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Research Paper

SOIL PHYSICO-CHEMICAL PROPERTIES AS INDICATORS OF SITE SUITABILITY FOR COMMERCIAL FOREST PLANTATION ESTABLISHMENT IN TANZANIA

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Abstract

Forest plantations were introduced to tropical regions to supply fuelwood, charcoal, fodder, sticks and building materials. Although the area of forest plantations has increased, there has been concern over the soil site suitability which influences commercial plantation productivity in Tanzania. The soil properties of tropical rain forest have been characterized by several researchers; however empirical data on site soil suitability for commercial forest plantation establishment in Tanzania are still limited or even lacking. This research is important to determine soil physical and chemical properties as an indicator of site suitability for forest productivity. A study was carried out in BFP, 252 composite soil samples were collected from 6 ranges located in the plantation. The physical analysis consisted of soil colour,structure,texture WHC and consistency.For chemical analysis, pH in (1:1) soil/ H2O suspension and in CaCl2) (1: 2.5) Electrical conductivity, Exchangeable bases; (Na, K, Ca, Mg) ,trace elements (B, Fe and Mn), available P, total Nitrogen, Soil Organic Matter (SOM),Soil Organic Carbon (SOC) and SAR were determined.The results indicated that the soils in the site have remarkable closeness in terms of colour ranging from brown (7.5YR 4/4) to yellow brown (10YR 5/6), structure as categorized single grained granular,single grained and granular blocky; texture as arrayed from sand clay to sand clay loam;Water Holding Capacity (WHC) as varied from 34-44% and consistency as ranged friable toose when moist and soft to loose when dry. The mean value for pH (in H2O) (1:1) was 4.08 while (in CaCl2) (1: 2.5) was 6.10 and of EC was 34.08 uS/cm. The mean values for Exchangeable Ca2+ was 0.61 Cmol/kg of soil, while Mg2+, was 0.58 Cmol/kg of soil, K+ was 0.19 Cmol/kg of soil and Na+ was 0.08 Cmol/kg of soil. The mean value of available P was 2.18 mg/kg of soil while for total N was 0.05%. The mean value for B was 57.46 mg/kg soil whereas for Mn and Fe was 10.75 and 43.14 mg/kg of soil respectively. Moreover the content for SOC was 0.62 (%) and SOM was 1.24 (%). It can be concluded that BFP soils have remarkable difference in nutrients based on selected physical and chemical properties. Moreover, the soil fertility status of the site was relatively higher indicating a good potential of the site for commercial forest plantation establishment. However the established plantation will induce the process rehabilitating and replenishing soil fertility status of some degraded parts forest land in Biharamulo Forest Plantation (BFP).

Key words: *Commercial forest plantation,Soil physical properties, pH, Exchangeable cations, Basal fertility status, Trace elements.*

Introduction

Forest plantations were introduced to tropical regions to supply fuelwood, charcoal, fodder, sticks and building materials. They were also planted to restore degraded lands, to control soil erosion or to serve as buffer zones around roads and areas of natural forests (Evans, 1999; Hartemink, 2003; Jagger and Mishra et al., 2003). Plantations establishment forms an important alternative means of wood production in tropics and have been practiced for long time throughout the tropical countries since the colonial period by expansion of Forest plantations. In Tanzania, plantation forests were introduced as tentative solution due to respond to the increased demands for fuelwood, wood products and building materials. Today, commercial forest plantation in Tanzania is considered an option for industrial economy due to increase in demand of forest products. Although the area of forest plantations has increased, there has been concern over the soil site suitability which influences commercial plantation productivity. The establishment of forest plantations is often a subject of considerable hot debates between forester on one side and environmental organization and local communities on the other. For these reasons, forest plantations are mostly established on marginal soils identified and classified as marginally suitable for food crops. However, the impact of soils suitability on forest plantations productivity is not currently taken into consideration for commercial forest plantation establishment in Tanzania. Therefore, a study of soil properties clarified that belief for long-term commercial forest plantation investment in Tanzania. The hypothesis was that following different anthropogenic activities, soil suitability have been modified. Thus, the soil physical and chemical properties may differ in a site.

MATERIAL AND METHODS

Study site

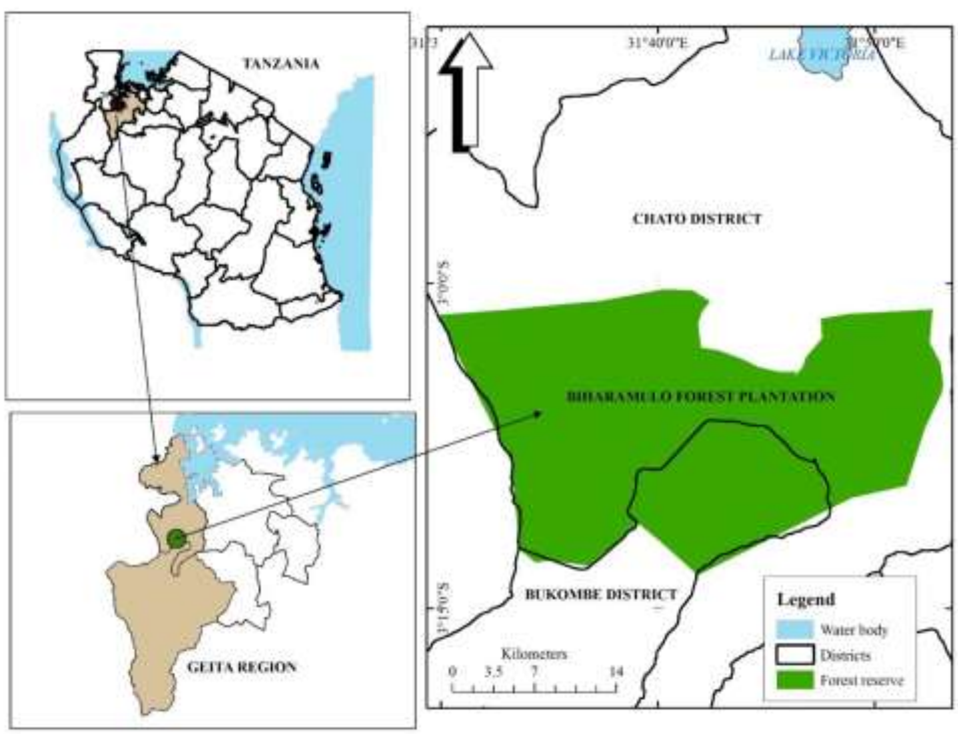

Figure 1: Location map of the study area

The area is located between 3^0 00'00"–$3^0$15'00" S and 31°30'00"–32°00'00" E (Figure 2.1). It is within the altitude ranging between 1135–1410 m a.s.l and borders Muleba District to the North, Bukombe District to the South, Biharamulo District to the West and Geita District to the East. The forest plantation covers an area of 69,756 ha. The climate in the district is mean annual precipitation is 850 mm, whose range varies from 700 mm to 1000 mm. In a dry year, the mean monthly rainfall may be as low as 36 mm, the average annual temperature ranges between 27°C to 31^0C. In terms of wind speed, the areas along the shore of Lake Victoria receive higher wind speed than other areas in the district. The soil in BFP area is classified as a Ferralsols according to FAO (1998), formed from the parent material of schists and granites mixed with mica schist and quartzite (Steiner, 1998; Verdoodt and Van Ranst, 2003). To determine the soil suitability field survey method (entailing description of soil) was conducted. Butengo, Nyakayondwa, Matabe, Nyantimba/Nyalutefye, Idoselo/Nyamparahala, and Bwanga Ranges were selected for this purpose. In each range, soil was investigated as follows: A transect was laid out 100 m from the selected profile mark point. Location of Soil profiles was based on observed variability, particularly topography (i.e. flat versus sloping land), and vegetation cover during the transect walk. Profile sites were marked using the hand-held Global Positioning System (GPS) receiver and geodetic values recorded. The soil profile description focused on soil layers from the surface to a depth of one metre. Three profile pits were randomly excavated in each selected Range.

Soil sampling and Laboratory Analysis

Soil samples were taken by soil corer at 2 depths (0 – 30 cm, and 30 - 60 cm) as described by Kooch*et al.*, (2012) resulting to 42 samples in each range per mentioned depths; A total of 252 soil samples were collected to all six ranges. To avoid deviations from final destinations, the GPS was used to maintain the bearing. Soil samples were collected along transverses aligned so as to cover different landforms and vegetation types as noted from maps. Soil sampling points were located on sites with soils that are representative of the BFP with the aim of investigating soil suitability for long term productivity. However, hardness/compaction of soil was assessed by using a soil hardener test.

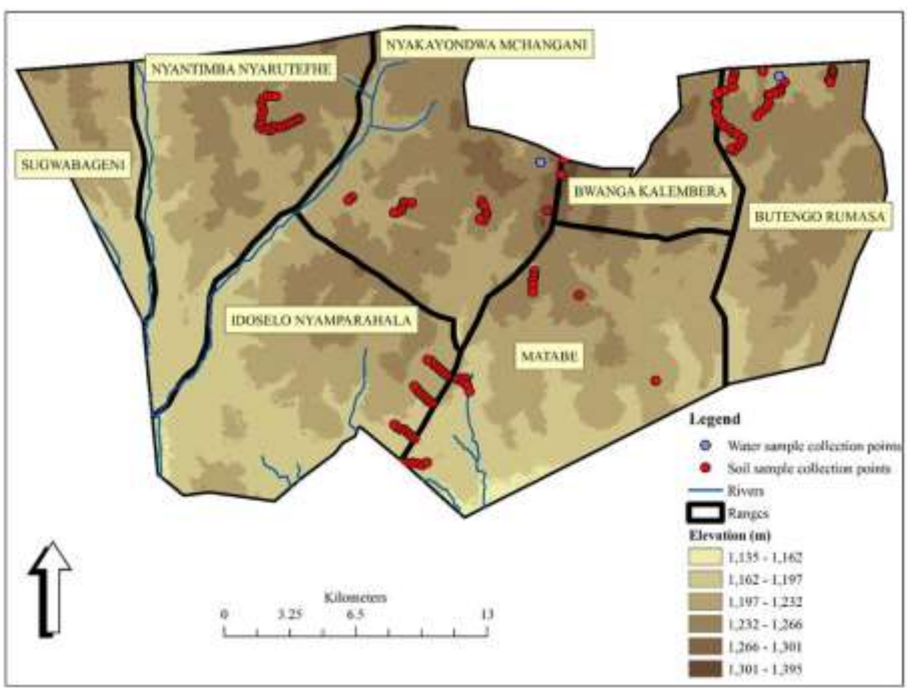

Figure 2: Location of sampling points in the Ranges of the BFP

The collected Soil samples were placed in properly labelled plastic bags, air dried, pulverized using pestle and motar, and sieved to pass through a 2.5 mm mesh. Particle size (texture) was estimated by hydrometer method (Bouyoucos, 1962). Structure and consistency of the soil were determined by the hand feeling method, water holding capacity was estimated using funnel gravity method. pH in 1:1 soil/water suspension (and also in 1:2.5.01M CaCl2) was determined by a glass electrode. Particle size distribution was estimated by ASTM calibrated hydrometer (Day, 1965) Electrical conductivity, Ec (at 250C) was determined with a conductivity meter in 1:5: water suspension (Peech, 1965). Exchangeable bases; Potassium and Sodium were determined by flame emission spectrophotometry (FES) while Calcium and Magnesium were determined by Atomic Absorption Spectrophotometry (ASS). Trace elements Boron (B), Iron (Fe) and Manganese (Mn) were also determined by ASS. Available P was determined by the Bray-1 procedure (Bray and Kurtz, 1945). Total Nitrogen was determined by micro-Kjeldahl digestion-distillation method as described by Bremner and Mulvaney (1982). The Soil Organic Matter (SOM) and Soil Organic Carbon (SOC) were determined by wet oxidation using Wakley and Black method (Allison, 1965). Soil hardness/compaction was determined by soil hardener tester at field level, Soil laboratory analyses were done at the Research laboratory of Soil Sciences at Tanzania Forestry Research Institute (TAFORI) and Sokoine University of Agriculture (SUA), Tanzania.

Statistical analysis

Descriptive statistics were carried out using the Statistical Package for Social Scientists (SPSS) software (SPSS Inc., 2005) to examine the differences in 13 soil variables and their contribution to commercial forest plantations establishment in Tanzania. All data were expressed as means ± standard deviation. Mean values of soil attributes were calculated using one-way analysis of variance (ANOVA), with the Tukey's honest significant difference at the 5% probability level.

Results

Physical properties

The values and conditions of soil physical properties are as shown in Table 1.The soils in the BFP have remarkable closeness in terms of matrix colour which ranges from brown (7.5YR 4/4) at NN to yellowish brown(10YR5/6) at BT. Other soil colour fall in 7.5YR Hue with varied Values and Chroma (Table 1). The brownness of soils colour is associated with the accumulation of organic material and iron oxidation processes at the soil surface level. Similar studies have associated a high percentage of organic matter in the surface soil that promotes brown colour and better aggregation (Genxu *et al*., 2004). The soil revealed four categories of soil structures (Table 1) namely: single grained granular (NN and NK), granular (BT and MT) and single grained (BW), and granular blocky (ID). Such characteristic of soil structure signifies that a large part of plantation soils offers porous space for air, and water; as well as root penetration. The result from ranges indicated that the soil texture arrays from sand clay to sand clay loam Table 1. Sand clay loam was the dominant soil texture across all ranges. Water Holding Capacity (WHC) varied from (BW) 34% to (ID) 44% (Table 3.3). The soils can retain acceptable amount of water as an important factor in influencing fertility of the soils for forest plantation establishment. Soil consistency varied from (Friable to Loose) when moist and (soft to loose) when dry. The soils materials are held together and resist deformation and rupture which influences favorability for tree growth.

Table 1: Physical properties used to investigate soil suitability in the BFP

Range name	Soil textural class	Water holding capacity (WHC) (%)	Soil structure	Munsell Soil colour position	Colour name	Consistency	
						Moist	Dry
NN	Sandy clay	40	Single grained-granular	7.5YR4/4	Brown	Friable	Loose
NK	Sandy clay loam	40	Single grain-Granular	7.5YR4/4	Brown	Friable	Soft
MT	Sandy clay loam	36	Granular	7.5YR5/3	Dull brown	Friable	Loose
BT	Sandy clay	38	Granular	10YR5/6	Yellowish brown	Loose	Soft
BW	Sandy clay loam	34	Single grained	7.5YR5/6	Bright brown	Loose	Soft
ID	Sandy clay	44	Granular-Blocky	7.5YR4/2	Greyish brown at	Friable	Soft

Note: NN=Nyantimba/Nyalutefye, NK=Nyakayondwa, MT=Matabe, BT=Butengo/Rumasa, BW=Bwanga, and ID=Idoselo

Chemical properties

Table 2 shows the values of soil acidity pH($CaCl_2$), pH(H_2O)) and electrical conductivity of ranges at BFP. For pH in $CaCl_2$, the highest value was 4.50 for MT, followed by BW. The lowest value was 3.76 NN. In addition, Table 3 also shows that the highest value of pH (H_2O) was 8.27 for MT. However, the lowest value was 5.50 for NN. For electrical conductivity the highest value was 49.70uS/cm and the lowest value was 28.70uS/cm. The mean value of EC was 34.08 uS/cm, for pH (in H2O) (1:1) was 4.08 while (in CaCl2) (1: 2.5) was 6.10 as shown in Table 3. The pH of most of the soils in the BFP were within the satisfactory range for forest tree growth. The acidic nature of the soils probably was due to the acidic nature of the parent materials and somehow extensive weathering of the soils and leaching Landon (1991). In addition, the site soil acidity also has a relationship with the existing vegetation. A study conducted by Juo and Manu (1996), showed that growing vegetation tended to influence the increase or decrease of soil pH, and nutrient stocks. Most trees grow better in soils with acidic to slightly acid reaction. Sakurai *et al*. (1995), stated that tree growth and root elongation were restricted with strong acidity condition.

Table 2: Soil pH and Electrical conductivity in the Biharamulo Forest Plantation

Ranges	Soil pH (1: 2.5) (in $CaCl_2$)	Soil pH (1:1) (in H_2O)	EC(uS/cm)
ID	3.89	5.75	31.00
MT	4.50	8.27	49.70
NN	3.76	5.50	32.40
BW	4.20	5.78	28.70
NK	3.93	7.57	29.20
BT	4.19	5.70	33.45

Note: ID=Idoselo, MT=Matabe, NN=Nyantimba/Nyalutefye, BW=Bwanga, NK=Nyakayondwa, and BT=Butengo/Rumasa

Table 3: Electrical conductivity and soil pH in the BFP

Soil Properties	**Means**
pH (1:1) (in H2O)	4.08
pH (1: 2.5) (in CaCl2)	6.10
EC	34.08

Exchangeable cations (Na, K, Ca, Mg) (Cmol/kg of soil) of the ranges are in shown in Table 4. The highest Ca^{2+} value was 2.22 Cmol/kg for BW, $Mg^{2+}$was 1.79 Cmol/kg for BW, Na^{+}0.21 Cmol/kg for BW andK^{+} 0.37 Cmol/kg for BW while the lowest value wasCa^{2+} value was 0.09 Cmol/kg for ID, $Mg^{2+}$was 0.10 Cmol/kg for BT, Na^{+} 0.02 Cmol/kg for ID and K^{+} 0.11 Cmol/kg for MT. The mean values for Exchangeable cations (Na, K, Ca, Mg) of the area are shown in Table 5. For Ca^{2+}, mean value was 0.61 Cmol/kg of soil, while Mg^{2+}, was 0.58 Cmol/kg of soil and for K+ was 0.19 Cmol/kg of soil. However, for exchangeable Na^{+} mean was 0.08 Cmol/kg of soil. If the soils had Na+ contents > 1 Cmol (+)/kg they could be taken as alkali or sodic soils (Landon, 1991) and somewhat unsustainable for tree growing. The soils in the area are of low levels of Na+ thus conducive for tree growth. The soils have a minimal capacity to hold K^{+} very tightly and resist leaching, hence imbalance aerobic microbial activity which are essential for making Potassium available to forest trees. The soils have low saturation of Ca^{+} which is a sturdy building material composed of cell walls for forest trees. Landon (1991) categorised levels of exchangeable Calcium and indicated that < 4 Cmol (+)/kg is considered as low and > 10 Cmol (+)/kg is considered as high. The soils have the reasonable amount of Mg^{2+} for plant uptake (Table 4). Magnesium helps plants move Phosphorus to where it is needed in the plant. Landon (1991), reported that soils having < 0.5 Cmol (+)/kg are Magnesium deficient and soils having > 4.0 Cmol (+)/kg had high Magnesium content.

Table 4: Levels of exchangeable cations (Na, K, Ca, Mg) (Cmol/kg of soil) in the BFP

Exchangeable	**Ranges**					
Bases	**ID**	**MT**	**NN**	**BW**	**NK**	**BT**
Ca^{2+}	0.09	0.45	0.59	2.22	0.20	0.09
Mg^{2+}	0.25	0.51	0.65	1.79	0.15	0.10
Na^{+}	0.02	0.08	0.10	0.21	0.03	0.02
K^{+}	0.12	0.11	0.21	0.37	0.18	0.14

Note: ID=Idoselo, MT=Matabe, NN=Nyantimba/Nyalutefye, BW=Bwanga, NK=Nyakayondwa, and BT=Butengo/Rumasa

Table 5: Mean values for Exchangeable cations (Na, K, Ca, Mg) Cmol/kg of soil in the BFP

Soil Properties	**Means (Cmol/kg)**
Ca^{2+}	0.61
Mg^{2+}	0.58
Na^{+}	0.08
K^{+}	0.19

The values of available P and N between ranges are shown in Table 6. The available P of MT was considerably higher at 3.93 mg/kg than those of the other ranges. The mean value of available P was 2.18 mg/kg of soil in the area (Table 8). Available P contents in the soils ranged from 3.9-19 m kg^{-1} fell within the low to medium fertility classes (Enwezor *et al*., 1990). The rate of bioorganic Phosphates to be chelated in organic complexes and designed to favour microbiological activity that converts Phosphorus to a more available form for forest tree use is low in the area. While the value of N was higher (0.06%) for ID followed by MT. The mean value for N was 0.05% as shown in Table 8. The average soil Nitrogen implies that either leaching of nitrogen is high in all ranges or the parent material from which the soils are derived, is not a rich source of Nitrogen. Resolution seems to depend on the fact that once the Plantation is established it will be a functional whole, that is nutrient inputs via rain, nitrogen fixation by plants and micro-organisms nutrient cycling and above all gross reduction of fire and deforestation, will all have additive values to a nitrogen pool.

Table 6: Status of basal fertility (N%, Pmg/kg soil and K Cmol/kg soil) in the ranges of BFP

Basal fertility	Ranges					
	ID	**MT**	**NN**	**BW**	**NK**	**BT**
N	0.06	0.05	0.04	0.04	0.04	0.04
P	1.52	3.93	2.60	2.71	1.02	1.30
K	0.12	0.11	0.21	0.37	0.18	0.14

Note: ID=Idoselo, MT=Matabe, NN=Nyantimba/Nyalutefye, BW=Bwanga, NK=Nyakayondwa, and BT=Butengo/Rumasa

Table 7 shows the values for trace elements (B,Mn and Fe) for the area. The highest for B was 64.72 mg/kg in Nk range. The mean value for B in the BFP ranges was 57.46 mg/kg soil. These results are within the range of values obtained by Daudu (1989) and Kparmwang *et al.* (2000). There was a gradual increase in the contents of available B to soil horizons which could be related to higher clay contents. Considering 1.0 – 2.4 mgkg-1 available B as critical limit (Wolf, 1971), B contents of the soils are in reasonable range and might be important factor for forest plantation establishment. For Mn, the highest value was 18.49 mg/kg in ID range followed by NN. The mean value for Mn was 10.75 mg/kg of soil (Table 8). The Mn content in soils is higher than the critical limit of 1.0 mg/kg as reported by Tisdale et al. (2003). Most of the soils have available Mn above the critical soil Mn of 1 – 4 mg kg-1 (Sims and Johnson, 1991). However, Lombin (1983) had reported that the northern Nigerian savanna soils which are predominantly mildly to medium acid seem well supplied with Mn at present and the prospect of deficiency problems in the foreseeable future seems remote. The high values could be due to acid conditions of the soils. For Fe, the highest value was 66.02 mg/kgin ID range. The site had a mean value of 43.14 mg/kg of soil which is sufficient Fe content for tree growth (Table 8). The high levels of Fe in all soils could be attributed to the low pH and nature of the parent material from which the soil was formed (Alloway and Ayres, 1990). These values are within the reported values by Kparmwang *et al*. (2000). Although available Fe is generally high in the tropical soils, localized deficiencies of Fe are known to occur (Enwezor *et al*., 1990). Available Fe poses no fertility problem in the soils studied. However, the lowest value for B was 47.55mg/kg in ID. For Mn, the lowest value was 5.92mg/kg in BT while for Fe the lowest value was 22.70 mg/kg in BT range (Table 7).

Table 7: Status of trace elements (B, Mn and Fe) mg/kg soil in the BFP Ranges.

Trace elements	Ranges					
mg/kg	**ID**	**MT**	**NN**	**BW**	**NK**	**BT**
B	47.55	52.60	61.20	58.90	64.72	59.80
Mn	18.49	10.87	12.05	9.68	7.50	5.92
Fe	66.02	34.90	56.87	42.23	36.12	22.70

Note: ID=Idoselo, MT=Matabe, NN=Nyantimba/Nyalutefye, BW=Bwanga, NK=Nyakayondwa, and BT=Butengo/Rumasa

Table 8: Mean values for Basal fertility status (N%) (P mg/kg soil) (K Cmol/kg of soil), Trace elements (B, Mn, Fe), mg/kg soil and (SOC and SOM) %.

Soil Properties	Means
N	0.05
P	2.18
K	0.19
B	57.46
Mn	10.75
Fe	43.14
SOC	0.62
SOM	1.24

The levels of SOC and SOM decrease down the profile with the top 0-30 cm having the highest amount. Implying that microbial activity at the surface layer is higher which controls the breakdown of plant residues which are abundant on the surface layer of soils. Percentage of soil organic matter (SOM) and soil organic carbon (SOC) for the ranges in BFP are shown in Table 9. ID had the highest (1.25%) SOM and while the lowest was 0.87% SOM for BT. Percentage of total organic carbon of ranges are shown in Table 4. ID had the highest (0.73%) SOC and the lowest was for BT (0.50%). For SOC the mean value was 0.62 (%). However, the mean value for SOM was 1.24 (%) in BFP (Table 8).

Table 9: Soil Organic Carbon and Organic Matter (%) in the BFP Ranges

Range	SOC-BlkW	SOM
ID	0.73	1.25
MT	0.71	1.22
NN	0.54	0.93
BW	0.63	1.09
NK	0.63	1.09
BT	0.50	0.87

Note: ID=Idoselo, MT=Matabe, NN=Nyantimba/Nyalutefye, BW=Bwanga, NK=Nyakayondwa, and BT=Butengo/Rumasa

Conclusion

This paper has narrated the roles that analysis of soil properties can play in indicating site suitability as the important aspect on commercial plantation establishment in Tanzania. Recognizing the contribution of soil analysis for commercial forestry programmes to make communities aware of value soil as an indicator for forest investment is important. It is reasonable to expect some variations in the soil attribute among the studied ranges here. Soil physical characteristics were, however very closely related to all ranges. The exchangeable cation concentrations were slightly different from the soils of each range, resulting into difference in base saturation and soil acidification. It can be concluded that the ranges have significant differences based on selected physical and chemical properties. The ID was more fertile compared to other ranges in BFP. Based on the analysis it was revealed that soil management technique is a suitable method in rehabilitating and replenishing soil fertility status of abandoned degraded shifting cultivation land ranges.

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