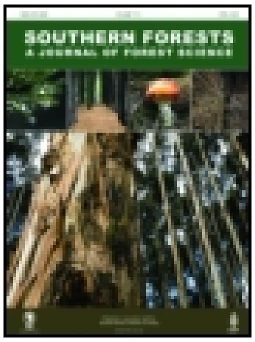

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Restoration of degraded ecosystems in the Afromontane highlands of Ethiopia: comparison of plantations and natural regeneration§

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The scale of deforestation in sub-Saharan Africa underscores the need for forest restoration. Information is scarce for evidence-based restoration options. Sown *Senna didymobotrya*, planted *Ficus thonningii* cuttings, sown *S. didymobotrya* and planted *F. thonningii* combined, and previously occurring native non-browse shrubs (NNS) were compared for their effect on selected plant nutrients and occurrence of *Olea europaea* subsp. *cuspidata* in north-west Ethiopia. The treatments were applied to experimental units established on previous grazing land. At the end of the fourth year, 60% of planted *F. thonningii* stakes survived. The leaf biomass production was encouraging. *Senna didymobotrya* attained close to 1 m height and crown width. Natural regeneration of *O. europaea* was observed only under previously occurring shrubs. Six previously occurring NNS species were identified. Soils immediately under these shrubs were richer in nutrients than between shrubs in the open spaces. Our results suggest that vegetative stakes and NNS could be promising tools for ecological restoration of decimated ecosystems in the highlands of Ethiopia. Management interventions, which aim at steering succession close to pre-disturbance forest community structure by facilitation, should be selective of the shrub species.

Keywords: facilitation, nursing trees and shrubs, restoration, shrubs, soil attributes, succession

Introduction

The quality of environmental services is declining sharply in the Ethiopian highlands due to deforestation and accompanying processes, such as soil erosion (Hurni 1988). Although there are encouraging results, the magnitude of the current scale of deforestation underscores the need for evidence-based restoration. The practice of forest restoration is a challenging task, which is cited as an acid test of our understanding of the concept of ecology (Bradshaw 1987; Young et al. 2005). Succession is an important concept in ecological restoration. It is a directional change in community organisation that may result either from positive (facilitation), negative (competition) or food-web interactions (Pickett et al. 1987). Compared with competition, historically, positive interactions or facilitation have received lesser recognition in shaping species assemblages in plant communities (Bruno et al. 2003; Brooker et al. 2008; Brooker and Callaway 2009). Callaway (2007) suggests that perceiving facilitation in the context of competition is a fundamental prerequisite for understanding how interactions among plant species affect natural community organisation.

Facilitation is a major process driving dynamics of ecosystems after disturbance (Callaway 2007). Particularly when later successional species are not adapted to harsh post-disturbance conditions, early successional species are required for establishment of those species (Grime 2006). Plants may facilitate other plants, to the next higher cohort class, directly or indirectly (Bruno et al. 2003; Brooker et al. 2008; Assede et al. 2012). Direct facilitation may be by increasing availability of a key resource, improving substrate conditions, or ameliorating some unfavourable environmental characteristics (López et al. 2009; Maestre et al. 2009; Prieto et al. 2011). Indirect facilitation may be by introduction of beneficial organisms (e.g. seed dispersers, pollinators, mycorrhizae or soil microbes) or protection from herbivores (Garcia and Ramon 2003; Smit et al. 2010; Schleicher et al. 2011).

Vegetative stakes have been used for restoration (Zahawi 2008; Zahawi and Holl 2009). The facilitative function of nurse shrubs has also been used to restore degraded ecosystems elsewhere in the world (Maestre et al. 2001; Gómez et al. 2004; Castro et al. 2006; Valladares and Gianoli 2007). Increased natural regeneration of late-successional tree species, e.g. *Olea europaea* L. subsp. *cuspidata* (Wall. ex G.Don) Cif., hereafter referred to

§ This article is based on a paper presented at the African Forest Forum workshop 'Forests, People and Environment' held on 4–5 September 2015 preceding the XIV World Forestry Congress in Durban, South Africa as *O. europaea*, was observed under pioneer shrubs, such as *Dodonaea angustifolia* L.f. in north-east Ethiopia (Bekele 2005) and under *Euclea racemosa* L. and *Vachellia etbaica* (Schweinf.) Kyal. & Boatwr. (*Acacia etbaica* Schweinf.) in northern Ethiopia (Aerts et al. 2006, 2007).

Scientific information is still scarce on the importance of positive effects of plants in shaping early-successional woody plant community organisation and, hence, in determining the trajectory of ecological succession in the dry Afromontane region. Hence, the objectives of this study were to compare effects of vegetative stakes, artificially sown and naturally occurring shrubs on the recruitment of *O. europaea*, and to compare the effects of native nurse shrubs (NNS) on selected soil chemical characteristics.

Materials and methods

Study site

The study was carried out in the Gonder area of north-western Ethiopia. The average altitude is 2 290 m. The minimum and maximum temperatures vary between 13 and 27 °C, and the mean annual rainfall is 1 085 mm. The rainfall occurs from June to September. Human and livestock impacts are obvious on the forest vegetation of the area. The tree and shrub species growing naturally in the site are composed of *Vachellia negrii* (Pichi-Sermolli) Kyal. & Boatwr. (*Acacia negrii* Pichi-Sermolli), *Albizia schimperiana* Oliv., *Apodytes dimidiata* E.Mey. ex Arn., *Bersama abyssinica* Fresen., *Calpurnia aurea* Benth., *Carissa spinarum* L., *Clausena anisata* (Willd.) Hook.f., *Croton macrostachyus* Hochst. ex Delile, *Dovyalis abyssinica* (A.Rich.) Warb., *Ficus thonningii* Blume, *Ficus sur* Forssk., *Ficus vasta* Forssk., *Grewia ferruginea* Hochst. ex A.Rich., *Maesa lanceolata* Forssk., *Myrsine africana* L., *Nuxia congesta* R.Br. ex Fresen., *O. europaea*, *Osyris quadripartita* Salzm. ex Decne., *Rhus glutinosa* Hochst. ex A.Rich., *Schefflera abyssinica* (Hochst. ex A.Rich.) Harms, *Schrebera alata* (Hochst.) Welw. and *Vernonia amygdalina* Delile. There has been a long history of human encroachment and free-range grazing of livestock.

Experimental design and data collection

Four treatments with three replications were set up in a randomised complete block design on degraded former grazing land. The treatments were:

(1) planting 2-metre-long cuttings of *Ficus thonningii*, and clearing all previously occurring shrubs and seedlings; the number of *F. thonningii* cuttings per plot was 25, and the size of the plots was 25 m × 25 m;
(2) sowing seeds of *Senna didymobotrya* (Fresen.) H.S.Irwin & Barneby to serve as nurse shrubs, and clearing other shrubs; the seeds of *S. didymobotrya* were sown by broadcasting with a seeding rate of 0.25 kg per plot;
(3) applying the above-mentioned treatments, i.e. 2-metre-long cuttings of *F. thonningii* and sowing seeds of *S. didymobotrya*, and clearing other shrubs occurring naturally at the site; and
(4) leaving naturally occurring shrubs before the start of the experiment.

Shrub traits such as height, crown width (average of two perpendicular measurements), height to the lowest crown, height to the broadest crown, diameter at the root collar and number of stems were measured for *S. didymobotrya*. Leaf biomass production of vegetative stakes of *F. thonningii* was measured by collecting all the leaves from the individual trees in the fourth year.

Soil samples were collected under each shrub and in between the shrubs in the third year. From each treatment, three replicate samples were taken from three soil depths (0–10, 11–30 and 31–50 cm). The air-dried samples of a single section from a given sampling point were mixed properly to obtain homogeneous composite samples from the respective soil depths. Soil organic carbon (OC), nitrogen (N), calcium (Ca) and phosphorus (P) were determined with a LECO TruSpecCN. Available P was extracted with Bray-II solution and the P concentration was determined colori-metrically. Calcium and magnesium (Mg) were determined with ammonium acetate. Exchangeable cations were determined using the barium chloride extraction method, and dry combustion was used for sulphur (S) extraction.

Data analyses

T-square plot-less sampling techniques (Engeman et al. 1994) were used to collect data on frequency of newly recruited *O. europaea* seedlings. Density estimates of *O. europaea* recruitment were analysed using the methods suggested by Byth (1982). One-way analysis of variance (ANOVA) was employed to check for statistically significant differences among treatments in the frequency of *O. europaea*.

One-way ANOVA was conducted on the soil OC, N, P, potassium (K), Ca, Mg and S for each species and depth separately. The level of significance of difference between the means was tested using least significance difference (LSD) with significance level of $P = 0.05$.

Plant nomenclature in this article follows that of the *Flora of Ethiopia* (Hedberg and Edwards 1989) and *Floras of Ethiopia and Eritrea* (Edwards et al. 1995, 2000; Hedberg et al. 2003, 2004, 2006).

Results

Shrubs, vegetative stakes and density of O. europaea seedlings

Six shrub species, comprising *C. macrostachyus*, *D. angustifolia*, *Maytenus senegalensis* (Lam.) Exell, *Otostegia integrifolia* Benth., *R. glutinosa* and *Vernonia rueppellii* Sch.Bip. ex Walp. were identified growing in the area. The survival of planted *F. thonningii* vegetative stakes was about 60%. The major cause for mortality of planted stakes was termite attack. The average annual production of leaf biomass per individual tree varied from 100 to 2 000 g. *Senna didymobotrya* attained a mean (± SD) height of 1.02 ± 0.54 m and crown width of 1.38 ± 1.02 m.

Significant differences were observed among the treatments in the number of newly emerged seedlings of *O. europaea*. There was no *O. europaea* recruitment inside plots where *F. thonningii* was planted and *S. didymobotrya* was sown or in both. *Olea europaea* recruitment was observed only inside the plots where native shrubs were maintained.

The T-square plot-less density estimator showed the presence of about 19 seedlings ha^{-1} with confidence limits (95%) of 16–23 seedlings ha^{-1}.

Effects of NNS on chemical characteristics of soils

Significant differences were observed among shrubs and between different depths in mean values of soils in their OC, N, P and K content (Figure 1, Table 1). Soils immediately under the shrubs were richer in OC, N, P and K than the plots between shrubs. Soil OC, N, P and K decreased more or less with increasing depth. The highest OC value was recorded under *C. macrostachyus* with a value of 68.92 mg g^{-1} followed by *R. glutinosa* and *M. senegalensis*, which had approximately equal values with 60 mg g^{-1} for the upper 10 cm depth.

Subsequent lower depths showed decreasing trends with a magnitude of 20 mg g^{-1} for all shrub species. The highest N content (6.38 mg g^{-1}) was recorded under *C. macrostachyus*, followed by the plots under *R. glutinosa* and *M. senegalensis*, which had approximately equal values (5 mg g^{-1}) for the upper 10 cm depth. The highest value of soil P was observed under *R. glutinosa* followed by *M. senegalensis* and *C. macrostachyus*. Soil K was higher under *C. macrostachyus* followed by *V. rueppellii*, *D. angustifolia* and *O. integrifolia*. Similar

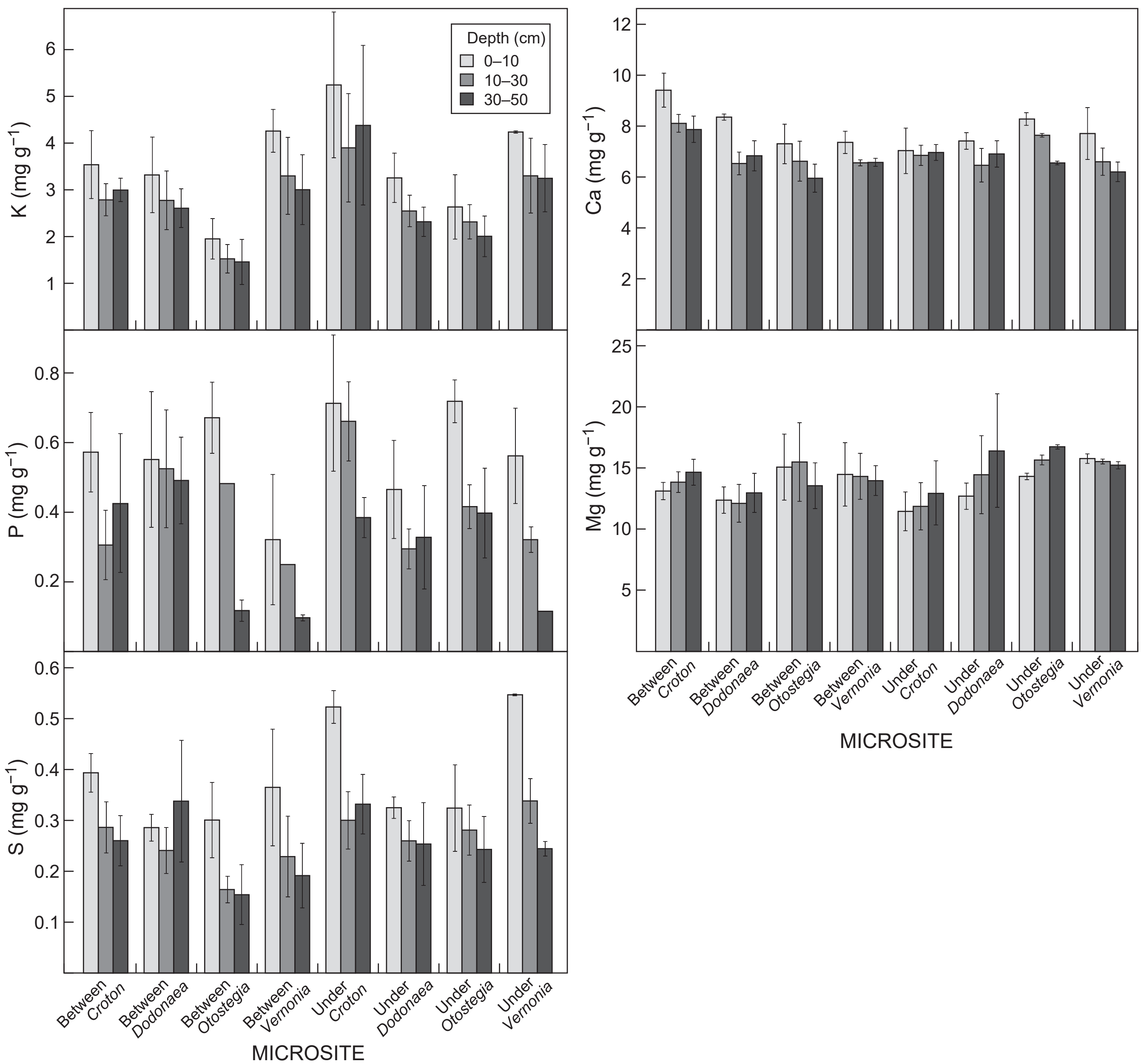

Figure 1: Status of selected soil nutrients under and between native nurse shrubs

Table 1: Total soil nitrogen (N) and soil organic carbon (C) under and between nurse shrubs for 0–10, 10–30 and 30–50 cm soil depths. Values in parentheses are the standard error of the mean

	N (mg g^{-1})			C (mg g^{-1})		
	0–10 cm	10–30 cm	30–50 cm	0–10 cm	10–30 cm	30–50 cm
Under *Croton*	3.83 (0.56)	2.15 (0.33)	2.31 (0.47)	40.00 (4.98)	22.65 (6.20)	23.63 (8.02)
Between *Croton*	2.35 (0.62)	1.37 (0.49)	1.37 (0.49)	26.88 (5.35)	13.93 (5.98)	14.22 (6.72)
Under *Dodonaea*	2.15 (0.30)	1.69 (0.52)	1.45 (0.64)	23.85 (3.36)	18.31 (7.01)	14.47 (7.85)
Between *Dodonaea*	1.70 (0.18)	1.38 (0.54)	1.54 (0.99)	17.92 (4.48)	13.50 (6.20)	15.42 (11.22)
Under *Otostegia*	2.91 (0.97)	1.99 (0.89)	1.52 (0.76)	32.63 (13.78)	20.67 (10.55)	16.24 (9.85)
Between *Otostegia*	1.77 (0.88)	1.19 (0.29)	0.67 (0.35)	19.37 (9.04)	10.12 (4.23)	4.62 (3.85)
Under *Vernonia*	3.84 (0.03)	1.00 (0.43)	1.52 (0.13)	41.85 (2.63)	21.28 (5.24)	14.75 (1.44)
Between *Vernonia*	2.19 (1.32)	1.18 (0.46)	0.88 (0.40)	23.74 (14.56)	12.48 (8.08)	9.68 (8.23)

trends were observed for other macro- and micronutrients (Figure 1).

Discussion

Shrubs, vegetative stakes, and density and recruitment of O. europaea *seedlings*

The performance of vegetative stakes of *F. thonningii* was encouraging, although it did not bring enhanced recruitment of *O. europaea* seedlings. Zahawi (2008) used extra-large vegetative stakes from three tree species and observed increased canopy area and canopy height, which increased the visit frequency of potential seed dispersers, in a manner that mimics the role of remnant trees in facilitating forest recovery. Similarly, Zahawi and Holl (2009) used vegetative stakes of 10 tree species to compare different methodology of forest restoration. These authors showed that using stakes was more productive, in terms of below- and aboveground biomass, and less costly than nursery-raised seedlings for restoration. Using larger vegetative stakes modulated the environment faster than nursery-raised seedlings by increasing fruit reward for frugivorous birds, decreasing stress and competition for late colonists. Height of planted stakes is reported to be more important than species diversity in modifying ecological variables (Zanne and Chapman 2001). In general, plant architectural features are reported to affect seed influx, modify nutrient status, moisture regime and light environment below the shrub to favour facilitation (Duncan and Chapman 2003; Cook et al. 2005). The constraints associated with use of vegetative stakes is that they are heavy to transport, and only a limited number of tree species is suitable for vegetative propagation.

The density of newly emerged seedlings of *O. europaea* varied among treatments. This difference can be discussed in relation to the facilitative or inhibitive processes inherent in the area or created by the treatments. Lack of *O. europaea* recruits may be due to seed and establishment limitation caused by diminished mother trees and insufficient disperser activity (Aerts et al. 2006, 2007), or absence of soil seed banks and their depletion with cultivation (Teketay and Granstrom 1995; Teketay 1997). Planting vegetative stakes and other shrubs facilitating later colonists, such as *O. europaea* by endozoochorous seed rain in Ethiopia was reported earlier (Aerts et al. 2006, 2007). Moreover, increasing availability of a key resource, ameliorating some unfavourable environmental conditions (López et al. 2009; Maestre et al. 2009; Prieto et al. 2011) or protection from herbivores (Smit et al. 2010; Schleicher et al. 2011) facilitates restoration.

The absence of *O. europaea* seedlings under *S. didymobotrya* suggests that this species is not a suitable nurse shrub for expediting the ecological restoration of decimated ecosystems. Gacheru and Rao (2005) used this species as short-duration planted shrub fallow to replenish soil fertility and control of *Striga* weed infestation. Their results showed that *S. didymobotrya* suppressed the emergence of *Striga*. This may suggest that this species is more competitor than facilitator. The competition may arise from allelopathy or shade effect of leaves, which determine the amount of solar radiation that influences the environmental conditions at the ground.

Six shrub species have been identified in the study area. Except for *D. angustifolia* (Bekele 2005), these shrubs have not been mentioned earlier in facilitating ecological restoration in Ethiopia. Aerts et al. (2006, 2007) reported the importance of *V. etbaica* in northern Ethiopia facilitating *O. europaea*. Nurse shrub species variation according to region was reported in other works in different parts of the world (Callaway 1998; Landero and Valiente-Banuet 2010). The results of this study could be a starting point for further study in analysing the nursing effect of NNS and nurse shrub variation according to regions.

Differences in height, crown diameter and collar diameter were observed among shrubs. These plant architectural attributes are supposed to bring structural heterogeneity.

Effects of NNS on chemical characteristics of soils

The values of OC, N, P and K in the soil samples were significantly different. Soils under nurse shrubs were richer in these nutrients than soils between shrubs. In general, the beneficial role of shrubs on soils in Ethiopia has been widely discussed. This is consistent with previous studies (e.g. Descheemaeker et al. 2006; Abiyu et al. 2011). Similarly, Mekuria et al. (2007) found higher soil organic matter content, total N, available P, exchangeable bases, and cation exchange capacity values following land abandonment and reappearance of shrubs.

Conclusions

Plantation of tree species and passive restoration through natural and assisted natural regeneration have been experimented in restoring native flora and improving soil properties. Active restoration, with all its advantages, may not be appropriate in all cases, especially from the species diversity perspective. Non-browse NNS are an important biological legacy for facilitation of late-successional trees and to affect soil properties positively. They should not be considered as unimportant weeds during restoration efforts. There should be further study on the biophysical and socio-economic long-term effects of these treatments. Further studies on the effects of farmer-managed natural regeneration practices on NNS and their effects are recommended.

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