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RELATIONSHIPS BETWEEN TREE SPECIES DIVERSITY WITH SOIL CHEMICAL PROPERTIES IN SEMI-DRY MIOMBO WOODLAND ECOSYSTEMS

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ABSTRACT

In Miombo woodland ecosystems, soil nutrients play an important role in the formation of plant communities. This study hypothesized that soil nutrients have an influence on tree species richness and diversity in Miombo woodland ecosystems. Important Value Index (IVI) and Shannon Wiener diversity index (H′) were used to indicate tree species dominance and diversity respectively. Soil properties were determined using laboratory standard methods. Pearson correlation analyses were performed in R software. *Pterocarpus tinctorius*, *Pterocarpus angolensis*, *Brachystegia spiciformis* and *Julbernardia globiflora* were the dominant tree species in terms of IVI. We recorded 123 tree species with H′ value of 4.23. Tree species richness was significantly ($p < 0.05$) direct correlated with total N, available P, Mg, Na and cation exchange capacity (CEC); and inversely correlated with Ca. Tree species diversity was significantly ($p < 0.05$) direct correlated with K, Na and total exchangeable bases (TEB); and inversely correlated with CEC. Kitulang'halo semi-dry Miombo woodland ecosystem is a typical miombo woodland and it is rich in tree species diversity. Its soil nutrients are also intact, suggesting that the woodland is not so much subjected to disturbances due to the current effective management measures imposed. Therefore, further studies in other ecosystems are recommended.

Key words: Dominance, soil nutrient factors, tree species richness, importance value index.

INTRODUCTION

Miombo woodland ecosystems are known for having the highest tree species diversity on the planet and essential for the survival of several living organisms that thrive there in (Ribeiro *et al.* 2013, Nadeau and Sullivan 2015). They supply a number of ecosystem goods and services such as timber and non-timber forest products like food and fuel (Trumbore *et al.* 2015). They harbor biodiversity, maintain carbon stocks (thereby regulating climate), control soil erosion, provide shade, modify hydrological cycles and maintain soil fertility, all of which are essential ecosystem services (Jew *et al.* 2016) for the livelihood of local communities. Apart from their significant importance, tropical forests are disappearing globally at a rate of 6 million ha per year (Keenan *et al.* 2015). Their diversity across plant communities have been significantly affected by both natural processes and ongoing human activities such as charcoal exploitation, illegal timber harvesting and need for more agricultural land (Madoffe *et al.* 2012, Lupala *et al.* 2014).

However, in tropical forest ecosystems soil nutrients play an important role in the formation of plant communities, their species and structural diversity (Perroni-Ventura *et al.* 2006). They are also considered as one of the main factors limiting tropical forest primary productivity and other biological processes such as plant root allocation, growth, and litter production (Wright *et al.* 2011, Zhang *et al*. 2015). The presence and abundance of dominant species in a tropical forest are also determined by soil quality (Jakovac *et al.* 2016). According to several studies on tropical vegetation, plant species richness is positively related to soil fertility (Poulsen *et al.* 2006, Dybzinski *et al.* 2008, Neri *et al.* 2012). Janssens *et al.* 1998 found a positive relationship between plant species diversity and the concentration of extractable phosphorus (P) and potassium (K) in the soil. Kumar *et al* (2010) found a strong positive correlation between tree species richness and the concentrations of nitrogen (N), phosphorus (P), and carbon (C) in a dry deciduous forest of western India. Others have reported that tree community structure can be limited by lack of soil nutrients (Zhang *et al.* 2015, Nagy *et al.* 2016, Cárate-Tandalla *et al*. 2018).

Moreover, some studies have reported controversial results (Enright *et al.* 1994, Nadeau and Sullivan 2015), which therefore render the performance of in-depth studies necessary, especially on tropical landscapes. In this context, there is still a large knowledge gap regarding the relationship between attributes of plant communities and soil characteristics (Assis *et al.* 2011). Huston (1979) predicted that as nutrient availability increases, species richness should decrease because a few competitive species should exclude other species. Indeed, Huston (1980) reported that greatest species richness was found on sites with lowest nutrient values in Costa Rica. Other studies in contrast, report that tree species diversity does not vary (Clinebell *et al.* 1995, Tuomisto *et al.* 2002) or even increases with increasing soil fertility (Duivenvoorden 1996, Poulsen *et al.* 2006). Given these contrasting results, there is obviously still much to learn about how soil nutrients affect tree species diversity in the tropics. Therefore, the objectives of this study were to (i) determine tree species dominance (ii) evaluate tree species diversity and (iii) determine the relationship between tree species diversity and soil nutrient factors in semi-dry Miombo woodland ecosystems in south-eastern Tanzania.

MATERIALS AND METHODS

This study was conducted in Mikese division, in Morogoro District, Tanzania (Figure 1). Kitulang'halo semi-dry miombo woodland ecosystem is situated at 37°57' to 38°01′E and 06°39' to 06°43′S. The elevation varies from 800 meters above sea level to 1,500 meters above sea level. The area is within the 700 mm to 1,000 mm rainfall belt with wet season from October to May and dry season from June to September. The mean annual temperature is 24.3°C while the annual minimum and maximum temperature are 18°C and 30°C, respectively. Vegetation is characterized by semi-dry Miombo woodland and the predominant genera are *Brachystegia* and *Julbernardia*, reaching a height of 15-20 m, while most of other trees are in under-storey at 5-10 m height including *Diplorhynchus condylocarpon* and tree species in the genus *Combretum*. Kitulang'halo soils are shallow due to hard pan, mostly sandy loam and classified as Cambisol, Phaeozem and Lixisol according to FAO-UNESCO classification (Msanya *et al.* 1995). The ecosystem is distributed under four different management regimes namely; (a) 1200 ha by central government under Tanzania Forest Services (TFS) Agency, 500 ha by Sokoine University of Agriculture (SUA) under the college of Forestry, Wildlife and Tourism, Ngerengere forest under the Tanzania People's Defence Force (TPDF) and general land managed by village governments.

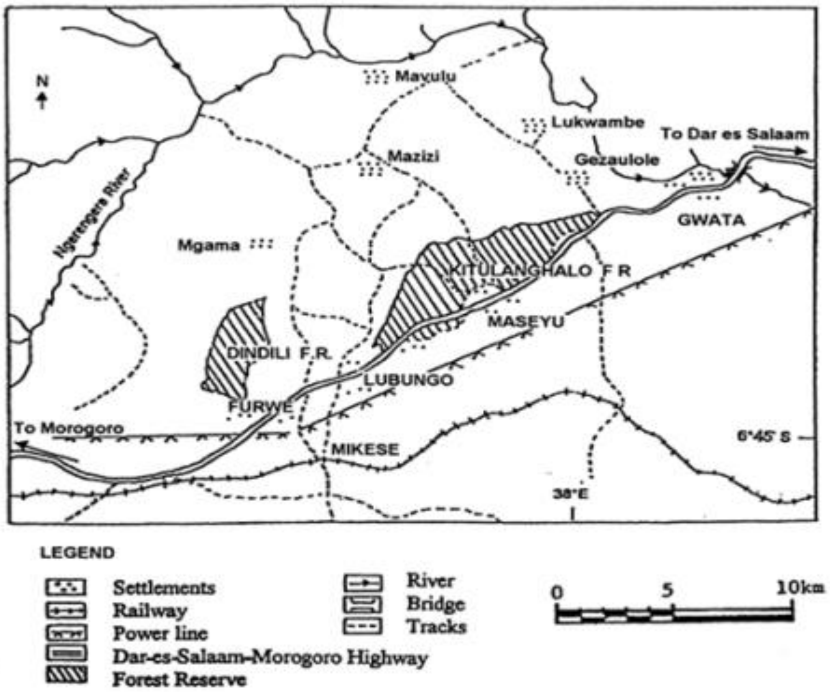


Figure 1. A map of Mikese division, showing the villages containing the Kitulang'halo Miombo woodlands ecosystem (*Source*: Luoga, 2000).

The National Forest Resource Monitoring and Assessment (NAFORMA) exercise conducted between 2009 and 2013 established a number of sampling clusters in Morogoro district, which are characterized by Miombo woodlands. During this study, four NAFORMA clusters found in the study area were used, and six clusters were added in order to improve the reliability of the estimates. Figure 2 shows the old NAFORMA clusters (yellow in colour) and new clusters (black in colour) in the Kitulang'halo Miombo woodlands ecosystem. Each cluster comprised of 10 circular plots of 15 m radius spaced at an interval of 250 m (Figure 3 left). Five plots were located in a south to north transect while the other five plots were located west to east. In this study only three plots in each cluster (plots 4, 7 and 10) were chosen systematically for data collection, making a total of 30 plots. In each plot, three sub-plots were demarcated at an interval 5 m from the plot centre (Figure 3 right) and slope correction was considered during plot layout.

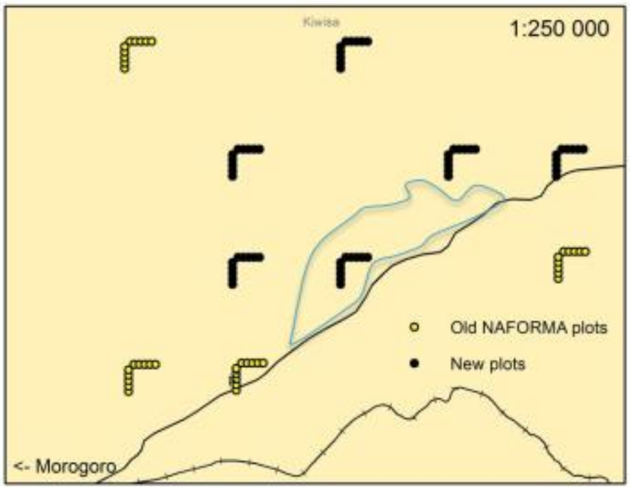


Figure 2: Distribution of ten clusters in the Kitulang'halo Miombo woodland ecosystem.

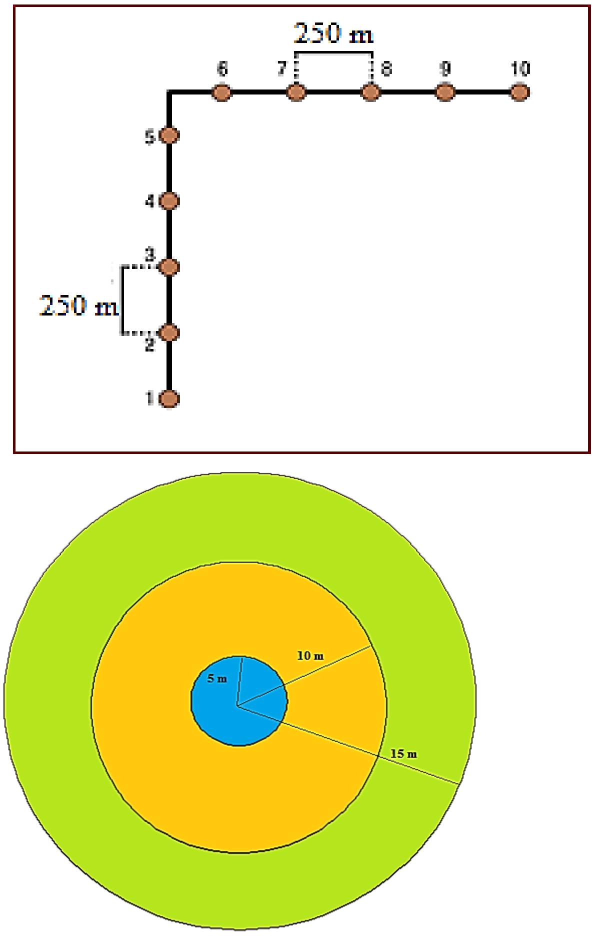


Figure 3: Cluster and plot design in the Kitulang'halo Miombo woodland ecosystem.

A hand-held GPS (Map76cx) was used to record geographical location and altitude for each plot. In each sampling plot we used the NAFORMA protocol, in which four points located systematically at the main cardinal points of the compass (north, south, east and west) were identified. A soil mini-pit was excavated at each point to 20 cm depth with at least one vertical surface that was used for volumetric soil sampling. The collected soil samples were placed into a clearly labelled paper bag to create a composite sample. The total weight of the soil sample was measured using a digital weighing scale to the nearest gram. In each sub-plot, all plant species with diameter at breast height (DBH) ≥ 5 cm were measured, counted and identified by their botanical names. If plants could not be identified in the field, voucher specimens were collected then identified in the Tanzania National Herbarium. We used the measurement criteria shown in Table 1.

Table 1: DBH measurements within a sample plot

Plot radius (m)	Tree DBH (cm)
5	$5 \geq DBH \leq 10$
10	$10 > DBH \leq 20$
15	$DBH > 20$

Tree species diversity measurements were calculated using the following formula: Importance value index (IVI) = Relative density + Relative frequency + Relative dominance.

$$Relative\ density = \frac{Density\ of\ a\ species}{Total\ density\ of\ all\ species} * 100$$

$$Relative\ frequency = \frac{Frequency\ of\ a\ species}{Total\ frequency\ of\ all\ species} * 100$$

$$Relative\ dominance = \frac{Dominance\ of\ a\ species}{Total\ dominance\ of\ all\ species} * 100$$

$$Density = \frac{Number\ of\ a\ species}{Total\ area\ sampled}$$

$$Frequency = \frac{Area\ of\ plots\ in\ which\ species\ occurs}{Total\ area\ sampled}$$

$$Dominance = \frac{Total\ basal\ area\ of\ species}{Total\ area\ sampled}$$

Tree species richness was estimated as the number of tree species found in the 0.071 ha plot (Figure 3 right, i.e., 15 m radius = 15*15*3.14/10,000 = 0.071 ha) for the 30 sampled plots. The H' was computed as

$$H' = -\sum_{i=1}^{s} (pi)(\ln pi)$$

Where:

H' = the Shannon-Wiener diversity index

$pi = ni/N$ (ni = the number of individuals in a single species i,

N = the total number of individuals in the community for all species)

A larger value of H' indicates greater species diversity and vice versa. The index considers both species richness (number of different species present in a community) and species evenness or dominance (Kent 2012).

Air-dried soil samples were ground and passed through a 2 mm sieve (Sparks et al. 2020) to remove roots, stones and gravels. Soil organic carbon (SOC), total N, available P, soil pH, cation exchange capacity (CEC) and total exchangeable bases (TEB) (calcium ion (Ca^{2+}), magnesium ion (Mg^{2+}), potassium ion (K^+) and sodium ion (Na^+)) were analyzed. SOC was determined by the Walkley-Black dichromate wet oxidation method, Total N content was determined using Micro-Kjeldahl method while Available P was determined using Bray P-1 method. Ca^{2+} and Mg^{2+} were determined by Atomic Absorption Spectrophotometer (AAS) while Na^+ and K^+ were determined by Flame Emission Spectrophotometer (FES). After extraction of exchangeable bases, the residual soil was washed with ethanol and then the remaining ammonium ions (NH_4^+) were extracted with 10% Sodium chloride (NaCl) for determination of CEC by titration (Sparks et al. 2020). Soil pH based on water was measured using Beckman's glass electrode pH meter after 10 g of the soil sample was suspended in 25 mL distilled water (1:2.5 ratio of soil to water). Pearson correlation analyses between paired samples in R-software version 3.5.1 (R Development Core Team 2017) were used to identify the relationships between tree species richness and diversity with soil nutrient factors (SOC, TN, CEC, K^+, Na^+, Ca^{2+}, Mg^{2+}, P, TEB) and soil pH at $P \leq 0.05$.

RESULTS

Tree species dominance

The most dominant tree species are presented in Table 2. The results indicate that these species are the most important tree species in Kitulang'halo semi-dry Miombo woodland ecosystem. The top eight (8) tree species accounted for about 25% of the overall IVI (Table 1) while the rest 115 tree species contributed about 75% of the total dominance.

Table 2: Tree species dominance in terms of IVI at Kitulang'halo Miombo woodlands ecosystem.

Species name	IVI
Pterocarpus tinctorius	3.410
Pterocarpus angolensis	3.347
Senegalia nigrescens	3.217
Catunaregam spinosa	3.124
Brachystegia spiciformis	3.115
Flueggea virosa	3.093
Dalbergia boehmii	3.013
Julbernardia globiflora	2.762

Note: The values for IVI are out of 123 tree species.

Tree species diversity

Kitulang'halo Miombo woodlands ecosystem has 123 tree species and Shannon-Wiener diversity index of 4.23 (Table 3). This is regarded as high species diversity because the index value is greater than 2 (Giliba et al. 2011).

Table 3: Number of tree species (species richness) and tree species diversity (computed by Shannon-Wiener diversity index) for Kitulang'halo Miombo woodland ecosystem.

No. of species	Species botanical name	Abundance (ni)	Pi	LnPi	Pi*LnPi
1	*Afzelia quanzensis*	2	0.002	-6.371	0.011
2	*Albizia anthelmintica*	17	0.015	-4.231	0.062
3	*Albizia chinensis*	1	0.001	-7.064	0.006
4	*Albizia harveyi*	18	0.015	-4.174	0.064
5	*Albizia petersiana*	9	0.008	-4.867	0.037
6	*Albizia versicolor*	1	0.001	-7.064	0.006
7	*Beilschmiedia kweo*	8	0.007	-4.984	0.034
8	*Berchemia discolor*	1	0.001	-7.064	0.006
9	*Bombax rhodognaphalon*	1	0.001	-7.064	0.006
10	*Boscia salicifolia*	2	0.002	-6.371	0.011
11	*Brachystegia boehmii*	36	0.031	-3.480	0.107

No. of species	Species botanical name	Abundance (ni)	Pi	LnPi	Pi*LnPi
12	*Brachystegia microphylla*	6	0.005	-5.272	0.027
13	*Brachystegia spiciformis*	20	0.017	-4.068	0.070
14	*Bridelia cathartica*	3	0.003	-5.965	0.015
15	*Carpodiptera africana*	4	0.003	-5.678	0.019
16	*Casaeria battiscombei*	15	0.013	-4.356	0.056
17	*Cassia abbreviata*	1	0.001	-7.064	0.006
18	*Cassia fistula*	1	0.001	-7.064	0.006
19	*Catunaregam spinosa*	23	0.020	-3.928	0.077
20	*Combretum binderanum*	10	0.009	-4.761	0.041
21	*Combretum collinum*	20	0.017	-4.068	0.070
22	*Combretum fragrans*	6	0.005	-5.272	0.027
23	*Combretum gueinzii*	1	0.001	-7.064	0.006
24	*Combretum molle*	68	0.058	-2.844	0.165
25	*Combretum schumannii*	12	0.010	-4.579	0.047
26	*Combretum zeyheri*	17	0.015	-4.231	0.062
27	*Commiphora africana*	36	0.031	-3.480	0.107
28	*Crossopteryx febrifuga*	1	0.001	-7.064	0.006
29	*Croton scheffleri*	13	0.011	-4.499	0.050
30	*Crotton sylvaticus*	13	0.011	-4.499	0.050
31	*Cussonia arborea*	6	0.005	-5.272	0.027
32	*Cussonia spicata*	5	0.004	-5.454	0.023
33	*Cussonia zimmermannii*	5	0.004	-5.454	0.023
34	*Dalbergia boehmii*	24	0.004	-5.454	0.023
35	*Dalbergia melanoxylon*	5	0.021	-3.886	0.080
36	*Dalbergia nitidula*	2	0.002	-6.371	0.011
37	*Dalbergia obovata*	9	0.008	-4.867	0.037
38	*Deinbolia borbonica*	1	0.001	-7.064	0.006
39	*Dibera laranthfolia*	1	0.001	-7.064	0.006
40	*Dichrostachys cinerea*	30	0.026	-3.663	0.094
41	*Diplorhynchus condylocarpon*	52	0.044	-3.113	0.138
42	*Diospyros fischeri*	5	0.004	-5.454	0.023
43	*Diospyros sp.*	1	0.001	-7.064	0.006
44	*Diospyros consolatae*	1	0.001	-7.064	0.006
45	*Dombeya cincinata*	1	0.001	-7.064	0.006
46	*Dombeya rotundifolia*	28	0.024	-3.732	0.089
47	*Dracaena deremensis*	6	0.005	-5.272	0.027
48	*Drypetes gerrardii*	2	0.002	-6.371	0.011
49	*Drypetes reticulata*	2	0.002	-6.371	0.011
50	*Ehretia amoena*	1	0.001	-7.064	0.006
51	*Erythrococca kirkii*	2	0.002	-6.371	0.011
52	*Erythroxylum emarginatum*	1	0.001	-7.064	0.006
53	*Erythroxylum sp.*	2	0.002	-6.371	0.011
54	*Euphorbia nyikae*	7	0.006	-5.118	0.031
55	*Flueggea virosa*	25	0.021	-3.845	0.082

No. of species	Species botanical name	Abundance (ni)	Pi	LnPi	Pi*LnPi
56	*Gardenia ternifolia*	1	0.001	-7.064	0.006
57	*Grewia bicolor*	10	0.009	-4.761	0.041
58	*Grewia ectasicarpa*	2	0.002	-6.371	0.011
59	*Grewia goetziana*	15	0.013	-4.356	0.056
60	*Grewia similis*	3	0.003	-5.965	0.015
61	*Grewia sp.*	25	0.021	-3.845	0.082
62	*Haplocoelum inoploeum*	1	0.001	-7.064	0.006
63	*Holarrhena pubescens*	2	0.002	-6.371	0.011
64	*Julbernardia globiflora*	60	0.051	-2.970	0.152
65	*Kigelia africana*	2	0.002	-6.371	0.011
66	*Lannea schimperi*	4	0.003	-5.678	0.019
67	*Lannea schweinfurthii*	7	0.006	-5.118	0.031
68	*Lannea sp.*	5	0.004	-5.454	0.023
69	*Lecaniodiscus fraxinifolius*	1	0.001	-7.064	0.006
70	*Lonchocarpus bussei*	6	0.005	-5.272	0.027
71	*Lonchocarpus capassa*	2	0.002	-6.371	0.011
72	*Manihot asculenta*	2	0.002	-6.371	0.011
73	*Manilkara sulcata*	3	0.003	-5.965	0.015
74	*Markhamia obtusifolia*	7	0.006	-5.118	0.031
75	*Markhamia sp.*	7	0.006	-5.118	0.031
76	*Markhamia zanzibarica*	4	0.003	-5.678	0.019
77	*Millettia usaramensis*	24	0.021	-3.886	0.080
78	*Ochna schweinfurthiana*	2	0.002	-6.371	0.011
79	*Ozoroa insignis*	1	0.001	-7.064	0.006
80	*Philippia pallidiflora*	26	0.022	-3.806	0.085
81	*Pseudolachnostylis maprouneifolia*	21	0.018	-4.019	0.072
82	*Pteleopsis myrtifolia*	20	0.017	-4.068	0.070
83	*Pterocarpus angolensis*	10	0.009	-4.761	0.041
84	*Pterocarpus rotundifolius*	8	0.007	-4.984	0.034
85	*Pterocarpus tinctorius*	17	0.015	-4.231	0.062
86	*Rhus sp.*	11	0.009	-4.666	0.044
87	*Ritchiea albersii*	1	0.001	-7.064	0.006
88	*Scorodophleus fischeri*	39	0.033	-3.400	0.113
89	*Sclerocarya birrea*	13	0.011	-4.499	0.050
90	*Senegal mellifera*	14	0.012	-4.425	0.053
91	*Senegalia nigrescens*	35	0.030	-3.509	0.105
92	*Senegal pennata*	12	0.010	-4.579	0.047
93	*Senegal polyacantha*	3	0.003	-5.965	0.015
94	*Senna siamea*	4	0.003	-5.678	0.019
95	*Senna sp.*	1	0.001	-7.064	0.006
96	*Sorindeia obtusifolia*	5	0.004	-5.454	0.023
97	*Spirostachys africana*	6	0.005	-5.272	0.027
98	*Sterculia quinqueloba*	1	0.001	-7.064	0.006
99	*Sterculia africana*	9	0.008	-4.867	0.037

No. of species	Species botanical name	Abundance (ni)	Pi	LnPi	Pi*LnPi
100	*Sterculia appendiculata*	5	0.004	-5.454	0.023
101	*Sterculia stenocarpa*	2	0.002	-6.371	0.011
102	*Strychnos innocua*	1	0.001	-7.064	0.006
103	*Syzygium guineense*	1	0.001	-7.064	0.006
104	*Tamarindus indica*	4	0.003	-5.678	0.019
105	*Teclea simplicifolia*	4	0.003	-5.678	0.019
106	*Terminalia grandifolia*	2	0.002	-6.371	0.011
107	*Terminalia mollis*	3	0.003	-5.965	0.015
108	*Terminalia sambesiaca*	3	0.003	-5.965	0.015
109	*Turraea stuhlmanii*	1	0.001	-7.064	0.006
110	*Vachellia gummifera*	1	0.001	-7.064	0.006
111	*Vachellia hockii*	2	0.002	-6.371	0.011
112	*Vachellia nilotica*	12	0.010	-4.579	0.047
113	*Vachellia pentagon*	9	0.008	-4.867	0.037
114	*Vachellia robusta*	15	0.013	-4.356	0.056
115	*Vachellia sieberiana*	2	0.002	-6.371	0.011
116	*Vachellia sp.*	12	0.010	-4.579	0.047
117	*Vachellia tortilis*	6	0.005	-5.272	0.027
118	*Vangueria infausta*	2	0.002	-6.371	0.011
119	*Vangueria sp.*	8	0.007	-4.984	0.034
120	*Vernonia subuligera*	4	0.003	-5.678	0.019
121	*Xeroderris stuhlmannii*	17	0.015	-4.231	0.062
122	*Ximenia caffra*	1	0.001	-7.064	0.006
123	*Zanthoxylum chalybeum*	10	0.009	-4.761	0.041
	Total	**1169**	**1.000**		**4.230**

Relationships between tree species diversity with soil nutrient factors

Pearson correlation analyses indicated that tree species richness was positively related to TN, available P, Mg^{2+}, Na^{+} and CEC (Figure 4 (a), (b), (c), (e) and (f)). These relationships were found to be significant at ($p \leq 0.05$) (Table 4) meaning that the number of tree species increases as the concentration level of N, P, Mg^{2+}, Na^{+} and CEC in the soil increases. Tree species richness was inversely related to Ca^{2+} concentration in the soil (Figure 4 (d)). This relationship was found to be significant (P = 0.059, r = - 0.31) (Table 4) meaning that tree species richness tends to decrease as Ca^{2+} increases. Tree species diversity was positively related to Na^{+}, K^{+} and TEB (Figure 5 (a), (b) and (d)). These relationships were found to be significant at ($p \leq 0.05$) (Table 5) meaning that tree species diversity tends to

Table 4: Pearson correlation coefficients (r) with significance levels (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$) between tree species richness and soil nutrient factors (N = 30).

Statistical parameters tested	*P*-values	Significance codes
SOC*RICH	0.202	NS
TN*RICH	**0.001**	**
C/N*RICH	0.127	NS
Avail. P*RICH	**0.032**	*
CEC*RICH	**0.003**	**
Ca^{2+}*RICH	**0.054**	*
Mg^{2+}*RICH	**0.047**	*
K^{+}*RICH	0.103	NS
Na^{+}*RICH	**0.013**	*
TEB*RICH	0.108	NS
P^{H}*RICH	0.332	NS

Where: SOC=Soil Organic Carbon, TN=Total Nitrogen, C/N=Carbon to Nitrogen Ratio, Av. P=Available Phosphorus, CEC=Cation Exchange Capacity, Ca^{2+}=Calcium ions, Mg^{2+}=Magnesium ions, K^+=Potassium ions, Na^+=Sodium ions, TEB=Total Exchangeable Bases, pH=Soil pH, RICH=Tree Species Richness and NS=Not Significant.

increase as the concentration level of Na^+, K^+ and TEB in the soil increases. There was a negative relationship between tree species diversity and CEC (Figure 5 (c)). This relationship was found to be significant at (P = 0.047, r = - 0.27) (Table 5) indicating that tree species diversity decreases as the amount of CEC increases.

Table 5. Pearson correlation coefficients (r) with significance levels (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$) between tree species diversity and soil nutrient factors (N = 30).

Statistical parameters	*P*-values	Significance codes
SOC*DIV	0.2080	NS
TN*DIV	0.2100	NS
C/N*DIV	0.5840	NS
P*DIV	0.3770	NS
CEC*DIV	**0.0470**	*
Ca^{2+}*DIV	0.1570	NS
Mg^{2+}*DIV	0.4600	NS
K^+*DIV	**0.0090**	**
Na^+*DIV	**0.0008**	***
TEB*DIV	**0.0020**	**
P^H*DIV	0.1470	NS

Where: SOC=Soil Organic Carbon, TN=Total Nitrogen, C/N=Carbon to Nitrogen Ratio, Av. P=Available Phosphorus, CEC=Cation Exchange Capacity, Ca^{2+}=Calcium ions, Mg^{2+}= Magnesium ions, K^+=Potassium ions, Na^+=Sodium ions, TEB=Total Exchangeable Bases, pH=Soil pH, DIV=Tree Species Diversity and NS=Not Significant.

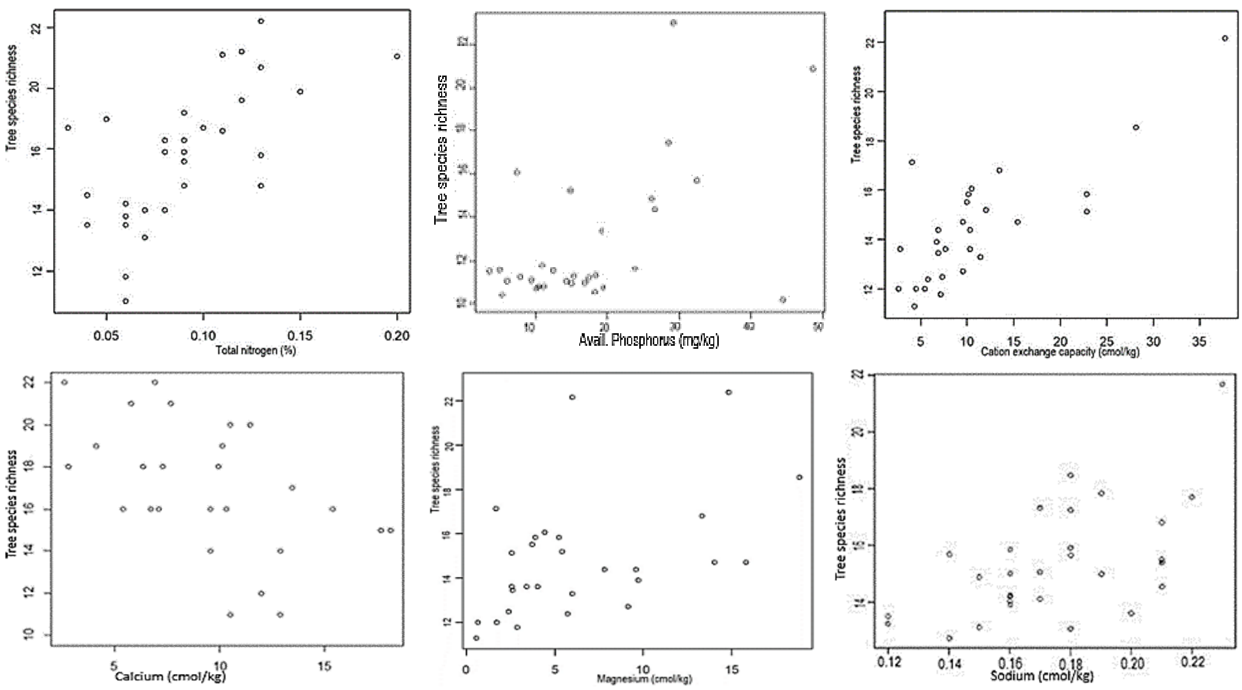
DISCUSSION

Tree species dominance

A study by Munishi *et al* (2008) concluded that dominance in terms of IVI gives an indication on which species come out as important element of the Miombo trees. Again, Zegeye *et al* (2006) and Kacholi (2013) reported that IVI is commonly used in ecological studies for showing ecological importance of tree species in a given ecosystem. This study suggests that the ecological system of Kitulang'halo Miombo woodland ecosystem is possibly driven by *P. tinctorius*, *P. angolensis*, *S. nigrescens*, *C. spinosa*, *B. spiciformis*, *F. virosa*, *D. boehmii* and *J. globiflora*. Our study is also in line with what was reported by Kacholi (2014) that *J. globiflora* and *B. spiciformis* were the most frequent and abundant species in Miombo woodland of the Kilengwe forest in Morogoro, Tanzania. Several studies in Tanzania and elsewhere in Africa on Miombo woodlands found that *J. globiflora* and *B. spiciformis* are the most important tree species due to their higher relative frequency, density, and dominance as compared to other species (Kacholi 2014, Hofiço and Fleig 2015, Zimudzi and Chapano 2016).

However, Miombo woodlands which are said to be under threat, their typical dominant tree species contribute a major proportion of the degradation for fire wood, charcoal production, poles and timber (Ribeiro *et al.* 2008, Hofiço 2014). And become dominated by under-storey tree species from genera like *Combretum* and *Diplorhynchus* (Ryan and Williams 2011, Jew *et al.* 2016). Effective conservation and management of Kitulang'halo Miombo woodlands ecosystem still need to be prioritized as 115 tree species had low IVI. Zegeye *et al* (2006) and Kacholi (2013) suggested that, IVI is used for prioritizing species conservation whereby species with low IVI value need high conservation priority compared to those with high IVI.

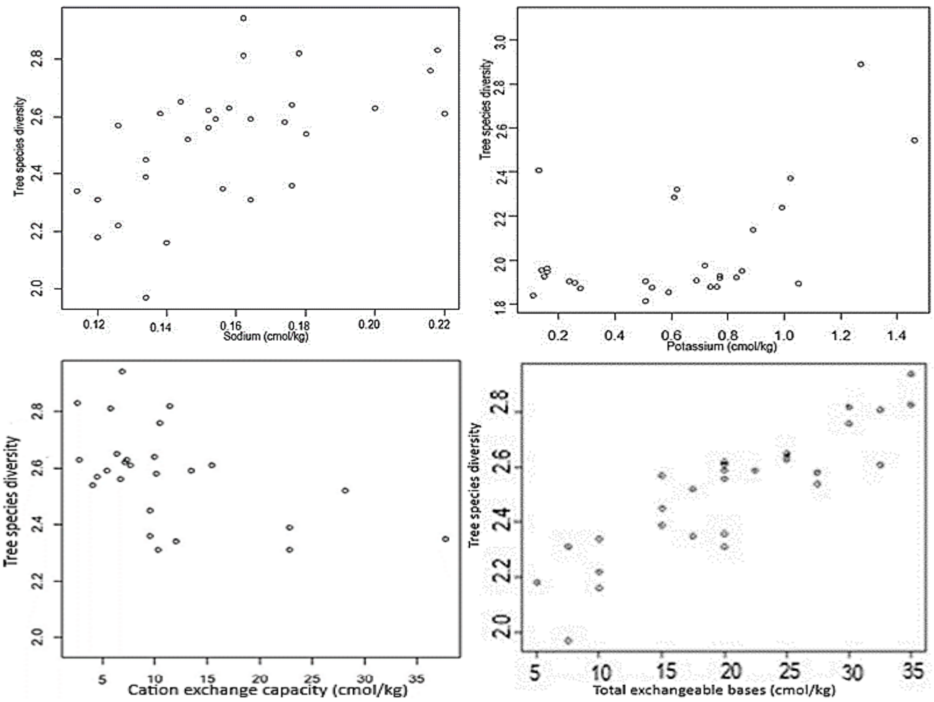
(a) **(b)** **(c)**



(d) **(e)** **(f)**

Figure 4: Scatter plots of the correlation between tree species richness and soil nutrient factors (N = 30).

(a) **(b)**



(c) **(d)**

Figure 5: Scatter plots of the correlation between tree species diversity and soil nutrient factors (N = 30).

Tree species diversity

Tree species richness recorded in this study was slightly higher compared to previous studies in Kitulang'halo Miombo woodlands (Figure 6). A repeated zig-zag trend (W-shaped graph) of species richness in this ecosystem is probably due to inconsistent of enforced regulations. The enforcement is sometimes ceasing and come up again perhaps due to insufficient management resources. Valkonen *et al* (2008) reported that Kitulang'halo Miombo woodland has existed for 15 years with enforced restrictions on tree harvesting, but prior to that extensive selective cutting had been practiced, resulting in substantial forest degradation. Since 2008 to date, the trend shows an increase in tree species richness (Figure 6) probably because currently the ecosystem is not directly exposed to human disturbances due to management objectives put in action by different authorities. A large part of Kitulang'halo Miombo woodland ecosystem is partly managed by SUA, TFS and TPDF while a relatively small part is a general land managed by village governments. Illegal utilization activities are less extensive in TFS, SUA's and Military part (TPDF) because it has been more strictly protected from harvesting. Intensive management need to be continually emphasized and supplied in order to maintain this trend as Kitulang'halo Miombo woodland is important in providing ecosystem services like water and nutrient cycling, carbon sequestration, and climate regulation.

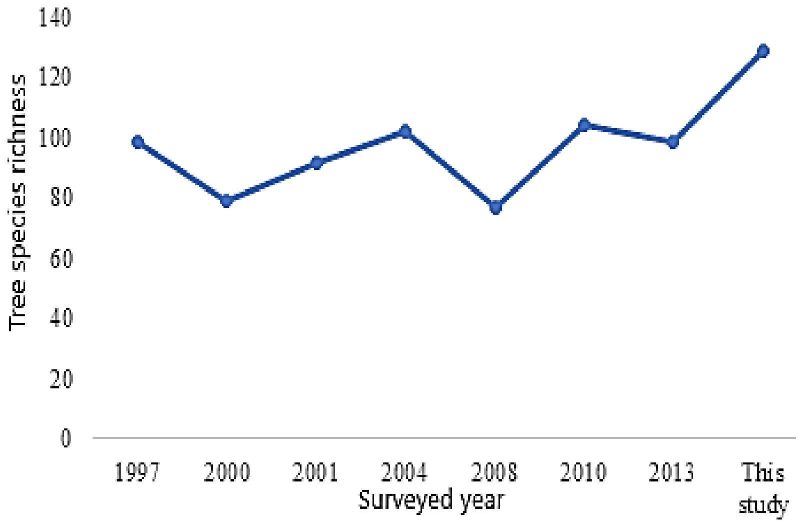


Figure 6: The trend of tree species richness in Kitulang'halo Miombo woodland ecosystem from this study and previous studies (Nduwamungu 1997, Luoga 2000, Malimbwi *et al*. 2001, Chamshama *et al*. 2004, Zahabu 2008, Valkonen *et al*. 2008, Obiri *et al*. 2010, Hammarstrand and Särnberger 2013).

Furthermore, Shannon-Wiener diversity index of 4.23 recorded in this study (Table 3) was found to be slightly high to what was recorded by other scholars elsewhere in Miombo woodlands (Zegeye *et al*. 2011, Missanjo *et al*. 2014, Kacholi 2014, Hofiço and Fleig 2015, Jew *et al*. 2016, Zimudzi and Chapano 2016). This is probably due to the existing management practices that has probably cause regenerating species to come up vigorously. The reasons for relatively small Shannon-Wiener diversity indices from other scholars may be due to difference in management objectives enacted, law enforcement programs and human disturbances. In contrast, Giliba et al. 2011 found slightly high Shannon-Wiener diversity index (4.27) in Miombo woodlands of Bereku Forest Reserve, Tanzania. Kalema (2010) reported that species diversity assessments are a way of auditing an ecosystem to understand its quality and how disturbance factors are impacting on it.

Relationships between tree species diversity with soil nutrient factors

The direct correlation between tree species richness and soil available P, TN, Mg, Na and CEC in this study support our hypothesis that there are some relationships between tree species richness and soil nutrient factors. Similarly, Shirima *et al.* (2016) found a strong positive relationship between tree species richness with P, Ca, Mg and K in Miombo woodlands of southern Tanzania. Long *et al.* (2012) and Cárate-Tandalla *et al.* (2018) found a positive relationship between species richness with nitrogen and phosphorus in a tropical monsoon climate and tropical montane forest, respectively. Huang *et al.* (2013), Schmidt *et al.* (2015) and Long *et al.* (2018) also reported a strong positive correlation between tree species richness with total N, total P, total K and organic matter in tropical coastal secondary forests, southern China. Plant species are selective to nutrients due to their specific physiological processes occurring in their bodies and depends entirely on the spatial heterogeneity of soil nutrient distribution and availability. Also, high nutrient factors in the soil may lead into lack of plant-nutrient competitions thereby increasing the chance of tree species survival. This proves that the ecosystem with high soil nutrient factors can attract many tree species. On the other hand, Nadeau and Sullivan (2015) found an inverse relationship between tree species richness with soil K, P, Ca contents and CEC. Abba *et al.* (2020) reported that the negative correlation exhibited by some of the soil nutrient factors may signify that, as the accumulation of such factors increases in the area there could be a reduction in the abundance and type of tree species. It may also imply insufficiency of soil nutrient factors in the vegetation type for the presence and even distribution of the species (Abba *et al.* 2020). For example, at low pH values result in reduced availability of important cations like Ca, Mg, K, and P, whereas Al, Cu, Mn, and Zn become more soluble and available for plant uptake (Brady and Weil 2002).

Moreover, the positive correlation between tree species diversity with K, Na and TEB (sum of basic cations Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) in our study is similar to those reported by Tuomisto *et al* (2014) who found a substantial increase in species diversity with increasing soil cation concentration in non-inundated rain forests in lowland Amazonia. Fu *et al.* (2004) and Long *et al* (2018) also found a positive significant correlation between tree species diversity and K contents in tropical forests. A study by Ali *et al.* (2019) done in tropical forests of southern China found that TEB and tree species diversity were significantly positive correlated. In addition, Kumar *et al.* (2011) found a significant positive relationship between species diversity and soil available P, exchangeable K and Ca in a tropical dry deciduous forest of Rajasthan, India. Ecological processes and functions occur differently in various micro-habitats within the ecosystem. As a result, their soil nutrient status and tree species nutrient uptake also differ and finally lead into species diversity. Soil nutrients are considered as one of the main factors limiting tropical forest structure (Vitousek *et al.* 2010), primary productivity, and other biological processes such as plant root allocation and growth (Zhang *et al.* 2015). Among environmental conditions, geology of a specific site which is determined by the bedrock quality, soil type and topography also play an important role in shaping diversity as both of them influence water and nutrient availability (Miyamoto *et al.* 2003, Philips *et al.* 2003, Tuomisto *et al*. 2003a). Vázquez-Rivera and Currie (2015) reported that, climatic water availability exerts a strong direct effect on stand structural complexity and any increase in atmospheric drought may directly diminish stand structural complexity and hence indirectly reduce tree species diversity. Therefore, tree species diversity in any ecosystem is attributed by a combination of factors both biotic and abiotic.

CONCLUSIONS

The most important tree species among others in Kitulang'halo Miombo woodlands ecosystem were *J. globiflora, B. spiciformis, P. tinctorius and P. angolensis* indicating that this forest is a typical Miombo woodland. Kitulang'halo Miombo woodlands ecosystem is rich in tree species diversity. The diversity is increased considerably as overall soil nutrient factors increased. This indicates that recently vegetation and soils in this ecosystem is not so much subjected to disturbances due to the current effective management measures imposed. However, management options for sustainable conservation of Kitulang'halo Miombo woodlands ecosystem should be intensified. Furthermore, joint management between SUA, TFS, TPDF and the communities will be of great conservation success at the landscape level. Therefore, this study recommends the need to conserve soil nutrients for more tree species diversity in Miombo woodlands. Further studies on the relationships between tree species diversity and soil nutrients associated with climatic factors specifically in other forest ecosystems in Tanzania is suggested.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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