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The role of fallowing in the restoration of woody species in the Woodlands of Northern Uganda

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Abstract

The study sought to determine the extent to which fallowing can lead to recovery towards an historic woody vegetation of Sudanian woodlands in northern Uganda. Fallow sites of three distinct ages were assessed. Plots were established in crop fields that had been under cultivation for over 10 years, sites that had been under fallow for 3–6 years (young fallow) and fallow sites of at least 9 years (old fallow) in three districts. In each plot, all woody plants were enumerated and species composition, diversity and richness assessed. Young fallow plots were dominated by pioneer species such as *Piliostigma thonningii* and *Annona senegalensis*, while old fallow by a mix of late and early successional species such as *Vachellia hockii* (formerly *Acacia hockii)* and *Combretum collinum*. *Vitellaria paradoxa* (Shea butter tree) was the most abundant in all fallow categories. Species composition in crop field was different from young and old fallow. Species richness increased significantly from abandoned Crop field to Young fallow and then to Old fallow. Simpson's Diversity Index showed similar trends. *V. paradoxa* contributed most to overall similarity among the fallow categories. Fallowing can facilitate restoration of characteristic species of Sudanian woodlands.

KEYWORDS
fallows, farming practices, succession, woodlands

Résumé

L'étude a cherché à déterminer dans quelle mesure la mise en jachère peut conduire à la reconstitution d'une végétation ligneuse historique des forêts soudaniennes dans le nord de l'Ouganda. Nous avons évalué des sites de jachère de trois âges différents. Des parcelles ont été établies dans des champs cultivés depuis plus de 10 ans, des sites en jachère depuis 3 à 6 ans (jeune jachère) et des sites en jachère depuis au moins 9 ans (vieille jachère) dans trois districts. Dans chaque parcelle, toutes les plantes ligneuses ont été dénombrées et la composition, la diversité et la richesse des espèces ont été évaluées. Les parcelles de jeunes jachères étaient dominées par des espèces pionnières telles que *Piliostigma thonningii* et *Annona senegalensis*, tandis que les vieilles jachères par un mélange d'espèces de succession tardive et précoce telles que *Vachellia hockii* (anciennement *Acacia hockii*) et *Combretum collinum*. *Vitellaria paradoxa* (arbre à beurre de karité) était le plus abondant dans toutes les catégories de jachères. La composition des espèces dans les champs de culture était différente de celle des jachères jeunes et anciennes. La richesse en espèces a augmenté de façon significative entre les champs de culture abandonnés, les jeunes jachères et les vieilles jachères. L'indice de diversité de Simpson a montré des tendances similaires. *V. paradoxa* a contribué le plus à la similarité globale entre les catégories de jachères. La mise en jachère peut faciliter la restauration des espèces caractéristiques des zones boisées soudanaises.

1 | INTRODUCTION

Woodlands are an important ecosystem that provide products such as food, wood, fibre, as well as supporting and regulating ecosystem services including soil and water conservation, climate regulation, biodiversity retention and protection (Kalaba et al., 2013; Ryan et al., 2016). They are a vegetation type that is dominated by woody plants, majorly trees, with canopy cover which is usually above 10 per cent, occurring in climates with a dry season of three or more months (Timberlake et al., 2010). In many parts of sub-Saharan Africa woodlands have been targeted for agricultural expansion (Chipika & Kowero, 2000; Kalema et al., 2015; Phalan et al., 2013) thus increasing their degradation and biodiversity loss (Laurance et al., 2014; Western & Maitumo, 2004). This has negatively affected the ecosystem functioning of these important natural landscapes (Woomer, 1993). The current study focused on the woodlands of northern Uganda that form part of the Sudanian regional centre of endemism (White, 1983). This is one of the phyto-geographical regions of Africa (Linder et al., 2012; White, 1983) which forms part of Africa's dry forest (Paré et al., 2010).

Slash and burn agriculture (shifting cultivation) characterised by fallowing and retaining of some trees and shrubs in the field is a common land-based livelihood strategy in the Sudanian-Sahelian landscapes (Kotto-Same et al., 1997). At the end of the fallow period, the regenerated trees and shrubs are cut down and burned to enable another opportunity of growing crops and when the soil fertility declines, the fields are again abandoned to facilitate recovery (Metzger, 2003; Syampungani et al., 2015). The fallow length can be up to 20–40 years but lately there has been a significant reduction in the fallow length to up to 1–3 years (Augusseau et al., 2006; Devereux & Naeraa, 1996; Houessou et al., 2019; Kalinganire et al., 2007). The abandoning of the land as fallow is usually due to decline in soil fertility or invasion of difficult to manage and aggressive weeds (Donfack et al., 1995).

We sought to determine the extent to which passive restoration through fallowing can lead to recovery towards an historic woody vegetation state of the Sudanian woodlands in northern Uganda. The specific objective was to determine the woody species composition, richness and, diversity of fallow categories of different fallow lengths.

The study was guided by the questions: To what extent does fallowing lead to restoration of the reference woody plant community of *Combretum*/*Vitellaria* woodlands of the Sudanian regional centre of endemism in Uganda? We tested the hypothesis that; there is no relationship between fallow length and woody plant species composition, richness and diversity. The study provides an opportunity to assess woody plant community change with fallowing which is useful in planning for restoration of degraded woodlands. The restoration of woodlands is important in fulfilling international commitments; for example the Land Degradation Neutrality initiative by the United Nations Convention to Combat Desertification and the African Forest Landscape Restoration initiative (Minelli et al., 2017; Reij & Garrity, 2016), REDD+ (Reducing Emissions from Deforestation and Forest Degradation) by the United Nations Framework Convention on Climate Change (Yirdaw et al., 2017) and the Bonn Challenge-a global initiative to restore 350 million hectares of degraded forest and agricultural land by 2030 (Verdone & Seidl, 2017).

2 | MATERIALS AND METHODS

2.1 | Study area

The study was carried out in the districts of Katakwi (01 54 54N, 33 57 18E), Lira (02 14 50 N, 32 54 00E) and Moyo (03 39N, 31 43 12E) in Uganda. These areas of woodlands are within the Sudanian-Sahelian region and share relatively similar biophysical conditions and land management practices relevant for the current study. The structure and composition of the vegetation in this region varies with mean annual rainfall and edaphic conditions (White, 1983). The areas with relatively high rainfall are characterised by dense shrub vegetation, woodlands and parkland landscapes (Boffa, 1999). The Sudanian-Sahelian region covers an area of about 30,000 square kilometres in Uganda (Ferris et al., 2001) and it is dominated by *Vitellaria* (formerly known as *Butyrospermum*) and *Combretum* woodland species that are broad-leaved and deciduous (Langdale-Brown, 1960). The common woody species in the Sudanian-Sahelian region of Uganda are *Vitellaria paradoxa* C.F. Gaertn., *Terminalia*, *Combretum*, *Albizia* and *Vachellia* (formerly known as *Acacia*) species (Langdale-Brown et al., 1964). The sites experience bimodal rainfall patterns. The two rainfall seasons occur from April to June and August to November. The average temperature in the Sudanian woodland region of Uganda is about 26.4°C compared to West Africa which is 29°C (De Bie et al., 1998). The soils in these districts vary from sandy, loamy and clay with a pH of 5.5–6.5 (mildly acidic) and are mainly ferralsols (GoU, 2009). Table 1 shows climatic characteristics and elevation of the sites studied.

The local population depends significantly on subsistence agriculture, charcoal production from indigenous woodland species using traditional earth kilns, livestock rearing and selling of *Vitellaria paradoxa* nuts or shea butter processed by them for their livelihoods

TABLE 1 Climatic, edaphic characteristics and elevation of the sites studied

Site	Average annual Rainfall (mm)	Mean annual maximum Temperature	Mean annual minimum Temperature	Average Elevation (m.a.s.l)	Main soil type	Geology	Landscape configuration
Katakwi	1250	31.3°C	20.1°C	1094	Ferralsols	Granites, gneiss, quartzites	Plateau with gentle undulating slopes
Lira	1218	30.6	22.5°C	1045	Ferralsols and Leptosols	Granites and quartzites	Flat or gently undulating
Moyo	1267	30	23.7°C	900	Ferralsols, Vertisols and Leptsols	Gneiss, Schist, quartzite and marble	Low plains

Sources: GoU (2011); GoU (2013); NEMA (2004); NEMA (1995).

(Gwali et al., 2012; Okullo et al., 2004). They mainly grow annual crops such as sorghum, millet, maize, beans and groundnuts using a rotational cropping and fallow system (Okullo et al., 2004). The current median fallow period practised by most farmers is three years, but this period varies widely between 1 to over 10 years (Byakagaba et al., 2011; Okullo et al., 2004). During cultivation, some farmers retain a few large-stemmed trees that are of socio-economic importance to them (Okullo & Waithum, 2007). Land is predominantly under customary communal ownership with few private customary individual holdings and freeholds which are characterised by perpetual exclusive individual rights of land ownership (GoU, 1998).

2.2 | Sampling design

Land owners and local leaders were interviewed extensively to identify sites within the Sudanian-Sahelian woodland region that had been converted into crop fields and later abandoned to fallow without any grazing (no grazing in the last 10 years) in each of the districts selected. Grazed areas were avoided because it would be difficult to replicate grazing intensity since the assessment was done on-farm on privately owned land, that is individuals or communities had exclusive tenure rights. Land owners were further interviewed to estimate the fallow ages (the number of years since the abandonment). This information was validated through further interaction with several members of the community in village meetings (Dalle & de Blois, 2006). History of intensity of cultivation, the length of the cropping-fallow cycle practised prior to abandonment, fire regime and intensity, and crops grown could not be validated or replicated. We sought for sites where the communities indicated that all the aforementioned factors were more or less similar. This information was validated through interviews with technical officers at each of the sites studied, especially agricultural extension officers, district forestry officers and district environment officers. Local leaders were interviewed to triangulate all the information.

Three different fallow ages, ranging between 0 to over 10 years were identified from the interviews. These included 0 years (crop field), 3–6 years (young fallow) and 9 and above years (old fallow). Three transects, each 1.5 km long, were laid in the north-south direction separated by a distance of 100 m in each fallow category (Ræbild et al., 2007; Summerville et al., 2004).

This was done to ensure the area assessed was a fair representation of the fallow category being assessed. If a transect crossed into land that could not be categorised in the targeted fallow type, then that area was skipped until the targeted category was reached. This meant that in some cases the transect per fallow category was >1.5 km. The transects were laid based on fallow length rather than land ownership or land utilised by a specific household. In some cases, the transects crossed into more than a single village to obtain the required plots. Ten 50 m × 50 m plots were laid systematically using a 100-m tape on each transect making 30 plots per fallow category and 90 per site thus making 270 in total for the three sites. The location of the first plot was randomly chosen for each transect and subsequent plots were laid out systematically, with distances of 100 m separating them along the transect (Chazdon et al., 2005).

2.3 | Data collection

All woody plants (≥5 cm in stem diameter and 1.5 m in height) in each plot within each of the fallow treatments were enumerated and recorded during the wet season (October to December 2009). Voucher specimens were preserved for further identification at Makerere University Herbarium. Preliminary identification in the field was carried out with the input of para-taxonomists and local people using names in the local language. Nomenclature was done following (FTEA, 1952–2012).

2.4 | Data analysis

Relative species density was used to determine the most dominant species across all sites in the different fallow categories as described in Savadogo et al. (2007).

It was determined using the formula:

$$\frac{\text{Number of individuals of one species}}{\text{Total Number of all individuals in all species encountered}} \times 100$$

Constrained ordination with Canonical Correspondence Analysis (CCA) was applied to show variation in species composition and distribution in relation to fallow length using CANOCO version 4.5 software (Lepš & Šmilauer, 2003). A biplot was generated to visually display the composition (Braak & Šmilauer, 2002). Rare species were downweighted using species frequencies (Auerbach et al., 1997) because they can have an unduly strong influence on the results. In all ordinations, rare species were regarded as those with frequency less than one fifth of the most common species (Auerbach et al., 1997) and these were the ones excluded in the biplot. Downweighting reveals a more accurate species and environment relationship compared to untreated CCA, and helps to eliminate rare species in CCA (Cao et al., 2015).

The genera and species names were abbreviated using a code with only the first four and three letters respectively to avoid overcrowding of the biplot. The full name of each species represented in the biplot is provided in the legend of the biplot. Analysis of Similarity (ANOSIM) (Bradshaw et al., 2003) was used to determine whether there were any differences in species composition between the fallow field categories. ANOSIM procedure in CAP 3.1 software (Seaby & Henderson, 2006) was used to derive R_{ANOSIM} which is a nonparametric permutation procedure applied to rank similarity matrices underlying sample ordinations (Clarke, 1993). It produces a global R-statistic, which is an absolute measure of distance between groups. An R-value that is close to 1 suggests strongly distinct assemblages, while an R-value close to 0 is an indicator that the assemblages are barely separable implying that they have close similarity (Parr et al., 2012). One-way ANOSIM (Clarke & Warwick, 2001) was used to test the hypothesis of no significant differences between assemblages in the different fallow sites studied. The test was based on Bray–Curtis rank similarity matrix (Clarke, 1993). Similarity percentages (SIMPER) procedure in CAP 3.1 (Seaby & Henderson, 2006) was used to identify those species that contributed substantially to the average similarity within the group (Clarke & Warwick, 2001; White et al., 2005). Margalef's species richness index (Magurran, 2004) was calculated for each plot in the different fallow field categories using absolute number of species to avoid underestimation (Gamito, 2010). Species diversity was analysed using Simpson's diversity index (Lovett & Haq, 2000; Magurran, 2004). The reciprocal of the index was used in the comparison among the fallow categories, and therefore the higher the index the higher the diversity. The computer program *Species Diversity and Richness*4 (Seaby & Henderson, 2007) was used to calculate both Margalef's species richness and Simpson's diversity index. One-way Analysis of variance (ANOVA) in Minitab (version 17, Minitab, Inc.) software was used to conduct pairwise comparison of means of species richness and species diversity between the different fallow categories across all the three sites.

3 | RESULTS

3.1 | Species composition by relative density under different fallow types

The ten most abundant species in each fallow category in the three districts are shown in Table 2. Crop fields were dominated by *Vitellaria paradoxa* in all the sites. *Terminalia macroptera and Combretum molle* were the second and third most abundant species in the crop fields of Katakwi, while *C. collinum*, *Ficus vallis-choudae* in Lira and *Combretum collinum and Piliostigma thonningii* in Moyo. The young fallow category was dominated by *V. paradoxa* in all the sites.

The second and third most abundant species in Katakwi were *Piliostigma thonningi* and *C. collinum* respectively while in Lira and Moyo *Annona senegalensis* and *C. collinum* were the second and third most abundant. The most abundant species in old fallow plots assessed in each district was *V. paradoxa* except Lira where *C. collinum* was the most abundant. *Vachellia hockii* (formerly *Acacia hockii*) and *C. collinum* were the second and third most abundant species in old fallow plots in Katakwi and Moyo district while in Lira it was *V. paradoxa* and *Annona senegalensis* that were the second and third most abundant.

The relative density of each species in Katakwi, Lira and Moyo district under different fallow types is provided in Appendix 1. There were clear changes in tree composition with fallow length. *Combretum collinum* was characteristic for old fallow while *Piliostigma thonningi* for young fallow and *Vitellaria paradoxa* for crop fields (Figure 1). All pairwise comparisons differed significantly between the fallow categories ($p < 0.05$), indicating that each fallow category had a distinct tree/shrub assemblage (Table 3). The *R*-values of the comparison between young fallow and old fallow were relatively low compared to crop field and young fallow. The highest *R*-values were between crop

TABLE 2 The ten most abundant species, in declining order in each district within each fallow type

District	Current field	Young field	Old fallow
Katakwi	1. *Vitellaria paradoxa*	1. *Vitellaria paradoxa*	1. *Vitellaria paradoxa*
	2. *Terminalia macroptera*	2. *Piliostigma thonningi*	2. *Vachellia hockii*
	3. *Combretum molle*	3. *Combretum collinum*	3. *Combretum collinum*
	4. *Tamarindus indica*	4. *Annona senegalensis*	4. *Combretum schumannii*
	5. *Combretum collinum*	5. *Grewia mollis*	5. *Bridelia scleroneura*
	6. *Ficus platyphylla*	6. *Combretum schumannii*	6. *Harrisonia abyssinica*
	7. *Albizia coriaria*	7. *Bridelia scleroneura*	7. *Combretum molle*
	8. *Prosopis Africana*	8. *Terminalia macroptera*	8. *Terminalia macroptera*
	9. *Ficus glumosa*	9. *Vachellia hockii*	9. *Annona senegalensis*
	10. *Erythrina abyssinica*	10. *Harrisonia abyssinica*	10. *Grewia mollis*
Lira	1. *Vitellaria paradoxa*	1. *Vitellaria paradoxa*	1. *Combretum collinum*
	2. *Combretum collinum*	2. *Annona senegalensis*	2. *Vitellaria paradoxa*
	3. *Ficus vallis-choudae*	3. *Combretum collinum*	3. *Annona senegalensis*
	4. *Terminalia macroptera*	4. *Grewia mollis*	4. *Bridelia scleroneura*
	5. *Grewia mollis*	5. *Albizia zygia*	5. *Piliostigma thonningii*
	6. *Erythrina abyssinica*	6. *Bridelia scleroneura*	6. *Hymenocardia acida*
	7. *Senegalia campylacantha*	7. *Terminalia macroptera*	7. *Grewia mollis*
	8. *Ficus mucuso*	8. *Strychnos innocua*	8. *Albizia zygia*
	9. *Piliostigma thonningii*	9. *Piliostigma thonningii*	9. *Vitex doniana*
	10. *Albizia zygia*	10. *Combretum adenogonium*	10. *Erythrina abyssinica*
Moyo	1. *Vitellaria paradoxa*	1. *Vitellaria paradoxa*	1. *Vitellaria paradoxa*
	2. *Combretum collinum*	2. *Annona senegalensis*	2. *Vachellia hockii*
	3. *Piliostigma thonningii*	3. *Combretum collinum*	3. *Combretum collinum*
	4. *Ficus mucuso*	4. *Terminalia macroptera*	4. *Terminalia macroptera*
	5. *Euclea divinorum*	5. *Lonchocarpus laxiflorus*	5. *Grewia mollis*
	6. *Grewia mollis*	6. *Vachellia hockii*	6. *Piliostigma thonningii*
	7. *Ficus glumosa*	7. *Piliostigma thonningii*	7. *Annona senegalensis*
	8. *Lonchocarpus laxiflorus*	8. *Vachellia seyal*	8. *Vachellia seyal*
	9. *Tectona grandis*	9. *Grewia mollis*	9. *Combretum molle*
	10. *Vachellia seyal*	10. *Combretum molle*	10. *Lonchocarpus laxiflorus*

field and old fallow. The major species contributing to the overall similarity in species composition among the fallow sites were *V. paradoxa* (34.4%), *C. collinum* (14.8%), *Terminalia macroptera* (5.5%), *Combretum molle* (5.1%), *Grewia mollis* (4.9%) and *P. thonningii* (4.8%).

3.2 | Species richness and diversity under different fallow field categories

A total of 4339 individuals from 95 species, 68 genera and 32 families of which 93% were native to Uganda were encountered in the 270 plots. There were 58 species encountered in Katakwi, 50 in Lira and 51 in Moyo district respectively. The introduced tree species encountered included: *Mangifera indica*, *Gmelina arborea*, *Senna siamea*, *Tectona grandis*, *Psidium guajava* and *Moringa oleifera*. The most species-rich families (total number of species encountered is presented in parentheses) were *Fabaceae* (23), *Moraceae* (12) and *Anacardiaceae* (8). The most species-rich genera (total number of species is presented in parentheses) were *Ficus* (12), *Vachellia* (8) and *Combretum* (5). There were 14 species recorded in crop field of Katakwi, 30 in young fallow and 35 in old fallow. In Lira, there were 13 species encountered in crop field, 27 in young fallow and 31 in old fallow, while in Moyo, 17 species were recorded in crop field, 28 in young fallow and 32 in old fallow.

All pairwise comparisons of species richness differed significantly between the fallow types in all the districts except between old fallow and young fallow in Lira district (Table 4).

Margalef species richness was significantly higher in old fallow than young fallow and crop fields. Species diversity did not vary significantly between plots in young fallow and crop fields in Katakwi and Moyo but varied significantly in Lira (Table 5). Species diversity was significantly higher in old fallow than crop field in all the three districts (Table 5). It is only in Moyo where species diversity was significantly higher in old fallow than young fallow (Table 5).

4 | DISCUSSION

4.1 | Variation in species composition along the fallow length gradient

Overall, *Vitellaria paradoxa* was the most abundant species in the plots within the crop field and young fallow in all the sites. This is because farmers traditionally do not cut down this tree while cultivating because of its socio-economic and cultural values especially the vegetable oil from its nuts that is used to prepare shea butter (Gwali et al., 2012). It is therefore expected to have a high relative

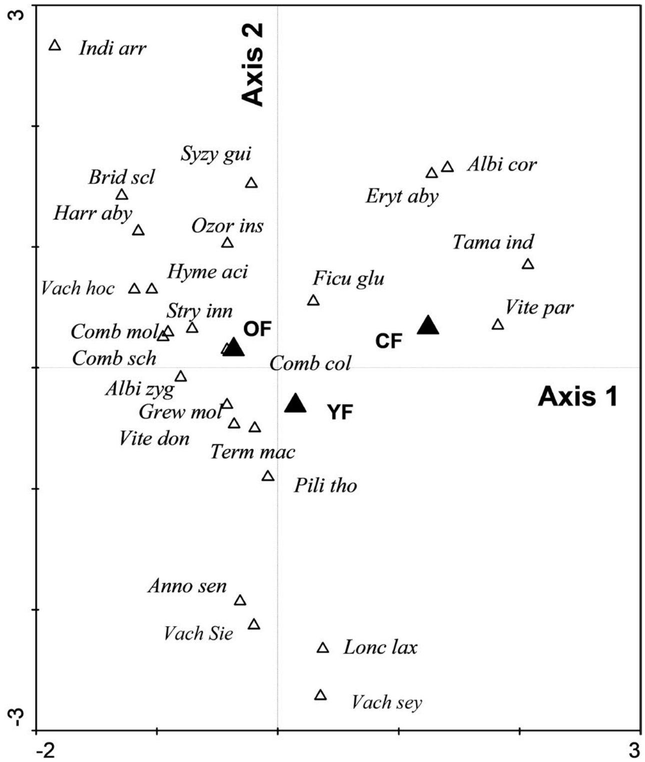

FIGURE 1 Biplot for Canonical Correspondence Analysis (CCA) showing species composition and distribution in the different fallow fields. Vach hoc, *Vachellia hockii* (early successional species); Vach sey, *Vachellia seyal* (early successional species); Vach sie, *Vachellia sieberiana*; (early successional species); Albi cor, *Albizia coriaria* (late successional species); Albi zyg, *Albizia zygia* (late successional species); Anno sen, *Annona senegalensis* (early successional species); Brid scl, *Bridelia scleroneura* (late successional species); Comb col, *Combretum collinum* (late successional species); Comb mol, *Combretum molle* (late successional species); Comb sch, *Combretum schumannii* (late successional species); Eryt abys, *Erythrina abyssinica* (early successional species); Ficu glu, *Ficus glumosa* (late successional species); Grew mol, *Grewia mollis* (Early successional species); Harr aby, *Harrisonia abyssinica* (late successional species); Hyme aci, *Hymenocardia acida* (early successional species); Indi arr, *Indigofera arrecta* (late successional species); Lonc lax, *Lonchocarpus laxiflorus* (early successional species); Ozor ins, *Ozoroa insignis* (late successional species); Pili tho, *Piliostigma thonningii* (early successional species); Stry inn, *Strychnos innocua* (late successional species); Syzy gui, *Syzygium guineense* (late successional species); Tama ind, *Tamarindus indica* (early successional species); Term mac, *Terminalia macroptera* (late successional species); Vite don, *Vitex doniana* (late successional species); Vite par, *Vitellaria paradoxa* (early successional species) . *Note*: Where, CF, Crop field; OF, Old *fallow*; YF, Young *fallow*

TABLE 3 Sample *R*-statistic between different pairs of fallow field and crop field, with *p*-values between brackets

Site	Sample statistic of CF and OF	Sample statistic of CF and YF	Sample statistic OF and YF
Katakwi	0.48 ($p < 0.001$)	0.26 ($p < 0.001$)	0.20 ($p < 0.001$)
Lira	0.72 ($p < 0.001$)	0.31 ($p < 0.001$)	0.26 ($p < 0.001$)
Moyo	0.30 ($p < 0.001$)	0.25 ($p < 0.001$)	0.04 ($p < 0.045$)

Note: Where, CF, Crop field; OF, Old fallow; YF, Young fallow.

density in crop field and young fallow because it is deliberately preserved in the cultivation practices of the local communities. It is the species that is more likely to be abundant when the crop field is abandoned as fallow because of the individuals that were preserved during cultivation.

Piliostigma thonningi and *Annona senegalensis* were the second most abundant species in young fallow. The abundance of these species decreased with the increase in the age of the fallow. Similar observations were reported by Donfack et al., (1995) in Cameroon and Houessou et al. (2019) in Benin. The two species have prolific regeneration in sites that have experienced heavy human disturbance (Paré et al., 2010). This is because of their ability to regenerate through sprouting and coppicing (Ky-Dembele et al., 2007) and survival in soil which is recovering its fertility (Houessou et al., 2019). The density of these species declines with increase in the age of the fallow which is an indicator that old fallow conditions do not favour these species.

Vachellia hockii and *Combretum collinum* were the other most abundant species in plots within old fallow apart from *V. paradoxa* which is usually retained during cultivation by land owners. This suggests that there is co-existence between late and early successional species in the old fallow considering that *V. hockii* which is an early successional species and *C. collinum* a late successional species were both dominant.

This therefore implies that fallowing allows certain late successional species such as *C. collinum* to be established but does not

TABLE 4 Mean Margalef's (Mg) index in different fallow categories

District	Mean Mg index of YF and CF			Mean Mg index of OF and CF			Mean Mg index of OF and YF		
	Mean in YF	Mean in CF	*p*-value	Mean in OF	Mean in CF	*p*-value	Mean in OF	Mean in YF	*p*-value
Katakwi	2.3 ± 0.6	1.4 ± 0.8	0.000	2.6 ± 0.4	1.4 ± 0.8	0.000	2.6 ± 0.4	2.3 ± 0.6	0.017
Lira	2.1 ± 0.6	1.1 ± 0.6	0.000	2.3 ± 0.7	1.1 ± 0.6	0.000	2.3 ± 0.7	2.1 ± 0.6	0.282^{NS}
Moyo	2 ± 0.5	1.5 ± 0.6	0.001	2.3 ± 0.6	1.5 ± 0.5	0.000	2.3 ± 0.6	2 ± 0.5	0.020

Note: Where, CF, Crop field; OF, Old fallow; YF, Young fallow; NS, Not significant.

TABLE 5 Mean Simpson's (D) index in different fallow categories

District	Mean D index of YF and CF			Mean D index of OF and CF			Mean D index of OF and YF		
	Mean in YF	Mean in CF	*p*-value	Mean in OF	Mean in CF	*p*-value	Mean in OF	Mean in YF	*p*-value
Katakwi	7.9 ± 4.4	5.9 ± 7.1	0.18^{NS}	9.3 ± 5.1	5.9 ± 7.2	0.034	9.3 ± 5.1	7.9 ± 4.4	0.259^{NS}
Lira	7.5 ± 4.9	2.7 ± 1.6	0.000	7.3 ± 4.3	2.7 ± 1.6	0.000	7.3 ± 4.3	7.5 ± 4.9	0.916^{NS}
Moyo	5.9 ± 2.1	5.4 ± 5	0.66^{NS}	8.4 ± 6.2	5.4 ± 5	0.046	8.4 ± 6.2	5.9 ± 2.1	0.038

Note: Where, CF, Crop field; OF, Old fallow; YF, Young fallow; NS, Not significant.

completely result into displacement of early successional species such as *V. hockii* that were established earlier when the fallow was still young. This scenario may be because woodlands always experience disturbances such as fire, grazing and selective tree cutting (Zida et al., 2008) that trigger establishment of early successional species in old fallow. Fires are a common occurrence in old fallow in the *Vitellaria* woodlands of Uganda (Okullo et al., 2004) thus creating the disturbance necessary for early successional species to regenerate and co-exist with late successional species. *Vitellaria paradoxa* was also dominant in old fallow because it is preserved in cultivated field due to its socio-economic values and thus fallowing only increases its density compared to other species which are usually removed during cultivation.

It was observable that *Vachellia hockii* was abundant in old fallow but not young fallow yet it is an early successional species. This implies that old fallow conditions facilitate its establishment more than young fallow. These results are comparable to those of Traore et al. (2008) who found that *V. hockii* relative density was influenced by landuse intensity. The areas that did not experience much disturbance such as protected areas which are analogous to old fallow in the current study, had relatively higher recruitment of juvenile individuals of *V. hockii* than those that had recently experienced human disturbance. This suggests that old fallow environmental conditions favour *V hockii*. In their study in the Sudanian-Sahelian zone of West Africa, Traoré, Zerbo, Schmidt, & Thiombiano (2012) found that *V. hockii* was more abundant in soils with high exchangeable bases such as vertisol and cambisol. The soil characteristics may have been different between young and fallow thus resulting into the trend observed.

Combretum collinum was in the top three abundant species of all the fallow types. It has a great ability to sprout from stumps, and capacity to cope with the disturbances such as cutting and fire (Devineau, 1999). This therefore explains its relatively high abundance in all fallow types since they experience disturbances such as fire and cutting of mature trees for charcoal and firewood in all the three sites studied (Gwali et al., 2012).

The findings therefore show that abandonment of crop field as fallow can result into establishment of early successional species (pioneer) especially *Annona senegalensis* and *Piliostigma thonningi* (Ahmed, 1983; Donfack et al., 1995; Leßmeister et al., 2019; Oke & Jamala, 2013) in the first six years and if the fallow length is extended, late successional species such as *Combretum collinum* can be established without displacing the early successional species. This is reflected by occurrence of early successional species in old fallow albeit at relatively lower density. This however cannot be generalised to be representative of all Sudanian woodlands in Africa. This is because post-cultivation succession is a function of site history especially frequency and intensity of disturbance (Donfack et al., 1995) which may vary among different sites.

The most abundant families in the old fallow were *Fabaceae* and *Combretaceae* while young fallow was dominated by *Annonaceae* and *Sapotaceae*. Crop field was mostly dominated by *Sapotaceae*. Analysis of Similarity (ANOSIM) showed strongly distinct assemblages between crop field and old fallow. This may have been due to differences in site conditions among the fallow types. Sites that have been under fallow for a relatively long time are susceptible to annual fires due to high coverage of grass and herbaceous layer that provide fuel (Devereux & Naeraa, 1996). This might therefore explain the relatively high abundance of fire-resistant species such as those in *Combretaceae* within old fallows. They are fire resistant due to their characteristic thick bark (Gashaw et al., 2002). The exclusion of fire in areas that were turned into crop field might have reduced the abundance of fire resilient species and those that need fire to regenerate.

While choice of site for the current study was informed by no grazing for at least ten years, it is possible that there was sporadic grazing in fallow field that the local people were not aware of that may have influenced species composition. This however may not have been crucial considering that the study sites had just recovered from an insurgency of over twenty years at the time the data were collected and therefore it was plausible to have fallow field of over 10 years that may not have been grazed because most households were living in internally displaced camps during the insurgency.

4.2 | Species richness and diversity under different fallow field categories

Crop field had very low woody species richness and diversity. This might be because farmers only preserve tree species that are of socio-economic and cultural value to them when cultivating the land. The most abundant species in the crop field was *Vitellaria paradoxa* while other species had relatively very few individuals. *V. paradoxa* fruits are eaten when ripe while the nuts are processed into a vegetable oil.

It is also used in cultural ceremonies of the local communities such as initiation of newly born children and installing of traditional chiefs (Gwali et al., 2012). These uses could have motivated farmers to retain this tree when cultivating land for crop production. The low species richness and diversity is an indicator that farmers are not protecting other trees species that are not considered valuable in the crop fields.

The old fallow plots were the most diverse in comparison with the young fallow and crop field. This therefore implies that the longer the fallow length, the higher the recruitment of new species. The observed pattern suggests that old fallow conditions provide more chances for the survival of several rare species thus increasing species diversity and richness. This trend was also found by Augusseau et al. (2006) in Burkina Faso where woody species richness increased with fallow age. This may be attributed to increase in organic matter and soil nutrients that is associated with increase in age of fallow (Aweto, 1981). High organic matter and nutrients in old fallow could have provided suitable edaphic conditions for more recruitment and establishment of woody species that require high soil fertility. This finding therefore suggests that changes in landuse through cycles of crop fields and fallows has implications on species diversity and richness of woody plants in the Sudanian woodlands.

5 | CONCLUSION

The findings from the study confirm that fallowing can lead to recovery of species that characterise Sudanian woodlands of northern Uganda within a ten-year time frame. Species composition varies along the fallow length gradient. The old fallow was dominated by *Vitellaria paradoxa*, *Vachellia hockii* and *Combretum collinum*, while young fallow by *V. paradoxa*, *Piliostigma thonningi* and *Annona senegalensis* and crop field by *V. paradoxa*. Both early and late successional species were found in the young and old fallow thus indicating co-existence of these species in the two fallow categories albeit with varying densities. The density of early successional species was high in young fallow while the density of late successional species was high in old fallow. Species composition in crop field was different from young and old fallow. The old fallow was the most diverse in comparison with the young fallow and crop field thus confirming that the longer the fallow length the higher the recruitment of new species to increase species richness and diversity. Abandoning crop fields as fallows can lead to recovery of characteristic species (*V. paradoxa* and *C. collinum*) of 'mature' Sudanian Woodlands.

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CONFLICT OF INTEREST

We have no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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APPENDIX 1

Species Relative density in Katakwi, Lira and Moyo under different fallow lengths

Species	Family	Successional status	RD in Katakwi			RD in Lira			RD in Moyo		
			RD in CF	RD in YF	RD in OF	RD in CF	RD in YF	RD in OF	RD in CF	RD in YF	RD in OF
Vitellaria paradoxa C.F Gaertn.	*Sapotaceae*	Early	1.45	2.97	2.03	4.24	3.87	1.73	2.95	3.39	2.35
Vachellia hockii De wild	*Fabaceae*	Early	0.00	0.32	1.84	0.00	0.05	0.00	0.02	1.20	2.33
Combretum schumannii Eng.	*Combretaceae*	Late	0.05	0.58	1.82	0.00	0.00	0.00	0.00	0.00	0.00
Combretum collinum Fresen.	*Combretaceae*	Late	0.16	1.15	1.66	0.39	0.83	3.30	0.90	1.77	1.61
Bridelia scleroneura Müll. Arg.	*Euphorbiaceae*	Early	0.02	0.44	1.66	0.05	0.37	1.54	0.00	0.09	0.21
Harrisonia abyssinica Oliv.	*Simaroubaceae*	Late	0.07	0.30	1.04	0.00	0.00	0.00	0.00	0.00	0.00
Combretum molle Engl. &Diels	*Combretaceae*	Late	0.18	0.14	1.01	0.00	0.02	0.00	0.05	0.44	0.39
Terminalia macroptera Mart.	*Combretaceae*	Late	0.28	0.41	0.81	0.14	0.30	0.28	0.07	1.38	1.06
Annona senegalensis Pers.	*Annonaceae*	Early	0.02	0.78	0.74	0.00	2.10	1.61	0.00	1.38	0.74
Grewia mollis Juss.	*Tiliaceae*	Late	0.09	0.74	0.58	0.14	0.67	0.71	0.14	0.76	0.94
Strychnos innocua Delile	*Loganiaceae*	Late	0.02	0.02	0.48	0.02	0.30	0.18	0.00	0.00	0.02
Piliostigma thonningii Schumach.	*Fabaceae*	Early	0.00	1.27	0.35	0.09	0.30	0.92	0.32	1.13	0.88
Vachellia sieberiana Scheele	*Mimosaceae*	Late	0.00	0.23	0.30	0.02	0.21	0.14	0.00	0.00	0.00
Albizia zygia J.F Macbr.	*Fabaceae*	Late	0.00	0.07	0.21	0.07	0.44	0.44	0.00	0.00	0.00
Ozoroa insignis Delile	*Anacardiaceae*	Early	0.07	0.02	0.18	0.05	0.02	0.07	0.00	0.00	0.02
Ficus platyphylla Del.	*Moraceae*	Late	0.16	0.00	0.16	0.00	0.00	0.00	0.02	0.00	0.02
Albizia coriaria Welw.	*Fabaceae*	Late	0.16	0.12	0.14	0.05	0.02	0.14	0.00	0.02	0.02
Prosopis africana Guill, Perr. & A. Rich	*Fabaceae*	Early	0.12	0.12	0.12	0.00	0.00	0.00	0.02	0.12	0.16
Pseudocedrela kotschyi Harms	*Meliaceae*	Late	0.00	0.12	0.12	0.02	0.00	0.00	0.05	0.09	0.07
Senegalia polyacantha Willd.	*Fabaceae*	Early	0.00	0.12	0.09	0.00	0.00	0.00	0.00	0.00	0.00
Ficus glumosa Delile	*Moraceae*	late	0.12	0.07	0.09	0.02	0.12	0.07	0.14	0.09	0.00
Erythrina excelsa Baker	*Fabaceae*	late	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00
Ficus dekdekana A. Rich.	*Moraceae*	late	0.07	0.09	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Senna singueana (Del.) Lock	*Fabaceae*	Early	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00

(Continues)

APPENDIX 1 (Continued)

Species	Family	Successional status	RD in Katakwi			RD in Lira			RD in Moyo		
			RD in CF	RD in YF	RD in OF	RD in CF	RD in YF	RD in OF	RD in CF	RD in YF	RD in OF
Indigofera arrecta Hochst.	*Fabaceae*	Late	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Gmelina arborea Roxb.	*Lamiaceae*	Introduced	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tamarindus indica L.	*Fabaceae*	Late	0.18	0.07	0.07	0.00	0.12	0.00	0.07	0.07	0.12
Lonchocarpus laxiflorus Guill. and Perr.	*Fabaceae*	Early	0.00	0.07	0.07	0.02	0.14	0.14	0.14	1.27	0.37
Sclerocarya birrea Hochst.	*Anacardiaceae*	Late	0.05	0.05	0.07	0.00	0.00	0.00	0.02	0.07	0.07
Carissa edulis Vahl	*Apocynaceae*	Early	0.00	0.02	0.07	0.00	0.02	0.00	0.00	0.00	0.00
Trichilia emetica Vahl	*Meliaceae*	Late	0.00	0.00	0.07	0.00	0.02	0.02	0.00	0.00	0.00
Lannea schweinfurthii Engl.	*Anacardiaceae*	Late	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Vitex doniana Sweet	*Lamiaceae*	late	0.00	0.14	0.05	0.02	0.09	0.32	0.02	0.12	0.09
Lannea barteri Engl.	*Anacardiaceae*	late	0.00	0.07	0.05	0.07	0.07	0.00	0.05	0.12	0.12
Rhus natalensis Bernh. Ex Krauss	*Anacardiaceae*	Early	0.00	0.07	0.05	0.00	0.05	0.00	0.00	0.00	0.00
Albizia glaberrima Benth.	*Fabaceae*	Late	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.05
Rhus vulgaris Meikle	*Anacardiaceae*	Late	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Terminalia africana Fresen.	*Combretaceae*	Late	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Mangifera indica L.	*Anacardiaceae*	Introduced	0.12	0.07	0.02	0.23	0.00	0.00	0.23	0.00	0.07
Gardenia ternifolia Schumach.	*Rubiaceae*	Late	0.00	0.07	0.02	0.05	0.02	0.18	0.05	0.00	0.02
Vachellia africana (L.) Wild	*Fabaceae*	Late	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.21	0.00
Kigelia africana (Lam.) Benth	*Bignoniaceae*	Late	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Pavetta crassipes K. Schum.	*Rubiaceae*	Late	0.00	0.00	0.02	0.00	0.02	0.09	0.00	0.00	0.00
Allophylus abyssinicus Radlk	*Sapindaceae*	Late	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
Maytenus senegalensis (Lam.)	*Celastraceae*	Late	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.02	0.09
Senna siamea (Lamarck)	*Fabaceae*	Introduced	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Erythrina abyssinica Lam.	*Fabaceae*	Early	0.12	0.14	0.00	0.14	0.05	0.32	0.00	0.02	0.02
Dichrostachys cinerea L.	*Fabaceae*	Early	0.00	0.09	0.00	0.05	0.00	0.00	0.00	0.00	0.00
Ficus sycomorus L.	*Moraceae*	Late	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Milicia excelsa Welw.	*Moraceae*	Late	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(Continues)

APPENDIX 1 (Continued)

Species	Family	Successional status	RD in Katakwi			RD in Lira			RD in Moyo		
			RD in CF	RD in YF	RD in OF	RD in CF	RD in YF	RD in OF	RD in CF	RD in YF	RD in OF
Tectona grandis Linnaeus	*Lamiaceae*	Introduced	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00
Psidium guajava L.	*Myrtaceae*	Introduced	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Teclea nobilis Delile	*Rutaceae*	Late	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vachellia seyal Delile	*Fabaceae*	Early	0.02	0.02	0.00	0.00	0.00	0.00	0.12	0.99	0.58
Dombeya rotundifolia Planch.	*Sterculiaceae*	Early	0.00	0.02	0.00	0.00	0.00	0.07	0.00	0.07	0.02
Sarcocephalus latifolius (SM.) E.A Bruce	*Rubiaceae*	Late	0.00	0.02	0.00	0.00	0.07	0.00	0.00	0.00	0.00
Vachellia gerrardii Benth.	*Fabaceae*	Early	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vachellia macrothyrsa Harms	*Fabaceae*	Early	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trema orientalis Blume	*Ulmaceae*	Early	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Moringa oleifera Lam.	*Moringaceae*	Introduced	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hymenocardia acida Tul.	*Euphorbiaceae*	Early	0.00	0.00	0.00	0.02	0.25	0.81	0.00	0.00	0.00
Syzygium guineense (Willd.) DC	*Myrtaceae*	Late	0.00	0.00	0.00	0.00	0.12	0.21	0.12	0.05	0.35
Ficus vallis-choudae Delile	*Moraceae*	Late	0.00	0.00	0.00	0.16	0.14	0.16	0.00	0.00	0.00
Euclea divinorum Hiern.	*Ebenaceae*	Early	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.02
Boscia salicifolia Oliv.	*Capparaceae*	Late	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.02
Solanecio mannii Hook.f.	*Asteraceae*	Late	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Steganotaenia araliacea Hochst.	*Apiaceae*	Late	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Antidesma venosum E. Mey.	*Euphorbiaceae*	Early	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00
Nauclea latifolia Blanco	*Rubiaceae*	Late	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.14	0.00
Parinari curatellifolia Planch.	*Chrysobalanaceae*	Late	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00
Zanthoxyllum chalybeum Engl.	*Rutaceae*	Late	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Balanites aegyptiaca L.	*Balanitaceae*	Late	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Euclea latidens Stapf	*Ebenaceae*	Late	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Combretum adenogonium Steud.	*Combretaceae*	Late	0.00	0.00	0.00	0.05	0.30	0.14	0.00	0.00	0.00
Ficus trichopoda Baker	*Moraceae*	Late	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00

(Continues)

APPENDIX 1 (Continued)

			RD in Katakwi			RD in Lira			RD in Moyo		
Species	Family	Successional status	RD in CF	RD in YF	RD in OF	RD in CF	RD in YF	RD in OF	RD in CF	RD in YF	RD in OF
Allophylus africanus P. Beauv.	*Sapindaceae*	Late	0.00	0.00	0.00	0.00	0.02	0.05	0.00	0.00	0.00
Albizia grandibracteata Taub.	*Fabaceae*	Late	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
Ficus thonningii Blume	*Moraceae*	Late	0.00	0.00	0.00	0.05	0.16	0.02	0.00	0.00	0.00
Ziziphus abyssinica Hochst. Ex A. Rich.	*Rhamnaceae*	Late	0.00	0.00	0.00	0.02	0.12	0.02	0.02	0.07	0.00
Stereospermum kunthianum Cham.	*Bignoniaceae*	Late	0.00	0.00	0.00	0.00	0.00	0.02	0.12	0.25	0.14
Ximenia americana L.	*Olacaceae*	Late	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
Senegalia campylacantha Hochst.	*Fabaceae*	Early	0.00	0.00	0.00	0.12	0.12	0.00	0.00	0.00	0.00
Vitex madiensis Oliv.	*Lamiaceae*	Early	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.02
Ficus ovata Vahl	*Moraceae*	Late	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
Schinus molle Hort.	*Anacardiaceae*	Early	0.00	0.00	0.00	0.02	0.05	0.00	0.00	0.00	0.00
Melia azedarach Blanco	*Meliaceae*	Introduced	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Phyllanthus muellerianus (Kuntze)	*Euphorbiaceae*	Early	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Psorospermum febrifugum Spach	*Clusiaceae*	Late	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Ficus mucuso Welw.	*Moraceae*	Early	0.00	0.00	0.00	0.12	0.00	0.00	0.25	0.12	0.14
Ficus congensis Engl.	*Moraceae*	Early	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Hexalobus monopetalus (A. Rich.)	*Annonaceae*	Late	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.21
Afzelia africana Persoon	*Fabaceae*	Late	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18
Dalbergia melanoxylon Guill. and Perr.	*Fabaceae*	Late	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.12
Khaya grandifoliola C.D.C	*Meliaceae*	Late	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.12
Diospyros mespiliformis A. DC	*Ebenaceae*	Late	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.02

Abbreviation: CF, Current field; OF, Old fallow; RD, Relative density; YF, Young fallow.