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The effect of shortening fallow length on recovery of plant species richness, composition and growth in shifting cultivation landscapes of Kilosa District, Tanzania

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ABSTRACT
There is insufficient knowledge on the effects of shifting cultivation on vegetation change, especially in situations of land use intensification. This study investigated the effects of shortening fallow length on recovery of small (Dbh < 5 cm) and big (Dbh ≥ 5 cm) plant species richness, composition and height growth in a dry Miombo woodland in East Central Tanzania. Vegetation sampling was conducted on 40 (10 m x10 m) plots and 80 (5 m x 5 m) sub-plots from adjacent sites under fallow for 3, 5, 7 and 15 years and a control secondary forest. Results showed that shortening fallow length to not less than 7 years did not have a significant negative effect on recovery of plant species richness and height growth for both small and big sized plant species. However, there was a remarkable shift in composition of dominant species when fallow length was less than 15 years. Results showed that big size Miombo woodland defining species such as *Brachystegia bussei*, *B. boehmii*, and *B. spiciformis* were deprived in fallows younger than 15 years but dominant in secondary forest. Non-Miombo woodland defining species such as *Cassia burtii* and *Dombeya shumpangae* were instead dominant in younger fallows. These results imply that if the fallow length is shortened to 3 years as required by Village Land Use plans in Kilosa District, the sustainability of the shifting cultivation systems will be threatened, affecting ecosystems services offered by landscapes under shifting cultivation. It is therefore recommended that fallow length be prolonged to at least 7 years and that communities are encouraged to retain some of the Miombo woodland defining species in the fields under cultivation.

Keywords: Cropping frequency; Intensification; Species diversity; Succession; Slash-and-burn; Soil

INTRODUCTION
There has in the past decade been an increasing focus on the environmental effects of shifting cultivation, mainly because this farming system operates at the interface of forestry and agriculture and therefore has potentially high implications for greenhouse gas emissions (Heinimann *et*

al. 2017; Lawrence *et al.* 2010; Mukul *et al.* 2016). As shifting cultivation is practiced in many different ways and under diverse conditions, and especially because it is undergoing constant transformation (van Vliet *et al.* 2013), there is a need for studies that address the environmental consequences of such changes (van Vliet *et al.* 2012), especially when land use is intensified.

In Tanzania, traditional shifting cultivation has been practiced for decades (Campbell 1996). The practice is widespread in Miombo woodlands – a term used to describe the African ecosystem dominated by and/or genera *Brachystegia*, *Julbernardia* and *Isoberlinia,* from the legume family (Fabaceae, subfamily Caesalpinioideae) (White 1983). Miombo occurs in the western, central and southern parts of the Tanzania covering approximately 75% of the total forest cover (Maliondo *et al.* 2005). Recent official figures show that shifting cultivation occupies 33% of Miombo woodlands or 7.6% of the total country land area (URT 2015). Shifting cultivation is widespread in Miombo due to prevalence of poor soils, pest and diseases and a drier climate that make permanent agriculture challenging. Under such conditions that are also characterized by insecure land tenure, lower population density and poor infrastructure development, shifting cultivation is often the most rational land use for farmers.

Political and socio-economic pressures in Tanzania have forced the transformation of traditional shifting cultivation into complex short fallow systems or combination of short fallow, long fallow, and continuous annual cropping (Birch-Thomsen *et al.* 1996; Grogan *et al.* 2013; Kilawe *et al.* 2018). Formalization of land tenure system in rural areas is speeding up the transformation process due to conditions attached to land titles. For example, the Village Land Act CAP 114 [R.E.2002] prohibits leaving a piece of village land to fallow for a period of more than 5 years, otherwise the land is declared abandoned and the Act directs the Village Council to revoke the ownership and transfer it back to the Village Council or to another villager (URT 1999). In villages in Kilosa District, the maximum allowed fallow duration has been reduced to only 3 years (KDC 2012). Failure to comply with the by-law could lead to a fine of about TZS 50,000 (20 USD) or dispossession of the land holding (KDC 2012).

The ongoing transformation of the traditional shifting cultivation to short fallow systems is claimed to affect Miombo woodland species composition and diversity (Luoga *et al.* 2000; Lusambo *et al.* 2007; Mangora 2012; Norrlund and Brus 2004; Stromquist and Backeus 2009; URT 2015). However, there is little empirical evidence and the literature reveals conflicting accounts of the effects of shifting cultivation on recovery of species composition in Miombo woodlands. Some researchers have argued that the Miombo woodland defining species were not recovering after repeated shifting cultivation (Goncalves *et al.* 2017; Stromgaard 1986; Stromgaard 1988; Williams *et al.* 2008) whereas others suggest a steady succession toward Miombo woodland as fallow length increases (Kalaba *et al.* 2013; McNicol *et al.* 2015; Strang 1974; Wallenfang *et al.* 2015).

There is thus little clarity regarding the relationship between change in shifting cultivation and the environmental consequences in terms of vegetation change in Tanzania. However, this is also a more general concern and researchers have called on more studies that demonstrate empirical evidence for the often suggested environmental effects of shifting cultivation (Lawrence 2004; Mertz 2002; Mukul and Herbohn 2016; van Vliet *et al.* 2012). Further knowledge on this relationship will guide land use decisions in landscapes dominated by shifting cultivation (Mertz 2002) as well as when shifting cultivation practices are replaced by other farming systems.

The objective of the current study was thus to investigate the effects of fallow length on recovery of dry Miombo woodlands after fields have been left to regrow into fallow. It was hypothesized that shortening fallow length would negatively affect the recovery of species richness, composition and height growth.

MATERIALS AND METHODS

Description of the study area

This study was conducted in Ibingu village, Kilosa District in Morogoro Region. The village centre is found at latitude 6 ° 5'S and longitude 37 ° 7'E (Figure 1). The village was purposively selected due to the presence of traditional shifting cultivation and of fields with various fallow lengths.

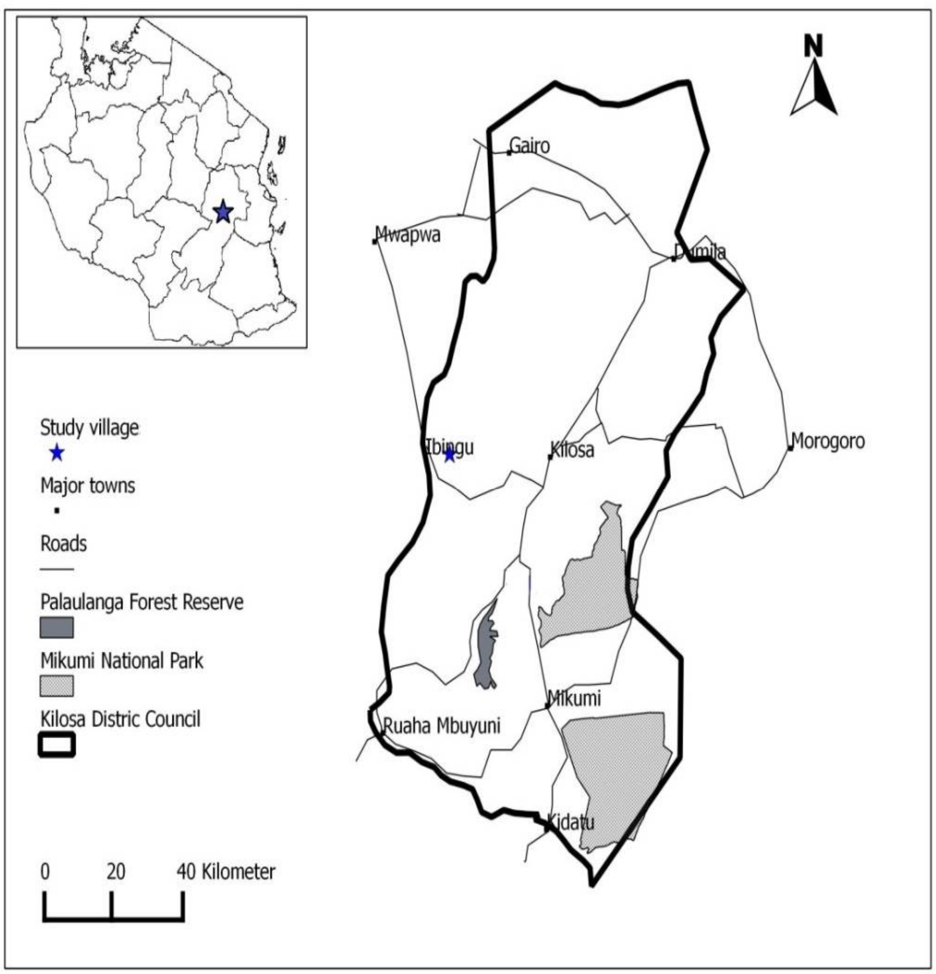

Figure 1. Map of study area

The annual rainfall varies from 700 mm in the lowland to 1400 mm in the highlands. Rainfall is distributed in two seasons (Long rains between March and May and short rains between November and December). Mean annual temperature ranges between 25-27 ºC. The soils range from brown sandy loam in the slopes to black clay loam in the valleys. The natural vegetation is categorized into: dry Miombo woodland, sub-montane forest in higher altitude, and riverine vegetation along the streams and rivers

About 18% of the households in Ibingu practice shifting cultivation on dry Miombo woodlands in the hill slopes. The cultivation cycle involves:

1) selective extraction of big trees for timber,
2) a deep tillage process called *Kukwatua* where the soil is loosened by a hand hoe to increase drainage and increase the decomposition rate of grasses and herbs,
3) slashing of small trees and shrubs,
4) arrangement/distribution of slashed vegetation and undecomposed grass into several horizontal lines across the slope and one thick vertical line along the slope,
5) burning of slash, and
6) cropping until the noticeable increase in soil erosion (measured by exposure of stones), increase in weeds and /or decline in crop yields, and fallowing for at least 3-4 years.

Selection of study sites

Sites under fallow for 3, 5, 7 and 15 years and a secondary forest – hereafter 3YF, 5YF, 7YF, 15YF and SF, respectively were selected for study in order to compare recovery in species composition, diversity and growth. The SF was a forest that had no history of cultivation but had been exposed to other disturbances such as wildfires and selective extraction of trees for timber, poles, firewood and charcoal. Knowledge about the fallows and their management was obtained through in-depth discussions with fallow owners. Recall of the fallow length was estimated to be very good due to good linkage with major known events such as general elections of 1995 and 2010, occurrence of major floods (El-Nino) in 1998 and the beginning of a REDD+ pilot project in 2009. All sites were situated in one location originally covered by dry Miombo woodland species. The furthest distance between the sites was 800 m and thus climate, altitude, and surrounding vegetation were assumed comparable. It was therefore assumed that the original vegetation in the fallows was once the same as in the secondary forest. The practice of shifting cultivation was similar although some of field management practices were different among the sites as summarized in Table 1.

Table 1. Characteristics of sites and histories of management on, 3YF, 5YF, 7YF and 15YF and SF

Site characteristics	Sites				
	3YF	5YF	7YF	15YF	SF
Site area (hectares)	5	10	5	15	50
Elevation (m.a.s.l)	1,192	1,150	1,123	1,194	1,133
Slope	30	40	40	30	40
Slope direction	East	East	South East	South East	East
No. of fallowing since the area was first cleared	2	2	2	1	-
No. of cropping since the area was first cleared (years)	5	7	10	8	-
Crops cultivated	Maize, beans, sorghum	Maize, beans	Beans	Maize, beans	-
Fertilizer/pesticides	No	No	No	No	-
Tillage practices	*Kukwatua*, Slash and burn	*Kukwatua*, Slash and burn	*Kukwatua*, , Slash and burn	*Kukwatua*, slash and burn	-
No. of small trees (Dbh<5 cm)	140	108	258	141	228
No. of big trees (Dbh≥ 5cm)	0	21	19	44	54

Vegetation Sampling

Vegetation assessment was undertaken in July 2012. A systematic sampling design was employed where plots and transects were established at fixed distance. The design is appropriate where meaningful site stratification cannot be established. Further, it increases precision of the estimate since the site is evenly surveyed (Luoga *et al.* 2009). Several forest recovery studies conducted in Miombo woodlands have used various plot sizes and shapes: Square plots 50 x 50 m (Williams *et al.* 2008), 20 x 20 m (Lawton 1978) and 2 x 2 m (Stromgaard 1986); rectangular plots 20 x 50 m (Goncalves *et al.* 2017; Wallenfang *et al.* 2015); and circular plots of 25 m radius (McNicol *et al.* 2015). Since most of the sites were small agricultural fields, square plots of 10 x 10 m sub-divided into four sub-plots of 5 x 5 m were used. In each study site, the first transect was marked from south to north direction through the center. Transect length covered the full extent of the site but at least five meters away from the boundary of the site under fallow or 100 meters away from the SF edge in order to avoid edge effects (Klanderud *et al.* 2009). Additional transects were marked parallel on each side of the main transect at a spacing of 20 m for sites under fallow and 100 m in SF. Larger spacing were used in SF in order to cover large variation in species richness and composition (Mullah *et al.* 2012). In each transect, the main plot (10 x 10 m), was marked at a spacing of 20 m in fields under fallow and 50 meters in SF. The main plot was divided into four sub-plots of 5 x 5 meters. In each main plot, all plants with Dbh ≥ 5 cm were identified and the respective diameters and height measured and recorded. Two sub-plots were selected randomly for in-depth study of regenerants. In each sub-plot, all plants with Dbh <5cm were identified, abundance recorded and the tallest was measured for height. Plant species were identified to species level by local botanists in *Kisagala* and *Kihehe* languages and their equivalent scientific names identified using species checklist book (Makonda and Ruffo 2010). Ten unidentified species were collected and brought to a plant taxonomist at the National Herbarium of Tanzania for identification.

Statistical analyses

The vegetation data from plots and sub-plots were analyzed for species richness, composition and height growth. Species composition was assessed as the list of all tree species in the site. The dominant tree species was the species with the highest number of stems (Shirima *et al.* 2015). Plant species richness was calculated as the mean number of species in each plot or sub-plot (Klanderud *et al.* 2009). For convenience, all plants with Dbh<5 cm were classified as small plants and those with Dbh≥5cm as big plants. Species richness and height growth was analyzed at sub-plot level (5 x5 m) for small trees and plot level (10x 10 m) for big trees. One-way ANOVA was used to determine and compare overall effect of sites on the richness and height growth. When a significant overall effect was found, height measured. In a group of plants, only means were compared by Tukey's HSD multiple comparison procedure.

RESULTS

Species richness

In total, 39 plant species were found in all sites of which 34 were small (Dbh<5 cm) plants, 19 big (Dbh≥5 cm) plants, and 14 being common to both groups. The total number of small plant species recorded in fallows was slightly higher than in SF. The number of species was: 24, 21, 22, 21 and 20 in sites 3YF, 5YF, 7YF, 15YF, and SF respectively. One way ANOVA performed at a sub-plot level (5 x5 m) revealed a significant difference in small tree species richness between sites ($F_{4, 66}$=2.5317, p<0.05). Tukey's HSD multiple comparison test showed that species richness in 7YF was significantly higher than in 3YF but not in 5YF, 15YF or SF (Fig. 2 A). The total number of big trees recorded in fallow was comparable or slightly higher than in SF. The number of tree species recorded was 9, 8, 15 and 8 in 5YF, 7YF, 15YF and SF, respectively. No big tree species were found in 3YF. One way ANOVA performed for plot level (10 x 10 m), revealed no significant difference in tree species richness between sites ($F_{3, 24}$=1.58, p>0.05, Fig. 2B).

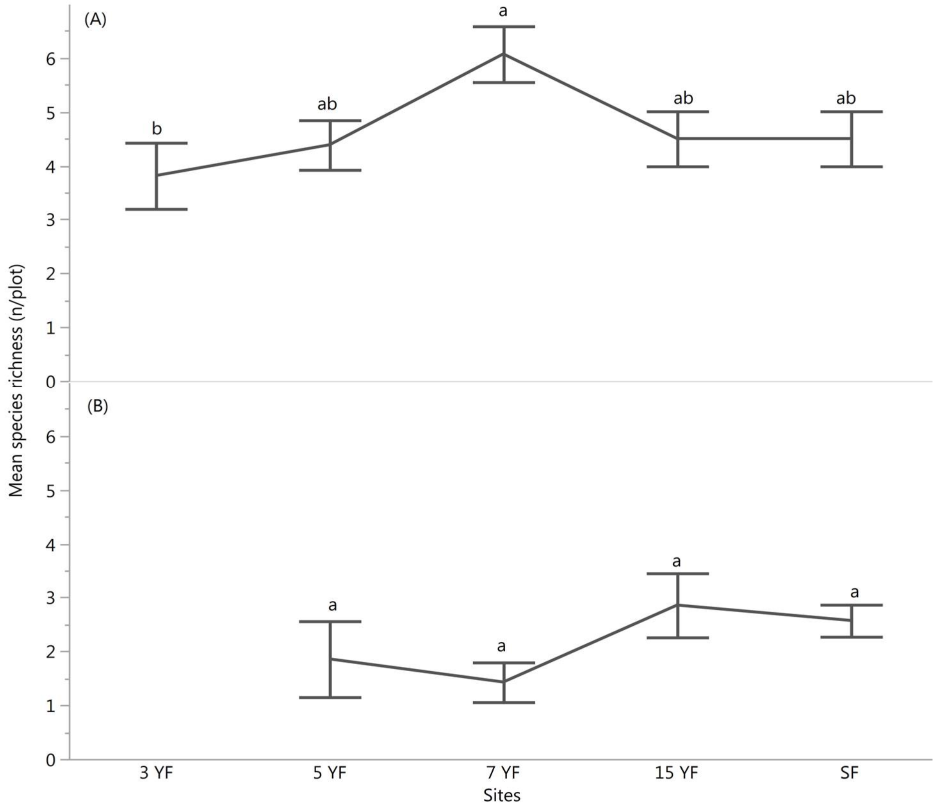

Figure 2. Estimated species richness (mean ± SE) of (A) small (Dbh<5cm) and (B) big (Dbh≥5cm) plant species. Error bars indicate standard error and bars not sharing same letters are significantly different (Tukeys' hsd, P<0.05).

Species composition and abundance

Results revealed that shortening of fallow length has a negative effect on recovery of plant species composition and abundance. The recovery of big sized Miombo woodland defining species (*Brachystegia spiciformis, B. bussei, B. boehmii*) was very poor in fallows younger than 15 years (Fig 3B). Younger fallows were dominated by non Miombo woodland defining species such as *Cassia burtii* and *Dombeya shupangae.* However, the small sized Miombo woodland defining species recovered well and dominates most sites under fallow (Fig 3A).

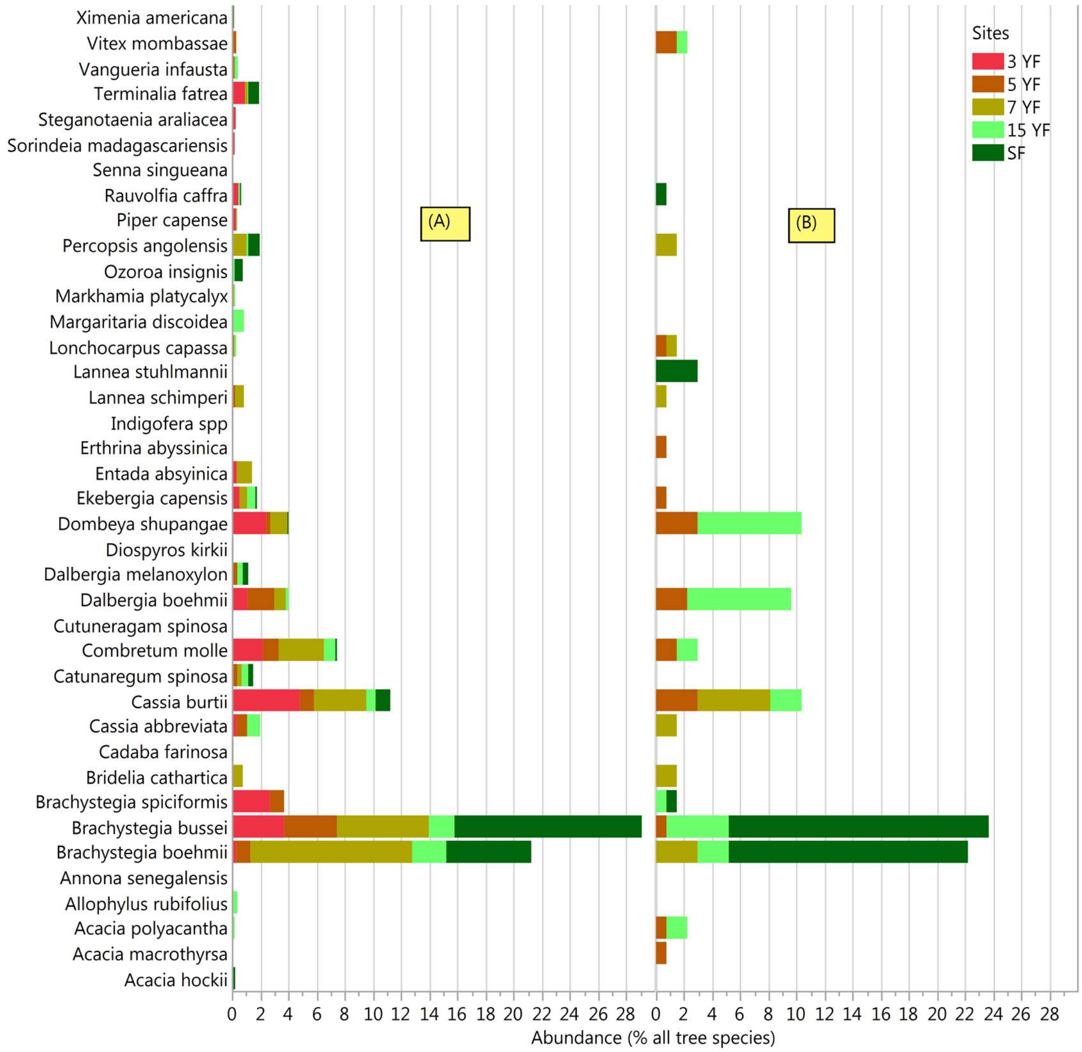

Figure 3. Species composition and abundance of (A) small (Dbh≤5cm) and (B) big (Dbh>5cm) plant species. The abundance is the sum of all stems of each species divided by the total number of stems of all species in all sites

Species height growth

There was no clear pattern on the effect of fallow length on height growth recovery of sapling and tree species. One way ANOVA showed significant difference in small plants height growth between sites ($F_{4, 870}=18.4$, $P<0.01$). Tukey's HSD multiple comparisons test revealed that small plants height growth was significantly higher in 7 YF than in 3-, 5-, 15 YF and SF (Fig. 4A). Furthermore, small plants were significantly shorter in in 3YF and 5YF than other sites except in the SF. Similar observation was made in big plants group where plants in 7YF had significant higher growth than 3- and 5YF but comparable to 15 YF and SF (Fig. 4 B).

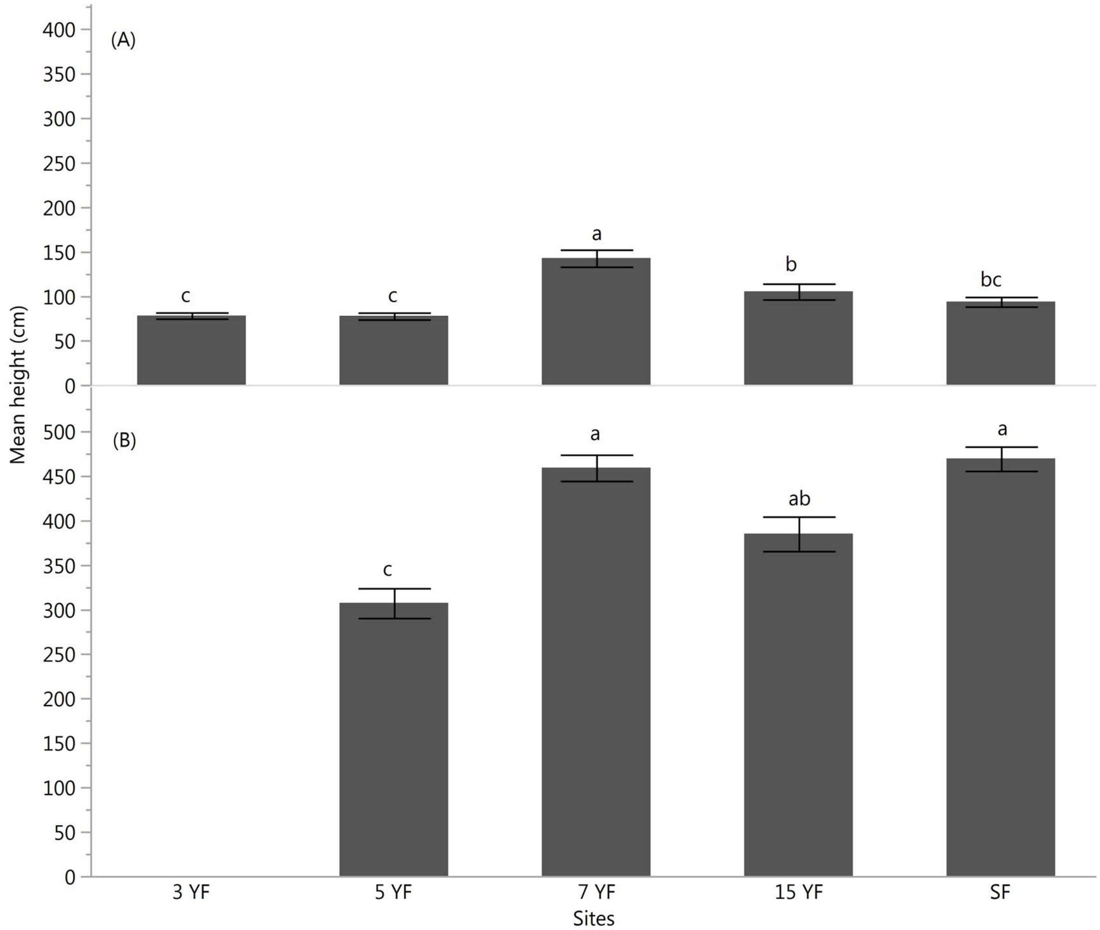

Figure 4. Estimated height growth (mean ± SE) of (A) small (Dbh <5 cm) and (B) big (Dbh≥ 5cm) plant species. Error bars indicate standard error and bars not sharing same letters are significantly different (Tukeys' hsd, $P<0.05$)

DISCUSSION

Species richness

Results showed that shortening fallow length to 3 years significantly affected plant species richness. However, as fallow attained medium age (5Y& 7Y), species richness became higher or comparable to older fallow (15 YF) and secondary forest (SF). The findings are in agreement with other studies by Stromgaard (1986), Lawrence (Lawrence 2004), McNicol (2015), and Wallenfang (2015) but contrary to Gonçalves *et al* (2016), Williams *et al* (2008), Klanderud *et al.* (2010), and Mullah *et al.* (2012), who found higher species richness in primary/secondary forest than in fallows. The difference in the observations made in other countries might be due to spatial variation between the countries and site management factors which differ significantly between farmers, regions and communities. Site management factors such as cropping cycles, fire intensity and fallow duration have been found strongly associated with species richness (Klanderud, 2009; Mullah, 2012). Higher species richness in sites under fallow can be explained by the presence of early colonizers and light demanding species which are absent in secondary forest. It has also been argued that low level of disturbance result in low diversity and dominance of most competitive species while moderate and high levels of disturbance leads to highest and lowest species richness respectively (Grime 1979).

Species composition and abundance

Results showed that the recovery of small sized Miombo woodland defining species (*Brachystegia spiciformis*, *B. bussei,* and *B. boehmii),* increased with increase in fallow length. The trend indicates that succession toward the structure and function of secondary forest could occur in the future. Stromgaard (1986), Klanderud *et al.* (2010) and Mullah (2012) observed similar patterns of recovery in studies conducted in Zambia, Madagascar and Kenya respectively. The small sized species could be regenerating from biological legacies such as stumps, roots and seed bank left behind the cleared older forest species or from seed dispersal from nearby secondary forests (Franklin 2000).

It would have been expected that since the recovery and dominance of small sized Miombo woodland defining species was increasing with increase in fallow length, the same pattern could have been observed for big sized species. However, results showed that except 15 YF, other fields under fallows were deprived of big sized Miombo woodland defining species. The results corroborate those reported by Stromgaard, (1986 and 1988) and Williams (2008) who found that the original Miombo woodland dominated by *Brachystegia spp* was replaced by *Combretum* savanna after repeated shifting cultivation in Zambia and Mozambique. The possible explanations could be that the re-occurring wild-fires at mid-recovery of fallows could be suppressing the growth of Miombo woodland (Backeus *et al*. 2006; Kalaba *et al*. 2013; Lawton 1978; Stromgaard 1986; Stromgaard 1988; Styger *et al.* 2007). This argument could be supported by the prevalence of fire tolerant species such as *Dombeya shupangae, Combretum molle, Dalbergia boehmii* and *Cassia burtii*. However, the secondary forest was not free from wild-fires, so at least similar changes could have been found. Furthermore, two photographs taken in one site under fallow in 2012 and 2015 shows that fire did not occur because the mulch left after abandoning the site was naturally decomposing (Fig. 5).

Figure 5. Photograph of a field under fallow in Ibingu village. The first photograph on the left was taken in July 2012 and the second one the right was taken in July 2015, both at the same spot as referenced by the rectangular box. The right hand side photo shows that the mulch left behind was still visible and naturally decomposing an indicator of absence of wild fires

The most compelling explanation could be that farmers deliberately remove or retain some tree species depending on the role the species play for the households or the community. Most Miombo woodland species, particularly *Brachystegia spp* could be the victims of this extraction due to high use value for charcoal, poles, ropes and firewood (Malimbwi *et al.* 2004; Nduwamungu *et al.* 2004). This argument is supported by field observation in the study area whereby *Brachystegia bussei*, *Diplorynchus condylocarpon, Brachystegia boehmii and Combretum molle* were widely used for firewood while *Percopsis angolensis* and *Brachystegia microphylla* were used for timber, and *Brachystegia boehmii* for building poles and ropes. The trees retained in fallows appear to provide several products to farmers such as medicine, fodder, fruits plus the fact that they might not be good for provision of timber, poles, charcoal or firewood (Luoga *et al.* 2009). Also, the removal of big trees could be an attempt to make the fallows looks younger. Fallows older than five years may lead to land tenure right dispossession as required by the Village Land Act CAP 114 [R.E.2002] (URT 1999).

Discussions with shifting cultivators in the study area revealed a preference of land dominated by Miombo woodland species for shifting cultivation. This implies that a change in the composition of the dominant species in fallows can affect farmers' propensity to continue to use the land for shifting cultivation. The new species dominant in fallows were still providing ecosystem services such as protection of surface soil against soil erosion and nursing the late successional species (Maki *et al.* 2008), but they would generally lead to a loss of ecosystem services (Beare *et al.* 1995).

Species height growth

Findings showed that shortening fallow length to ≥ 7 years did not have a significant effect on plant species height growth. Small and big sized plant species in 7 Y and 15 YF fallows were as tall as those in SF. Similar studies conducted in Myanmar and Amazon have reported a quick recovery of carbon and biomass in fallows to values comparable to secondary forest (Gehring *et al.* 2005; Maki *et al.* 2008). It is argued that most of the species that recover immediately after abandonment are pioneer species that have higher growth rates and can attain the size of tree species in secondary forest within a short time span.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study show that shortening fallow length to < 15 years has negative effects on recovery of plant species composition and abundance. It was found that the recovery of big sized (Dbh> 5 cm) Miombo woodland defining species (*Brachystegia spiciformis*, *B. bussei*, *B. boehmii*) was poor in fallows younger than 15 years. The younger fallows were instead dominated by non-Miombo species such as *Cassia burtii* and *Dombeya shupangae*. On the other hand, our results showed that an effect on plant species richness and height growth occurred only when fallow length was shorter than 7 years.

The results of this study imply that shifting cultivation will stop to be less sustainable in terms of vegetation recovery if fallow length is shorter than 7 years and especially if it is as short as 3 years as proposed by Village Land Use Plans in Kilosa District. Such short fallow shifting cultivation can lead to loss in ecosystem services including but not limited to primary production, crop yields and nutrient cycling.

It is therefore recommended that fallow length be prolonged to at least 7 years and that communities are encouraged to preserve some of the Miombo woodland defining species in their fields under cultivation. Agriculture and forest officers should make an effort to assist shifting cultivators identify and adopt the best practices that maximize regeneration of Miombo woodland defining species in their fallows.

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