pm 2.9 ^{a)}	24.3 \pm 2.0 ^{b)}	34.8 \pm 2.1 ^{a)}	4.13	0.02
Sand (%)	0–10	34.3 \pm 3.7 ^{b)}	32.8 \pm 3.3 ^{b)}	49.8 \pm 2.7 ^{a)}	32.8 \pm 1.9 ^{b)}	7.84	0.00
	10–20	32.8 \pm 2.2 ^{b)}	30.3 \pm 3.5 ^{b)}	48.3 \pm 4.6 ^{a)}	34.0 \pm 2.8 ^{b)}	5.70	0.01
BD (g cm ⁻³)	0–10	0.7 \pm 0.02 ^{c)}	0.9 \pm 0.02 ^{b)}	1.1 \pm 0.03 ^{a)}	0.9 \pm 0.02 ^{b)}	66.37	0.00
	10–20	0.8 \pm 0.01 ^{c)}	0.9 \pm 0.03 ^{b(c)}	1.1 \pm 0.03 ^{a)}	0.9 \pm 0.03 ^{b)}	28.77	0.00

^{a)}Different letters indicate significant differences between groups according to Tukey's HSD test.

*P values in bold face show statistically significant difference at $P < 0.05$.

Hartley (2002). Some NRNWS in particular, which are exposed to different stresses of herbivory, fire, and cutting, show highly modified morphology. However, when left in situ and relieved from stress with the establishment of enclosures, they can play a remarkable role in the recovery of tree canopy and forest microclimate and forest succession by resprouting. For instance, in situ persistence, the ability to produce vegetative shoots and hence modified morphology, is an important addition to other recruitment pathways such as recruitment via seed rain for *Olea europaea* ssp. *cuspidate* (Aerts et al 2008b).

According to studies from other different areas, tree plantations increase the diversity of understory woody vegetation, which varies with species (eg Kuusipalo et al 1996; Slocum 2000; Ashton et al 2001; Cusack and Montagnini 2004; Butler et al 2008). Similarly, among plantation species, the broad-leaved *Eucalyptus* sp. encouraged higher understory plant recruitment than the conifer (*Cupressus* sp.), which conforms to results from previous studies in Ethiopia (Yirdaw 2001; Lemenih et al 2004a; Yirdaw and Luukkanen 2004). Such variations are attributed to stand canopy characteristics that determine the amount of canopy gaps available for solar radiation, which influences the environmental conditions at the forest floor such as light and air and soil temperatures.

Our results also suggest that enclosure affected the soil chemical attributes desirably. This is consistent with previous studies (eg Descheemaeker et al 2009). Similarly, Mekuria et al (2007) found higher soil organic matter content, total nitrogen, available phosphorus, exchangeable bases, and CEC values in an enclosure (10 years old) than on the adjacent grazing land.

The plantations improved soil features associated with chemical characteristics better than the grazing land. This also conforms to previous reports (Mishra et al 2003; Lemenih et al 2004b; Lemma et al 2006; Boley et al 2009). For instance, Lemenih et al (2004b) reported lower bulk density and higher soil C, total N, CEC, base saturation, K, Ca, and Mg after 15 years of *C. lusitanica* plantation than in soils under cultivation.

The bulk density results from the soil in the enclosure are in agreement with previous reports (Descheemaeker et al 2006b; Castellano and Valone 2007; Jeddi and Chaieb 2010), which showed that grazing increased soil compaction, bulk density, and runoff.

Implications for practice

Recruitment of NRNWS and improved soil attributes can be achieved with the establishment of enclosures, given enough time. The major practical implications are: First,

enclosures can be established interspersed strategically with single- or mixed-species plantations to facilitate restoration of native vegetation. Second, future tree plantation activities should consider maintaining original vegetation to foster recruitment of seedlings/saplings either from seed rain or soil seed bank through

recolonization or advance regeneration through sprouting. However, further research will be required to gain insights into the comparative advantage of either enrichment planting of enclosures with the desired tree species or interspersing enclosures within blocks of single- or mixed-species plantations.

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REFERENCES

- Aalbaek A.** 1993. *Seed Zones of Ethiopia and Eritrea*. Addis Abeba, Ethiopia: National Tree Seed Project.
- Aerts R, Maes W, November E, Negussie A, Hermy M, Muys B.** 2006. Restoring dry Afromontane forest using bird and nurse plant effects: Direct sowing of *Olea europaea* ssp. *Cuspidata* seeds. *Forest Ecology and Management* 230(1–3):23–31.
- Aerts R, Negussie A, Maes W, November E, Hermy M, Muys B.** 2007. Restoration of dry Afromontane forest using pioneer shrubs as nurse-plants for *Olea europaea* ssp. *Cuspidata*. *Restoration Ecology* 15(1):129–138.
- Aerts R, Lerouge F, November E, Lens L, Hermy M, Muys B.** 2008a. Land rehabilitation and the conservation of birds in a degraded Afromontane landscape in northern Ethiopia. *Biodiversity and Conservation* 17:53–69.
- Aerts R, November E, Maes W, Van der Borgh I, Negussie A, Aynekulu E, Hermy M, Muys B.** 2008b. In situ persistence of African wild olive and forest restoration in degraded semiarid savanna. *Journal of Arid Environments* 72(6): 1131–1136.
- Ashton M, Gunatilleke C, Singhakumara B, Gunatilleke I.** 2001. Restoration pathways for rain forest in southwest Sri Lanka: A review of concepts and models. *Forest Ecology and Management* 525:1–23.
- Babaasa D, Eilu G, Kasangaki A, Bitariho R, McNeilage A.** 2004. Gap characteristics and regeneration in Bwindi Impenetrable National Park, Uganda. *African Journal of Ecology* 42:217–224.
- Black CA, Evans DD, White JL, Ensminger LE, Clark FE.** 1965. *Methods of Soil Analysis. Part 1. Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling*. Madison, WI: American Society of Agronomy.
- Boley JD, Drew AP, Andrus RE.** 2009. Effects of active pasture, teak (*Tectona grandis*) and mixed native plantations on soil chemistry in Costa Rica. *Forest Ecology and Management* 257(11):2254–2261.
- Brady NC, Weil RR, editors.** 2002. *The Nature and Properties of Soils*. 13th edition. Englewood Cliffs, NJ: Prentice-Hall.
- Brockerhoff EG, Jactel H, Parrotta JA, Quine CP, Sayer J.** 2008. Plantation forests and biodiversity: Oxymoron or opportunity? *Biodiversity and Conservation* 17:925–951.
- Butler R, Montagnini F, Arroyo P.** 2008. Woody understory plant diversity in pure and mixed native tree plantations at La Selva Biological Station, Costa Rica. *Forest Ecology and Management* 255(7):2251–2263.
- Castellano MJ, Valone TJ.** 2007. Livestock, soil compaction and water infiltration rate: Evaluating a potential desertification recovery mechanism. *Journal of Arid Environments* 71(1):97–108.
- Chapman HD.** 1965. Cation exchange capacity. In: Black CA, Evans DD, White JL, Ensminger LE, Clark FE, editors. *Methods of Soil Analysis*. Vol 9. Madison, WI: American Society of Agronomy, pp 891–901.
- Connell JH, Slatyer RO.** 1977. Mechanisms of succession in natural communities and their role in community stability and organization. *The American Naturalist* 111(982):1119–1144.
- Cusack D, Montagnini F.** 2004. The role of native species plantations in recovery of understory woody diversity in degraded pasturelands of Costa Rica. *Forest Ecology and Management* 188(1–3):1–15.
- Descheemaeker K, Muys B, Nyssen J, Poesen J, Raes D, Haile M, Deckers J.** 2006a. Litter production and organic matter accumulation in enclosures of the Tigray Highlands, Ethiopia. *Forest Ecology and Management* 233(1):21–35.
- Descheemaeker K, Nyssen J, Poesen J, Raes D, Haile M, Muys B, Deckers S.** 2006b. Runoff on slopes with restoring vegetation: A case study from the Tigray Highlands, Ethiopia. *Journal of Hydrology* 331(1–2):219–241.
- Descheemaeker K, Muys B, Nyssen J, Sauwens W, Haile M, Poesen J, Raes D, Deckers J.** 2009. Humus form development during forest restoration in enclosures of the Tigray Highlands, northern Ethiopia. *Restoration Ecology* 17(2):280–289.
- Edwards S, Mesfin T, Hedberg I.** 1995. *Flora of Ethiopia and Eritrea*. Vol 2, Part 2. Addis Abeba, Ethiopia: The National Herbarium, Addis Abeba University; and Uppsala, Sweden: Department of Systematic Botany, Uppsala University.
- Edwards S, Sebsebe D, Hedberg I.** 1997. *Flora of Ethiopia and Eritrea*. Vol 6. Addis Abeba, Ethiopia: The National Herbarium, Addis Abeba University; and Uppsala, Sweden: Department of Systematic Botany, Uppsala University.
- Farwig N, Sajita N, Böhning-Gaese K.** 2009. High seedling recruitment of indigenous tree species in forest plantations in Kakamega Forest, western Kenya. *Forest Ecology and Management* 257(1):143–150.
- Hartley MJ.** 2002. Rationale and methods for conserving biodiversity in plantation forests. *Forest Ecology and Management* 155(1–3):81–95.
- Hedberg I, Edwards S.** 1995. *Flora of Ethiopia*. Vol 7. Addis Abeba, Ethiopia: The National Herbarium, Addis Abeba University; and Uppsala, Sweden: Uppsala University.
- Hurni H.** 1988. Degradation and conservation of soil resources in the Ethiopian Highlands. *Mountain Research and Development* 8:123–130.
- Jeddi K, Chaieb M.** 2010. Changes in soil properties and vegetation following livestock grazing exclusion in degraded arid environments of south Tunisia. *Flora—Morphology, Distribution, Functional Ecology of Plants* 205(3): 184–189.
- Kuusipalo J, Jafarsidik Y, Ådjers G, Tuomela K.** 1996. Population dynamics of tree seedlings in a mixed Dipterocarp rainforest before and after logging and crown liberation. *Forest Ecology and Management* 81(1–3):85–94.
- Lee EWS, Hau BCH, Corlett RT.** 2005. Natural regeneration in exotic tree plantations in Hong Kong, China. *Forest Ecology and Management* 212(1–3):358–366.
- Lemenih M, Gidyelew T, Teketay D.** 2004a. Effects of canopy cover and understory environment of tree plantations on richness, density and size of colonizing woody species in southern Ethiopia. *Forest Ecology and Management* 194(1–3):1–10.
- Lemenih M, Olsson M, Karlton E.** 2004b. Comparison of soil attributes under *Cupressus lusitanica* and *Eucalyptus saligna* established on abandoned farmlands with continuously cropped farmlands and natural forest in Ethiopia. *Forest Ecology and Management* 195(1–2):57–67.
- Lemenih M, Teketay D.** 2005. Effect of prior land use on the recolonization of native woody species under plantation forests in the highlands of Ethiopia. *Forest Ecology and Management* 218(1–3):60–73.
- Lemma B, Kleja DB, Nilsson I, Olsson M.** 2006. Soil carbon sequestration under different exotic tree species in the southwestern highlands of Ethiopia. *Geoderma* 136(3–4):886–898.
- Lisanework N, Michelsen A.** 1994. Litterfall and nutrient release by decomposition in three plantations compared with a natural forest in the Ethiopian highland. *Forest Ecology and Management* 65(2–3):149–164.
- Lugo AE.** 1997. The apparent paradox of reestablishing species richness on degraded lands with tree monocultures. *Forest Ecology and Management* 99(1–2):9–19.
- Mekuria W, Veldkamp E, Haile M, Nyssen J, Muys B, Gebrehiwot K.** 2007. Effectiveness of enclosures to restore degraded soils as a result of overgrazing in Tigray, Ethiopia. *Journal of Arid Environments* 69(2):270–284.
- Mengistu T, Teketay D, Hulthen H, Yemshaw Y.** 2005. The role of enclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia. *Journal of Arid Environments* 60(2):259–281.

- Mishra A, Sharma SD, Gupta MK.** 2003. Soil rehabilitation through afforestation: Evaluation of the performance of *Prosopis juliflora*, *Dalbergia sissoo* and *Eucalyptus tereticornis* plantations in a sodic environment. *Arid Land Management and Research* 17:257–269.
- Nyssen J, Haile M, Naudts J, Munro N, Poesen J, Moeyersons J, Frank A, Deckers J, Pankhurst R.** 2009. Desertification? Northern Ethiopia re-photographed after 140 years. *Science of the Total Environment* 407(8):2749–2755.
- Olsen SR, Cole CV, Watanabe FS, Dean LA.** 1954. *Estimation of Available Phosphorous in Soils by Extraction with Sodium Bicarbonate*. USDA Circular 939. Washington, DC: USDA.
- Parrotta JA.** 1999. Productivity, nutrient cycling, and succession in single- and mixed-species plantations of *Casuarina equisetifolia*, *Eucalyptus robusta*, and *Leucaena leucocephala* in Puerto Rico. *Forest Ecology and Management* 124(1):45–77.
- Piotta D, Viquez E, Montagnini F, Kanninen M.** 2004. Pure and mixed forest plantations with native species of the dry tropics of Costa Rica: A comparison of growth and productivity. *Forest Ecology and Management* 190:359–372.
- Pohjonen V, Pukkala T.** 1990. *Eucalyptus globulus* in Ethiopian forestry. *Forest Ecology and Management* 36(1):19–31.
- Slocum MG.** 2000. Logs and fern patches as recruitment sites in a tropical pasture. *Restoration Ecology* 8(4):408–413.
- Teketay D, Granström A.** 1995. Soil seed banks in dry Afromontane forests of Ethiopia. *Journal of Vegetation Science* 6:777–786.
- Teketay D.** 1997a. The impact of clearing and conversion of dry Afromontane forests into arable land on the composition and density of soil seed banks. *Acta Oecologica* 18(5):557–573.
- Teketay D.** 1997b. Seedling population in dry Afromontane forests of Ethiopia. *Forest Ecology and Management* 98:149–165.
- Teketay D.** 1997c. Seedling populations and regeneration of woody species in dry Afromontane forests of Ethiopia. *Forest Ecology and Management* 98(2):149–165.
- Teketay D, Granström A.** 1997a. Germination ecology of forest species from the highlands of Ethiopia. *Journal of Tropical Ecology* 14:793–803.
- Teketay D, Granström A.** 1997b. Seed viability of Afromontane tree species in forest soils. *Journal of Tropical Ecology* 13:81–95.
- Teketay D.** 1998. Soil seed banks at an abandoned Afromontane arable site. *Feddes Repertorium* 109:161–174.
- Teketay D.** 2005. Seed and regeneration ecology in dry Afromontane forests of Ethiopia: I. Seed production - population structures. *Tropical Ecology* 46(1):29–44.
- Tekle K, Backéus I, Skoglund J, Woldu Z.** 1997. Vegetation on hill slopes in southern Wello, Ethiopia: Degradation and regeneration. *Nordic Journal of Botany* 17(5):483–493.
- Tekle K.** 1999. Land degradation problems and their implications for food shortage in South Wello, Ethiopia. *Environmental Management* 23(4):419–427.
- Tekle K, Bekele T.** 2000. The role of soil seed banks in the rehabilitation of degraded hill slopes in southern Wello, Ethiopia. *Biotropica* 32(1):23–32.
- Tekle K, Hedlund L.** 2000. Land cover change between 1958 and 1986 in Kalu district, southern Wello, Ethiopia. *Mountain Research and Development* 20(1):42–45.
- Tekle K.** 2001. Natural regeneration of degraded hill slopes in southern Wello, Ethiopia: A study based on permanent plots. *Applied Geography* 21:275–300.
- Tesfahun G, Abiyu A, Balkewu B, Menbere S, Getachew F, Admasu L, Berhane Z, Beyene A.** 2002. *Farming System in Tehuledere District, South Wello, Ethiopia*. Unpublished paper presented at the Amhara Region Agricultural Research Institute (ARARI) Annual Research Review Workshop. Bahir Dar, Ethiopia, 10–15 January 2002. Available from corresponding author of this article.
- Wassie A, Teketay D.** 2006. Soil seed banks in church forests of northern Ethiopia: Implications for the conservation of woody plants. *Flora—Morphology, Distribution, Functional Ecology of Plants* 201(1):32–43.
- Wassie A, Sterck FJ, Teketay D, Bongers F.** 2009. Tree regeneration in church forests of Ethiopia: Effects of microsites and management. *Biotropica* 41(1):110–119.
- Yirdaw E.** 2001. Diversity of naturally-regenerated native woody species in forest plantations in the Ethiopian Highlands. *New Forests* 22:159–177.
- Yirdaw E, Leinonen K.** 2002. Seed germination responses of four Afromontane tree species to red/far-red ratio and temperature. *Forest Ecology and Management* 168:53–61.
- Yirdaw E, Luukkanen O.** 2004. Photosynthetically active radiation transmittance of forest plantation canopies in the Ethiopian Highlands. *Forest Ecology and Management* 188:17–24.
- Zamora CO, Montagnini F.** 2007. Seed rain and seed dispersal agents in pure and mixed plantations of native trees and abandoned pastures at La Selva Biological Station, Costa Rica. *Restoration Ecology* 15(3):453–461.
- Zanne AE, Chapman CA.** 2001. Expediting reforestation in tropical grasslands: Distance and isolation from seed sources in plantations. *Ecological Applications* 11:1610–1621.