



## Research article

## Changes in tree structure, composition and soil in different disturbance categories in Miombo and agroecosystems in Malawi, central Africa



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## ARTICLE INFO

## Keywords:

Miombo  
Regeneration density  
Soil porosity  
Traditional agriculture  
Organic carbon

## ABSTRACT

This study aimed to characterise the floristic, structural composition of vegetation and soil status in the three land use types of protected area (PA), harvested woodland (HW) and traditional agriculture land (TA) in Salima District, Malawi. The HW and TA were further divided into categories based on the number of years the land was subjected to use as a disturbance i.e. into 1–5 years, 6–10 years, and 11+ years. Floristic data were collected on tree species, diameter at breast height (1.3 m from the ground) and regeneration categories of seedlings, saplings and poles. Soil samples were collected from the sampled plots where floristic data were collected. The study found 73 tree species from 58 genera and 31 families. High tree species diversity was recorded in HW used for over 11 years ( $p < 0.05$ ). Tree species dominance depended on land use. Although the HW and TA showed an inverse J-shaped structure indicating stable tree populations, the HW had fewer big trees. The PA showed signs of ageing tree population shown by the bell-shaped structure. The study area was dominated by Sandy loam soils with very high porosity of above 40%. The more the years of disturbance, the higher the fertility loss within the TA in terms of organic matter and organic carbon but the reverse was true for nitrogen. The decrease in soil fertility loss was however, higher in TA as compared to HW and PA. To address the unstable structural status of some species in the land uses, deliberative silvicultural interventions should be introduced in the land uses. There is need to integrate fertility-improvement tree species and manure use in the agricultural land to improve soil fertility.

## 1. Introduction

Miombo woodlands are the common vegetation type across southern African countries such as Mozambique, Malawi, Zambia, Zimbabwe, Tanzania and Angola. There are about 8,500 species of plants in the Miombo woodlands, the common ones being *Julbernardia* species and *Brachystegia* species, *Pseudolachnostylis maprouneifolia*, *Burkea africana* and, *Diplorhynchus condylocarpon* (Ribeiro et al., 2015). Mature woodlands usually form tall canopies of about 10–20 m high. Saplings and grasses are sparse in dense forests and flourish in disturbed areas. Common grasses include *Hyparrhenia*, *Londetia*, *Andropogon*, and *Digitaria*. About 54% of Miombo plants are considered endemic (Ribeiro et al., 2015). Previous studies showed that the floristic variations of Miombo at local scale was attributed to geomorphological changes, soil nutrients and moisture availability/scarcity (Cole 1986), changes in land use and other human induced land uses (Chidumayo 1989). Recent studies show that the floristic variations in woodlands are largely due to disturbance (tree harvesting, charcoal making, slash and burn agriculture) and recovery process, rather than soil condition, temperature,

rainfall and substrate (Geldenhuys 2015). These findings show that some species are critically endangered, making Miombo woodlands a conservation priority (Mittermeier et al., 2003; Shumba et al., 2010).

Most rural communities rely on small-scale agriculture and forestry products for their livelihoods (Lawson, 2014). Hence despite being a threat to biodiversity agriculture remains the main source of food and income to the ever increasing human population (Kadoya and Wachitani 2011). However, agricultural sustainability is heavily dependent on a thriving ecosystem. It is therefore, critical to ensure that agricultural production is not done at the expense of other valuable resources such as forestry (Perfecto and Vandermeer 2008). Soil is another resource that is critical to agricultural sustainability. Prasad and Power (1997) found that in order to maintain agricultural sustainability, soil fertility management is a major component to be considered at both, local scale (farm level) and general landscape level McGrath et al. (2014) describes soil fertility as the ability of soil to supply adequate nutrients in right proportions to plants. To complete a life cycle, a plant needs 16 elements of Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, Sulphur, Iron, Manganese, Copper, Zinc, Molybdenum,

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Received 10 January 2022; Received in revised form 21 March 2022; Accepted 9 September 2022

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Boron and Chlorine (McGrath et al., 2014). The first nine are major elements as they are needed in large quantities. In this study, Nitrogen (N), Phosphorus (P), Potassium (K) and Carbon (C) were prioritised because the first three are considered most limiting in the agricultural soils in Malawi (Njoloma et al., 2016) while C is important for soil structure improvement (Brady and Weil 1999).

Maize yield decline in Malawi is associated with soil fertility loss (Hardy 1998; Doward and Chirwa 2011). Past and recent studies have reported a decrease in organic matter (OM), soil organic carbon (SOC) and pH (Munthali 2007; Snapp 2008; Njoloma et al., 2016). Vargas and Omuto (2016) outlined steep slope cultivation, vegetation clearing, agricultural related activities in shallow soils, erosive rains, marginal land cultivation, and limited soil and water conservation measures as direct factors responsible for the loss of fertility. They listed sustainable land management gaps, awareness challenges, population increase of both livestock and human, increasing demand for fuelwood energy in urban areas, and unclear land tenure systems as some of the indirect factors leading to loss of soil fertility. They further reported that Malawi loses 29 tons of soil per ha per year, higher than the 20 ton per ha per year recorded in 1992 (World World Bank, 1992). Salima district had relatively low losses. However, most of these studies only concentrated on cropland. For effective agricultural extension service delivery on sustainable land management, farmers need to appreciate the fertility loss across disturbance gradients so that promotion of tree integration into cropland becomes a success. There are limited studies that have assessed soil fertility based on disturbance gradient i.e. from natural protected forests to agriculture land in Malawi. This study was part of the on-going biophysical studies after the initial study by Nyirenda et al. (2019), which focussed on vegetation floristic and termite abundance. This study focussed on vegetation floristics and soil condition and provides a new understanding in soil and tree dynamics on land that has been subjected to same period of disturbance. This study will therefore, determine tree structure and soil characteristics in the three land use types of protected area (PA); harvested woodlands (HW) and traditional agriculture (TA) land. The study aimed at answering the following questions: what are the variations in tree species composition and tree population density in the three land use types? what are the chemical and physical properties of soil in the three land types?

## 2. Materials and methods

### 2.1. Study area

The study was conducted in Salima District under Salima Agricultural Development Division (SLADD). The district experiences warm wet, hot dry and cool dry seasons (Department of Climate Change and Meteorological Services 2022). Rainfall is unimodal (800 mm–1300 mm) and the temperature ranges from 20 °C to 31 °C. The district is dominated by Miombo woodland with major species being *Brachystegia stipulata*, although *Julbernardia globiflora* also occurs in good numbers (Moyo et al., 1993; Nyirenda et al., 2019). The soils are dominated by Haplic, Chromic and Luvisol soils whose depth is less than 150 cm (Lowole 1995), with Sand to Sandy loam texture in the top (0–30 cm depth) layer. Vertisol and Calcimorphic alluvial soils (Inceptisol) are also found in some areas with medium Sandy clay loam and Clay loam texture (Lowole 1995; Saka et al., 2003). Land productivity for the major cereal crop, maize, in SLADD has been below the national average of 2 t ha<sup>-1</sup> (Salima Agricultural Development Division 2020). Major crops in the area have not been able to reach potential yield and notably, yields for maize and rice, which are the main cereal food crops have declined (Salima Agricultural Development Division 2020). Smallholder crop production dominates in the area with pure crop production being the common practice (Salima Agricultural Development Division 2017). Traditionally, where possible, farmers apply inorganic fertilizer at the rate of 92 kg N ha<sup>-1</sup> for maize yield improvement. One bag of 50 kg of each fertilizer type is applied per 0.4 ha. Usually, leguminous crops are not applied with inorganic

fertilizer. Some farmers apply organic manure for soil fertility improvement. Other practices include assisted natural regeneration for tree species that improve soil fertility such as *Philenoptera violacea* and *Faidherbia albida* (Beedy et al., 2015) and conservation agriculture, a system that minimises soil disturbance (FAO 2013).

### 2.2. Sampling design

The TA and HW were divided into periods in years under use, i.e. 1-5 years, 6–10 years, and 11 + years (Table 1). The TA comprised fields used for crop production such as sole maize, sole legumes and an intercropping of maize with a legume. The ages of woodland stands and agricultural land were determined through consultations with the local farmers, agricultural extension staff, forestry field staff as well as the Salima District Forestry Office. The actual sampling plots were chosen randomly in each of the age categories due to the nature of the study area. A list of farming households with fields cultivated for 0–5, 6–10 and 11 + years was produced, and each household was assigned a number and selected randomly through calculator random number generation. This was to ensure that we sampled fields with accurate years of cultivation. For PA and HW, random points were selected, ensuring a plot was at least 30 m away from the main roads or paths (Geldenhuys 2010). Circular nested plots (Figure 1) were randomly established in each of the land use areas, with 15 plots in each disturbance category. The disturbance intensity was theorised as in Figure 2.

### 2.3. Data collection

Tree stems were recorded by different size categories. From a 0.16 ha plot of 22.6 m radius, big trees of >30 cm stem diameter at breast height (DBH), i.e. at 1.3 m above ground level, were recorded by species and DBH. Smaller trees of >5 ≤ 29.9 cm DBH were recorded by species and DBH from an inner plot with radius 11.28 m (0.04 ha). Individual tree or multi-stemmed clumps with greater than half of their body within the plot were counted as being inside the plot (Anderson and Ingram 1993). During the time of data collection, all crops in the TA had already been harvested. In this study, circular plots were used as they relate well with similar studies by Syampungani (2008) in the Miombo region. The following regeneration categories were used: Seedlings as plants ≤1 m height; Saplings as plants >1 m height and ≤1 cm DBH; Poles as plants 1.0–4.9 cm DBH. Regeneration (stems <5 cm DBH) was recorded by stem counts per species by regeneration categories from an inner sub-plot of 5.65 m radius (0.01 ha) (Syampungani 2008). The regeneration was not categorised as from seed or stumps because it is generally understood that Miombo woodlands largely regenerate through coppicing or root stocks (Trapnell 1959; Piironen et al., 2008). Details on sample sizes are provided in Table 1.

### 2.4. Collection, handling and preparation of soil samples

To assess soil fertility status, data were collected on soil texture, bulk density, porosity, SOC, N, P, K and soil pH. For soil parameters, the samples in TA were collected based on their period under disturbance, i.e. 1-5, 6–10 and over 10 years, i.e. TA1-5, TA6-10, TA11 + in order to effectively link soil fertility to the level of disturbance. The HW was not treated in yearly categories because the level of soil disturbance was uniform (intact soils). Soil amendments and ploughing mainly impact on

**Table 1.** Number of sampled plots per disturbance category in the study area of protected area, harvested woodland and traditional agriculture, Salima, Malawi.

Traditional agriculture	Harvested woodland			Protected area		
	1-5*	6-10*	11+*	1-5*	6-10*	11+*
15	15	15	15	15	15	15

\*years under use by farmer/communities.

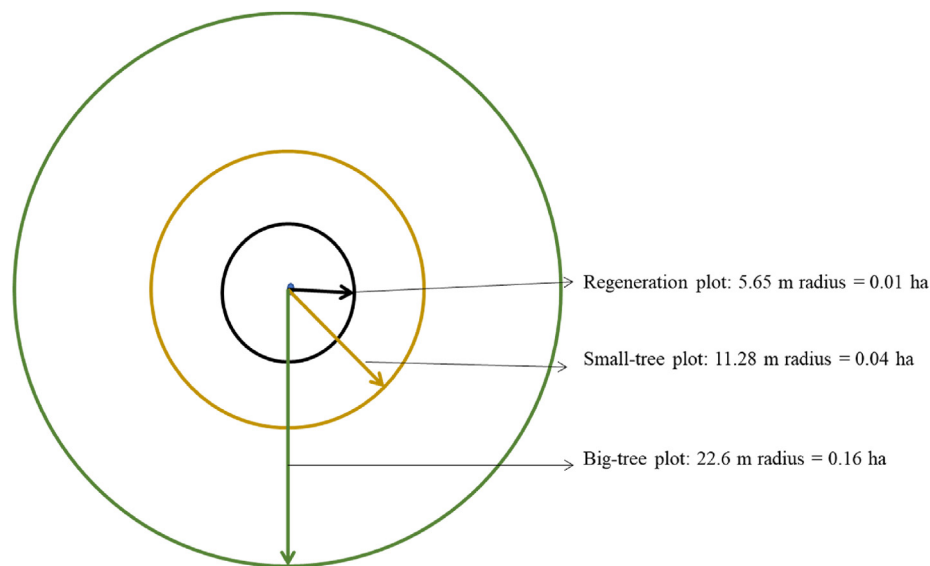


Figure 1. A schematic illustration of a nested circular sampling plot (Geldenhuys 2010).



Figure 2. Theorised disturbance gradient across the land uses. TA = traditional agriculture, HW = harvested woodland and PA protected forest reserve.

soil nutrient and OM changes in the short term rather than vegetation clearance (Compton and Boone, 2000). The TA was under various soil fertility amendments and cultivation levels. The yearly categorisation in the TA has a bearing on passing extension message to farmers on impacts of continuous cultivation on soil condition. Soil samples were collected at the depth of 0–15 cm, which is considered as top fertile soil (Brady and Weil 1999). A 4.5 cm diameter soil auger was used to collect soil samples in all the study sites. Five (5) points per plot were sampled and the soils were mixed to make a composite sample and then a sub-sample of about 1 kg was taken (Anderson and Ingram 1993). However, for bulk density, soil samples were collected using cores to ensure that undisturbed samples were collected. Fifteen (15) soil samples were collected from each disturbance category, i.e. 75 for bulk density and 75 for non-bulk density analyses.

At each sampling site, a general site description was recorded, noting understory cover, grass cover and soil colour. The soil samples were placed in sealed plastic bags. Soil samples meant for SOC, N, P, K and OM analysis were air-dried in a well-ventilated room to prevent contamination and other effects. The soil samples (except those of bulk density) were sieved to ensure that all materials of >2 mm were taken out of the soil before analysis. Finally, a fine soil sample weighing about 250 g was retained for analysis. The samples meant for bulk density were dried in the oven at 105 °C for about 24 h or until constant weight was achieved (Anderson and Ingram 1993).

### 2.5. Soil analysis

The soil samples were analysed in Lilongwe Malawi, at Chitedze Agricultural Research Station Soil Laboratory of the Department of Agricultural Research Services (DARS), under the Ministry of Agriculture. The hydrometer method was used to analyse soil texture to determine the percentage proportions of size classes for sand (2–0.05 mm), silt

(0.05–0.002 mm) and clay (<0.002 mm) in the soil samples (United States Department of Agriculture 1954, Gee and Bauder, 1979). Bulk density (weight of soil per given volume) was calculated as weight of dry soil divided by volume of core in  $\text{g cm}^{-3}$  (Brady and Weil 1999). Soil pH was determined using pH meter (Kalra 1995) while soil porosity was determined using the formula:

$$\text{Porosity}(\%) = \left[ 1 - \left( \frac{\text{Bulk density}}{\text{Particle density}} \right) \right] * 100$$

taking particle density as  $2.65 \text{ g cm}^{-3}$  (Prasad and Power 1997).

SOC and N were analysed following Walkley-Black procedures (Nelson and Sommer, 1982; Schumacher 2002) and Kjeldahl method (Bremner and Keeney 1966) respectively. OM was calculated by multiplying SOC values by a conversion factor of 1.72 (Brady and Weil 1999). P was analysed using Bray and Kurtz No. 1 extractant method while K by flame photometer reading (Bray and Kurtz 1945).

### 2.6. Data analysis

Tree species were identified by taxonomic experts from the Forestry Research Institute of Malawi (FRIM). The trees were identified in the field to species level, with both scientific and local names. Pielou Equitability Index (E) and Shannon-Wiener Diversity Index (H) were used to compute tree species evenness and diversity respectively, in each category of disturbance (Hill 1973; Magurran 2004). The stem diameter size class distribution (SCD) was analysed using Weibull fitting distributions (Ricci 2005; Muller 2014) as a pool for all trees  $\geq 5\text{cm}$  DBH per land use. The most important species were determined using the Importance Value Index (IVI) in order to explain tree composition and structure (Banda et al., 2008; Kalaba et al., 2012, Syampungani et al., 2015). The IVI is given by the formula:

$$\text{Importance Value Index} = \text{Relative dominance} + \text{Relative frequency} + \text{Relative density}/3$$

The most important species that had an IVI of  $\geq 30$  and occurred in more than one disturbance category (Geldenhuys 2010) were further analysed to assess structural performance on diameter SCD per disturbance category. Data for tree density, regeneration and soil parameters were tested for normality and homoscedasticity using Shapiro-Wilk normality test and Levene test respectively in R. This was to ensure rules of normality were met and that where necessary transformation made to meet the data format requirements. Where homoscedasticity was observed, one-way ANOVA as well as Tukey's post hoc test were performed to compare means whereas a non-parametric Kruskal-Wallis was used in cases of lack of homoscedasticity. To show regeneration density across disturbance categories, one-way ANOVA and Tukey's post hoc test was performed. A Canonical Correspondence Analysis (CCA) was run in R Statistical Software version 3.4.2 with vegan package (R Development Core Team, 2020) to assess the spatial distribution of regeneration density across the disturbance categories in the land uses. Soil variables like pH, OM, P, K, tree abundance have been included in regeneration assessment (Fei et al., 2013; Fernandez et al., 2015; Sarvade et al., 2016). In this study, OM, soil texture (Sandy loam, Loamy and Sandy clay loam), tree cover, tree abundance, land use and altitude were included since they were the discriminating factors across. The most discriminating parameters are used in CCA for determination of repartition between environmental factors and the variable under assessment (Assede et al., 2012); regenerations in this case. Since not all the factors responsible for regeneration density were collected in the field, CCA was an appropriate option to understand the relationship between the few sampled variables and regeneration density (Palmer 1993). All statistical analyses were performed in R Statistical Software version 3.4.2 (R Development Core Team, 2020). The significant difference was taken at  $p < 0.05$ .

### 3. Results

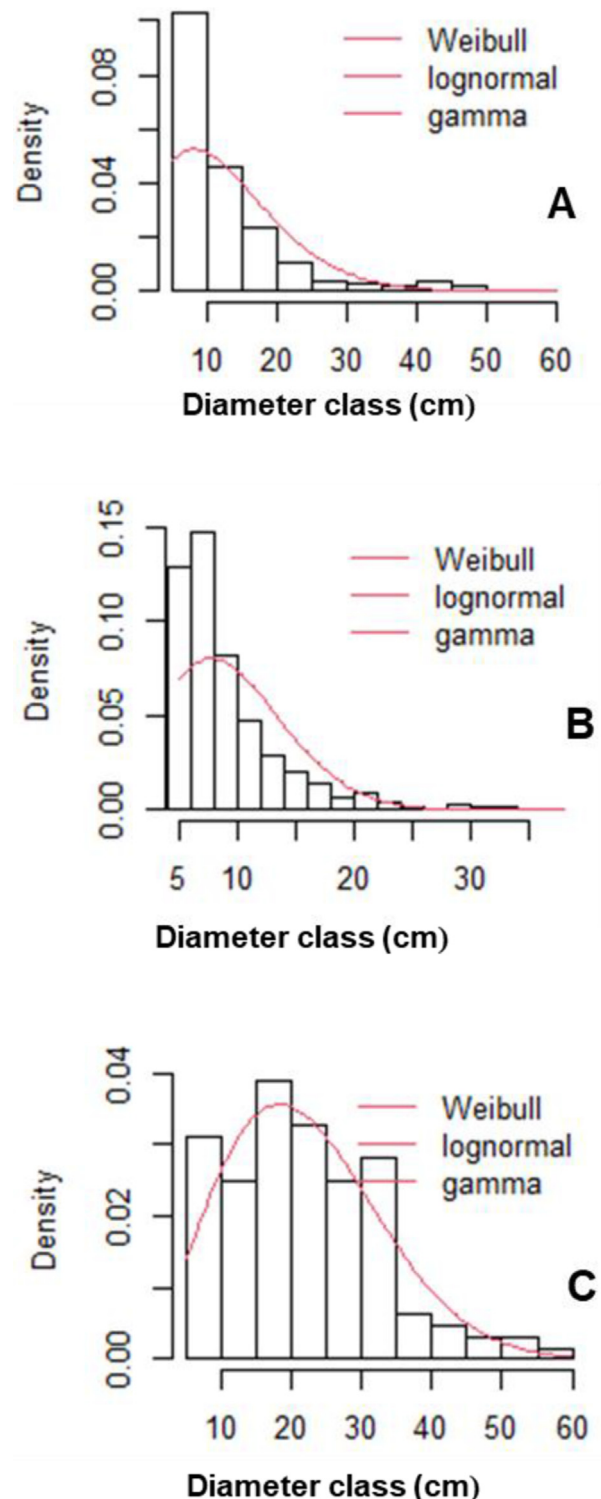
#### 3.1. Tree species diversity and structure

The study recorded 73 tree species with 58 genera and 31 families. The three most diverse families were Fabaceae, Combretaceae, and Euphorbiaceae. The tree species were more diverse in the HW categories and lowest in the PA. The Shannon-Wiener Diversity Index results showed higher diversity in HW. In total 1,448 tree stems of DBH  $\geq 5$  cm were measured for DBH of which 117 were from PA, 1,029 from HW and 422 from TA field. The ANOVA and Tukey's post hoc results showed significant difference for the average stem density across the disturbance categories. Generally, the HW had the highest number of stems per ha while TA sites and PA had the lowest. The HW1-5 had the highest number of stems per ha while TA1-5 had the lowest stems per ha. Table 2

**Table 2.** Average stem density in different land uses and disturbance categories in the protected area (PA), harvested woodland (HW) and traditional agriculture (TA) in Salima District. Same letters within a column of measured attribute indicate no significant difference ( $p < 0.05$ ). SR = species richness, H = Shannon-Wiener Diversity Index, E = Pielou Equitability Index.  $\pm$  means Standard error.

Disturbance category	SR	H	E	Stem density/ha
TA1-5	30a	1.44	0.43	60.2 $\pm$ 20.32a
TA6-10	28a	1.63	0.50	66.2 $\pm$ 10.60a
TA11+	21b	1.54	0.52	87.4 $\pm$ 16.82a
HW1-5	37c	1.85	0.52	385.1 $\pm$ 54.33b
HW6-10	40c	1.89	0.52	277.8 $\pm$ 79.10b
HW11+	47cd	2.00	0.52	286.7 $\pm$ 30.21b
PA	23b	1.52	0.50	124.3 $\pm$ 23.12a
p-value	0.013			0.001

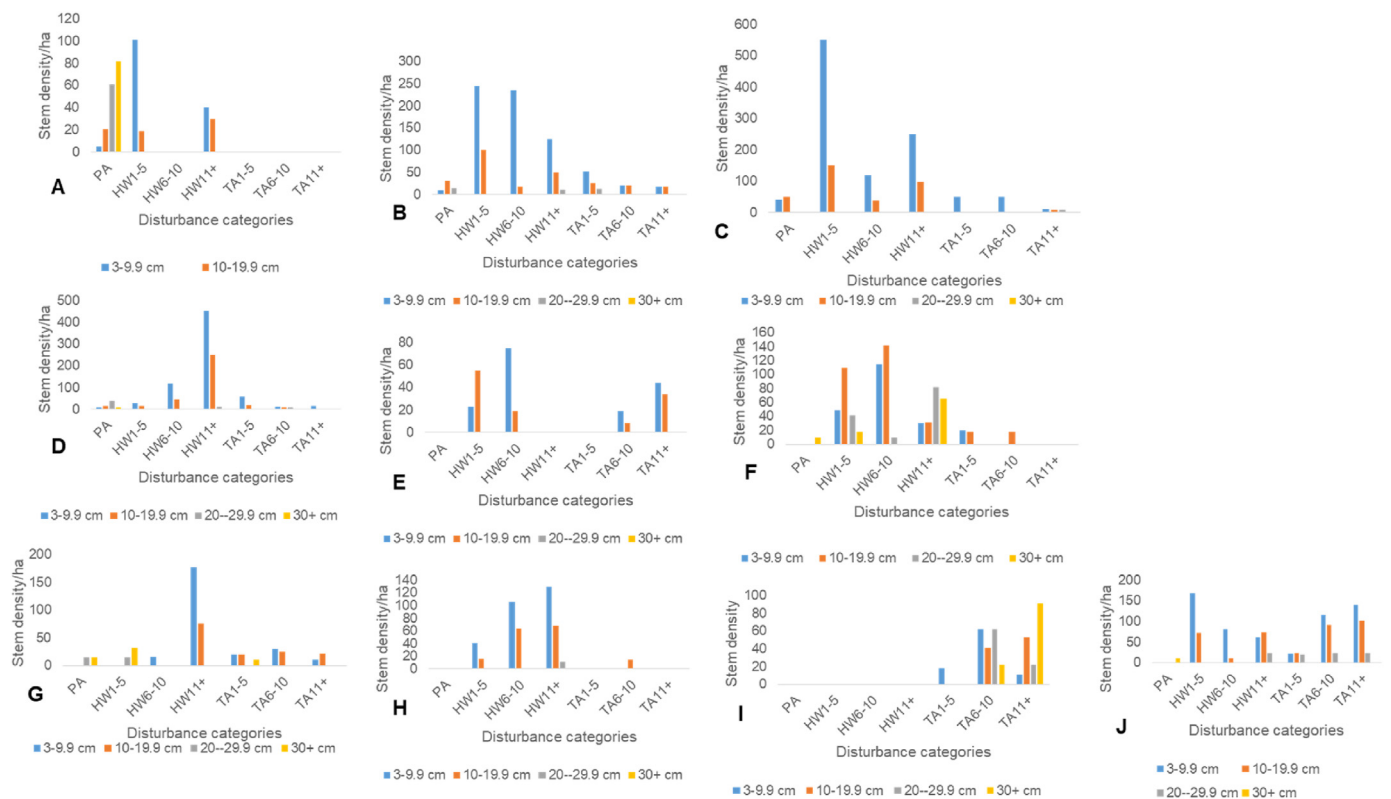
provides details of species diversity and stem density. The tree structure in TA and HW showed inverse J-shape while that of PA showed bell-shape (Figure 3). The most important species in the respective land uses are shown in Table 3. The performance of most important species in the land use disturbance categories showed signs of structural instability (Figure 4 A-J). A unique observation was the dominance of big trees for *Pterocarpus rotundifolius* and *F. albida* in PA and TA11 + respectively (Figure 4 A and I).



**Figure 3.** Pooled tree structure in the three land uses, Salima District, Malawi.

**Table 3.** Ten most important species and their respective Importance Value Index in the land uses. TA = traditional agriculture, HW = harvested woodland and PA protected forest reserve.

Species	TA1-5	TA6-10	TA11+	HW1-5	HW6-10	HW11+	PA
<i>Albizia harveyi</i> E.Fourn		21.9	14.1	20.6			
<i>Azadirachta indica</i> A.Juss			22.8				
<i>Bauhinia petersiana</i> Bolle	42.8	21.6		53.3	32.1	36.2	22.6
<i>Bauhinia thonningii</i> Schumach.		15.1		18.2			
<i>Brachystegia utilis</i> Hutch. & Burt Davy	21.18						22.2
<i>Combretum apiculatum</i> Sond.	30.0	16.7		40	35.0	30.0	33.1
<i>Combretum collinum</i> Fresen.	22.8			25.6	18.7		18.1
<i>Diospyros kirkii</i> Hiern.					25.4	18.9	
<i>Diplorhynchus condylocarpon</i> (Müll.Arg.) Pichon.	21.0	19.2			26.0	46.0	21.8
<i>Faidherbia albida</i> (Delile) A. Chev.)	27.8	55.0	50.0				
<i>Lanea discolor</i> (Sond.) Engl.					28		
<i>Markhamia obtusifolia</i> (Baker) Sprague.							15.6
<i>Pterocarpus angolensis</i> DC.	24.0		19.3			23.9	
<i>Philenoptera bussei</i> (Harms) Schrire		16.5	17.3	26.9			
<i>Pterocarpus rotundifolius</i> (Sond.) Druce				27.7		15.1	44.6
<i>Philenoptera violacea</i> (Klotzsch) Schrire	37.1	48.2	41.7	37.6	16.9	26.3	
<i>Senna siamea</i> (Lam.) H.S. Irwin & Barneby)			40.8				
<i>Stereospermum kunthianum</i> Cham.		14.8	32.6	28.5	16.9		
<i>Sclerocarya birrea</i> (A. Rich) Hochst			19.5				
<i>Tamarindus indica</i> L.	39.1						
<i>Uapaca kirkiana</i> Müll. Arg.							21.6
<i>Vachellia galpinii</i> Burt Dav					31.9		16.0
<i>Vachellia goetzei</i> Harms						28.6	
<i>Vitex mombassae</i> Vatke						22.5	
<i>Vachellia polyacantha</i> Willd	29.0			32.6	31.0	41.0	20.2
<i>Zanha africana</i> (Radlk.) Exell		36.1	24			33.4	



**Figure 4.** Stem diameter class distribution for selected ten most important tree species of  $\geq 5$  cm DBH across disturbance categories. A = *Pterocarpus rotundifolius*, B = *Combretum apiculatum*, C = *Bauhinia petersiana*, D = *Diplorhynchus condylocarpon*, E = *Stereospermum kunthianum*, F = *Vachellia polyacantha*, G = *Zanha africana*, H = *Vachellia goetzei*, I = *Faidherbia albida* and J = *Philenoptera violacea*.

3.2. Regeneration

For the regeneration, seedling, sapling and pole density varied across the disturbance categories in all the land uses. The Tukey's post hoc test showed significant differences for seedlings, saplings and poles ( $p < 0.05$ ) across the disturbance categories in the land uses (Figure 5 A-C). The PA and HW had respectively the least and highest regeneration numbers for all seedlings, saplings and poles. In some cases a single species dominated in some disturbance categories (Figure 6).

3.3. Soil condition across different disturbance gradient

For the analysed soil physical and chemical properties, significant differences across disturbance regimes were only for SOC, OM and bulk density (Table 4). The Tukey's post hoc test for soil pH showed no significant different across the disturbance category in the land uses ( $p > 0.05$ ). It ranged from 6.43 in the PA to about 6.54 in TA11+. The %SOC and % OM were significantly higher in the PA and HW and least in TA categories. P was not significantly different across the disturbance

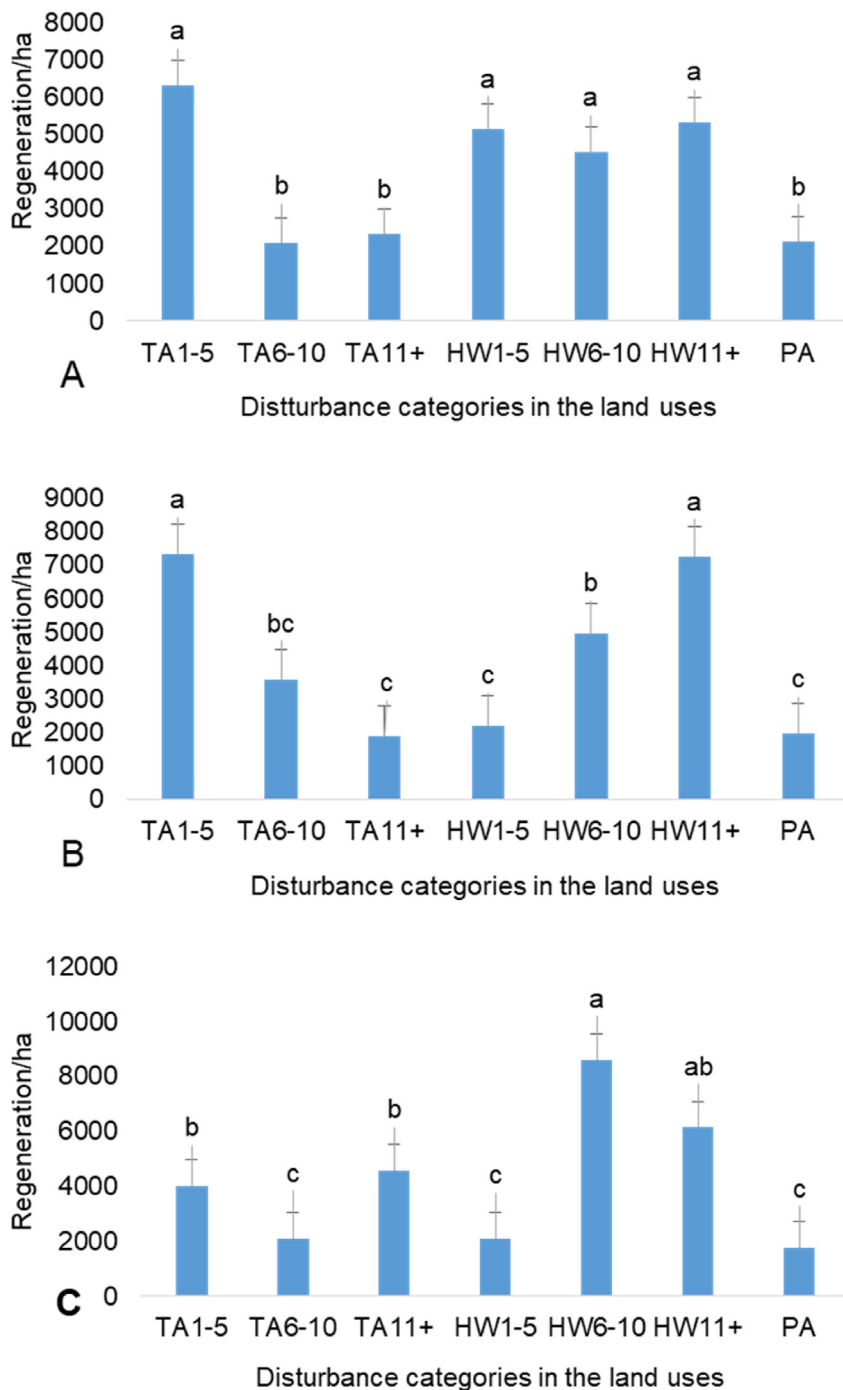


Figure 5. Regeneration density: seedlings (A), saplings (B) poles (C) for species combined in the land uses. Similar letters along the bars show no significant difference.



**Figure 6.** Regeneration of *Markhamia obtusifolia* Sprague in a new (1-year old-TA1-5) agricultural field in the study area. *Philenoptera violacea* Klotzsch selectively left (possibly for soil fertility improvement) when tree clearing for conversion to crop land was done.

**Table 4.** Soil characteristics for physical and chemical properties in traditional agriculture (TA), harvested woodlands (HW) and the protected area (PA), in Salima, Malawi. Similar letters along a column show no significant difference ( $p < 0.05$ ).

Treatment	pH	%SOC	%OM	%N	P (ug/g)	K (Cmol/Kg)	BD (g/cm <sup>3</sup> )
PA	6.43a	1.590a	2.747a	0.138a	5.3a	0.038a	1.27ab
HW	6.52a	1.732a	2.930a	0.128a	14.82a	0.045a	1.24a
TA1-5*	6.49a	1.061b	1.831b	0.09a	14.86a	0.06a	1.36c
TA6-10*	6.48a	0.844bc	1.457bc	0.07a	19.48a	0.044a	1.38c
TA11+*	6.54a	0.714c	1.230c	0.15a	16.99a	0.046a	1.34bc
p-value	0.58	0.001	0.001	0.204	0.609	0.609	0.015

\*Number of years under cultivation, pH = soil pH, SOC = soil organic carbon, OM = organic matter, N = nitrogen, P = phosphorus, K = potassium, BD = bulk density, P-value = Probability value.

**Table 5.** Soil texture and porosity in protected area (PA), harvested woodland (HW) and agriculture land (TA), Salima, Malawi. Similar letters along a column show no significant difference ( $p < 0.05$ ).  $\pm$  means Standard error.

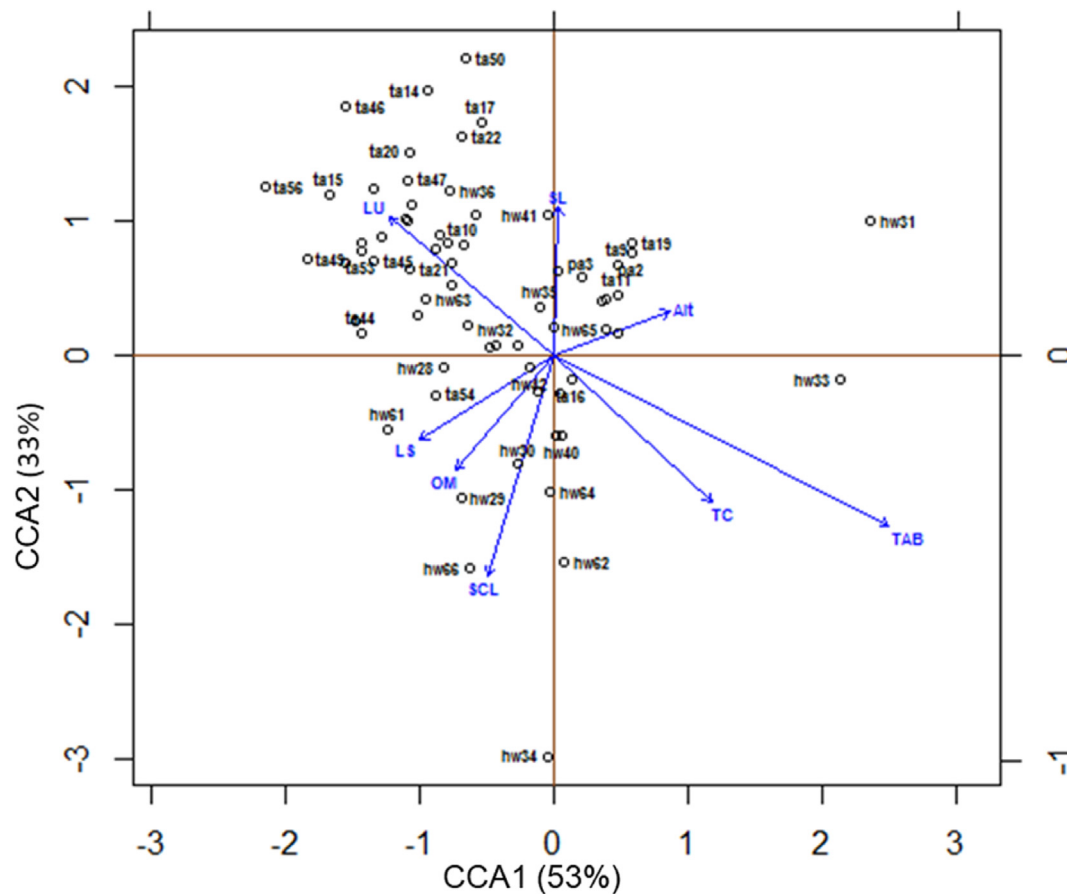
Disturbance category	Clay (%)	Silt (%)	Sand (%)	Porosity (%)	Dominant texture
PA	16.0 $\pm$ 1.88a	6.00 $\pm$ 1.549a	78 $\pm$ 1.880a	52 $\pm$ 2.192a	Sandy loam
HW	17.17 $\pm$ 2.056a	8.67 $\pm$ 2.044a	74.17 $\pm$ 2.796a	54 $\pm$ 3.997a	Sandy loam
TA1-5*	16.17 $\pm$ 3.005a	9.67 $\pm$ 1.202a	74.17 $\pm$ 3.664a	49 $\pm$ 2.291a	Sandy loam
TA6-10*	16.33 $\pm$ 2.231a	9.67 $\pm$ 1.67a	74 $\pm$ 2.380a	49 $\pm$ 1.975a	Sandy loam
TA11+*	15.67 $\pm$ 1.476a	9.33 $\pm$ 2.667a	75 $\pm$ 2.828a	50 $\pm$ 0.932a	Sandy loam
P-value	0.984	0.552	0.825	0.413	

\* = Number of years under cultivation, P-value = Probability value.

regimes ( $p > 0.05$ ). However, the actual figures were lowest in PA, and highest in TA6-10. K was also not significantly different across the disturbance levels ( $p > 0.05$ ). The bulk density showed significant difference across the disturbance categories ( $p < 0.05$ ). The dominant soil texture in PA, TA and HW was Sandy loam. The soil porosity in all the land uses and disturbance categories was 'very high' (Table 5) ranging from 48% to 54%.

The Canonical Correspondence Analysis (Figure 7), established a relationship on influence of environmental factors on regeneration repartition

in the land uses. The constrained variables in the CCA explained 14% of the total variation. The tree abundance had positive (82%) correlation with first axis while Sandy clay loam negatively correlated with the second axis at 54% (Table S1). Land use intensification reduced tree cover. Where tree cover was high, regeneration density decreased and increase in tree abundance also increased regeneration density. Most HW was characterised by Sandy loam, Loamy Sand and Sandy clay loam textural classes and high OM. Conspicuously, the PA had the lowest regeneration occurrence with high OM, SOC and tree cover conditions.



**Figure 7.** The Canonical Correspondence Analysis (CCA) showing the occurrence of regeneration. TC = tree cover, TAB = tree abundance, LU = landuses, SL = Sandy loam, LS = Loamy sand, SCL = Sandy clay loam, Alt = Altitude, OM = organic matter, pa = protected area, ta = agriculture land, hw = harvested woodlands.

## 4. Discussion

### 4.1. Tree structure and diversity dynamics in the land uses

The tree structure in the PA, TA and HW shows how different management affects diameter SCD. The PA could be said to be an ageing population while HW and TA having stable populations (Geldenhuis 2010; Nyirenda et al., 2019). The TA and HW distributions show that people use trees at different stages in different land uses. This could suggest that people cut bigger trees in the HW and young ones are left to grow while in the TA, bigger trees especially soil fertility improvement ones are left in the field. For TA, this observation was mainly made in TA11+. The TA sites and HW sites showed typical inverse J-shapes in the study area. This shows that as a landscape, the study area had good stand for tree structure. However, there is cause for worry as there are fewer big trees in most HW areas. In all the HW categories, no tree above 36 cm DBH was recorded suggesting mass removal of such sizes in the HW. This was most common for *C. apiculatum*, *P. petersiana*, and *D. condylocarpon*. High demand for big sized trees for various uses can be assumed. The rarity of big trees could be due to charcoal making and other household uses. Lowole et al. (1995) noted that the community members using poles from Chimaliro Forest Reserve, northern Malawi, targeted trees of DBH greater than 5 cm. In Tete, Mozambique, Sedano et al. (2016) reported a demand of trees  $\geq 15$  cm for charcoal production.

The trend for regeneration density in TA, HW and PA area indicates the effects of disturbance on regeneration status. When trees are cleared, there is high sprouting of stumps (Luoga et al., 2004) and that some previously dormant seeds also take advantage of the reduced competition to germinate (Peter 2005). This could explain more seedlings in TA1-5 sites though, continuous seasonal cultivation cause removal of these 'bushy' seedlings to pave way for crop production. The HW11 + experienced higher tree

removal which may have also influenced higher seedling frequency in the category. The findings of this study are in tandem with studies conducted in the Miombo woodlands in Zambia, Zimbabwe and Tanzania and other countries (Luoga et al., 2004; Neke et al., 2006; Tambara et al., 2012; Neelo et al., 2015). In Dedza District (neighbouring Salima), a study by Missanjo et al. (2014), found more regenerations in coppicing treatments than in control (non-disturbed area). In Tanzania, more regeneration was recorded in disturbed land than in protected Forest Reserve (Luoga et al., 2004; Neke et al., 2006). All harvested trees sprouted and commonly harvested trees had average DBH of 4 cm and with more shoots.

The condition in TA and HW could be said not limiting to regeneration while the PA conditions could be limiting regenerations. Taking advantage of this trend in TA, HW and PA can help strategise on general tree biodiversity management in both natural and agroecosystems. It can be argued that if well managed, the regeneration may substitute the tree planting programmes the district and country conduct whose uptake and impacts have been unclear (Meijer 2014). Tree planting in some parts of the country has been viewed as expensive and not a priority by most rural Malawian farmers (Meijer et al., 2015).

### 4.2. Soil characteristics and land uses

Soil OM is important to moderate temperature, pH, aeration, and moisture (Prasad and Power 1997; Brady and Weil 1999). The trend indicated that the higher the intensity of disturbance, the lower the %OM and %SOC. The high %OM in PA and HW could be attributed to more vegetation that allows the accumulation of OM from falling leaves and dead woods. In natural forests/woodlands where human disturbance is limited, there is high biological activities on soil surface and within that encourage litter accumulation and breakdown resulting in high %OM



and %SOC (FAO 2005). The decreasing %OM and %SOC in TA could be related to management practices. Usually land under crop system of conventional practices has low %OM compared to virgin forest/woodland soils (Prasad and Power 1997). It could also be related to microclimate particularly, higher temperature. William (1998) noted that increased soil surface temperature reduces moisture, possibly moisture in litter too. In forests, vegetation cover improves microclimate which enables decomposing microbes to act on detritus matter resulting into higher OM production than in traditional agriculture land. This also has a corresponding effect the release of N because of increased mineralization (Jansen 1996; Matus et al., 2008). The higher %OM and associated %SOC in TA1-5 was unexpected. This could, however, be attributed to its limited years of cultivation and deep litter thereby still having more %OM and %SOC. Coincidentally, many plots in this category had deep black soil colour indicating more organic matter in the soil (Brady and Weil 1999).

Like K and P, N is an important element for crop production (Prasad and Power 1997, Uchido, 2000). Despite lack of significant differences, N reduced with increased years of cultivation in the TA sites. Interestingly, there was an increase in the TA11 + although there was no significant difference. The increase of %N in TA11 + could be attributed to the dynamics of land preparation and type of tree species and general land management. Some farmers leave fertility-improving tree species to flourish. After attaining large size, these species could have soil ameliorating properties through leaf fall thus increasing N in the TA11 + sites in subsequent years. Some large tree species selectively left in the TA11 + farm fields included *Philenoptera violacea* and *Faidherbia albida*. These are commonly known N fixing species for fertility improvement and farmers traditionally manage these species (Ajayi et al., 2008). This could also explain why most of the soil-improving tree species were in the traditional agricultural (TA) fields than in the PA and HW land use types. Zheng et al. (2017) found that N was influenced by type of tree species in the 0–10 cm soil depth in Huoditang, China. Furthermore, some leguminous crops grown such as groundnut and cowpea could also be responsible for the increase in N. In some fields, biomass from these legumes was left to decompose rather than burning. The annual application of inorganic fertilizer may not be the reliable and sustainable means to manage and increase N in the agricultural land as they are expensive for most smallholder farmers. Some major sources of N are when OM in the soil mineralises to form nitrate and/or ammonia, and fixation by N-fixing bacteria (Galloway et al., 2004).

Potassium was not different statistically in all the disturbance categories and was low in TA1-5 and very low in the rest. The actual higher values in TA1-5 could be due to less years of cultivation which had limited effect on the element. However, the lower values in HW where burning take place may have other reasons. Usually burning takes place around June through September. These burning events accumulate ash/potash (Pachon et al., 2013). The burning activities are done as part of land preparation where crop residues and other plant materials are burnt before making crop ridges. Not all farmers burn the crop residues; however, others still include burning as a land preparation practice.

The amount of P was very variable in both TA and HW. Some farmers in the study area apply inorganic fertilizer (NPK) to aid land productivity for higher yields. The higher (14.86–19.48 ug/g) actual values for P in TA could be because of annual applications of NPK fertilizer and some leguminous crops. Management practices and plant species in the area could affect P amounts by conserving and/or increasing accumulation respectively (Ngwira et al., 2012). Some leguminous crops increase P availability in soil (Li et al., 2007). Moreover, P is immobilized quickly after application and moves very slowly making plants to use only a little (10–30%) in first year of application; the rest is used in the successive years. Plants/crops absorb higher quantities of K and N compared to those of P (Ludwick 1998). Depending on pH, P can undergo fixation by aluminium, iron or calcium making it less mobile and accumulate with

years (Prasad and Power 1997; Ludwick 1998). Therefore, there is need to ensure soil erosion is minimised so that top soil is not removed together with phosphates in the agricultural fields. In general, P was adequate in TA6-10, low in all disturbance regimes. and very low in PA, because it was less than 8 ug/g (DARS nd.).

Bulk density (BD) was considered not very high in the study area compared to other studies (Njoloma et al., 2016) in Malawi. At least in the top soil, it could be said that soils are not at compaction level and may not restrict root development as bulk density is less than 1.6 g/cm<sup>3</sup> (McKenzie et al., 2004). However, PA and HW had lower BD compared to the TA categories. Higher OM and OC was responsible for lower BD in PA and HW. These findings are similar to those in other studies where an increase in BD was associated with lower OM and OC (Arnalds et al. 2000, 2013; Chaudhari et al., 2013; Petursdottir et al., 2013; Arnalds 2015). The farming activities might have contributed to exposure of OM to some erosive forces, use by crop and burning during land preparation. The conventional tillage system currently practiced by many farmers in the area might not be conducive for OM and OC management. Lower BD and higher OM and OC is an important condition for plant growth and development (FAO 2005). A desirable tree-crop mix would help achieve this as it has been shown that type of trees can influence BD (Zheng et al., 2017). This would in turn increase soil carbon (Asase and Tetteh 2016). The HW were dominated by deep black soils except in some sites which had stony shallow soils and scattered litter.

Soil porosity was in the category of 'very high' across all the disturbance categories. According to the FAO (2006), porosity is classified as < 2% (very low), 2–5% (low), 5–10% medium, 15–40% (high) > 40% (very high). Porosity is an important feature, considered essential in soils for balanced aeration, water movement and is enhanced especially, if soils experience effects of burrowing animals like termites (FAO 2006). It is influenced by leaching, translocation, cracking, animal burrowing, rooting effects, and soil particles arrangement. The dominant soil texture classes in the study area were Sandy loam (most dominant), Loamy sand and to a lesser extent, Sandy clay loam. These textural classes are usually well drained soils and have more pore spaces (FAO 2006). These findings concur with those of Chaudhari et al. (2013) whose assessments revealed BD of 1.25–1.45 g/cm<sup>3</sup> with porosity of 40–49% in Sandy loam and Loamy sand texture classes.

With N, P, K amounts ranging from very low to moderate, there is need to improve sustainable land management interventions especially those that increase OM input into the soil such as agroforestry and manure (Makumba et al., 2006; Ajayi et al., 2008; Ahmad et al., 2016). The use of plant material high in C:N ratio and lignin like cereals and grass types, promotes immobilisation of nutrients, OM accumulation, formation of humus, development and improvement of soil structure in the long-term unlike the use of material with low C:N ratio which decomposes quickly and becomes useful for only one growing season (FAO 2005). The findings in this study agree with other findings from other countries. Soil condition in forests, grassland, agriculture land and bare land in Ethiopia showed higher SOC and OM in less disturbed area (forests) and lower in the highly-disturbed land use of agriculture and bare land in that order. The same trend was applicable for N levels. The BD was highest in agricultural land and lowest in forest land. However, more P was found in forest than in agricultural land, which is contrary to the findings from the present study. In Malawi, Njoloma et al. (2016) found that soil fertility in agricultural fields was poor dominated by acidic (4.5–5.5) conditions, low SOC, OM and N, high BD (1.24–1.61). Their findings also established %OM of less than 2% which was similar to that of the present study in agricultural land, although actual values in the present study are higher. This study found that BD was lower and, pH within plant requirements (6.4–6.5). Many crops thrive well under pH 5.8–7.5 levels (Brady and Weil 1996) and soil health could be considered low if pH is ≤5.5 (Karlen et al. 2003, Munthali 2007). This suggests that the soils in Salima study area were moderately better than in the other study areas.

## 5. Conclusion

Tree species composition varies with land use and disturbance levels. Higher species density and diversity are observed in harvested woodland. A Canonical Correspondence Analysis show that regeneration in the land uses was influenced by environmental factors. Soil fertility decreases with increasing years of cultivation in agriculture land. The accumulation of litter in the protected area and harvested woodland might have influenced improved soil conditions in these land uses. Notably, OM and OC were below the threshold of 1.5% and 0.88% respectively in agriculture land. Nitrogen, phosphorus and potassium were low in TA11+ and TA6-10, and medium in the rest of the disturbance categories. The soil pH in the study area was within favourable condition for most crops. In terms of physical properties, top soil was not at compacted level as bulk density was less than 1.6 g/cm<sup>3</sup> and might, therefore, not restrict root development. Intensification of agroforestry may help improve fertility in the agricultural land. For sustainability, there is need for site-specific management options to achieve tree management of various sizes.

## Declarations

### Author contribution statement

Harrington Nyirenda: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

### Funding statement

Mr Harrington Nyirenda was supported by Borlaug Higher Education for Agricultural Research and Development [BSF-G-11-00002].

### Data availability statement

Data will be made available on request.

### Declaration of interest's statement

The authors declare no conflict of interest.

### Additional information

Supplementary content related to this article has been published online at <https://doi.org/10.1016/j.heliyon.2022.e10664>.

## Acknowledgements

The author appreciates the roles of the Agricultural Extension Development Officer (Mr. Connellus Katsache) and Forestry Extension Officer (Mr. Elias Ben) of Makande Extension Planning Area for the assistance rendered during data collection in the field.

The author appreciates the financial assistance from Borlaug Higher Education for Agricultural Research and Development. The support was part of the feed the future initiative, under the CGIAR Fund, award number BSF-G-11-00002, and the predecessor fund the Food Security and Crisis Mitigation II grant, award number EEM-G-00-04-00013.

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