Original Research Article

Assessment of Soil Fertility Status for Bambara Groundnut Production in South-eastern Tanzania

ABSTRACT

Intensively farming practiced in the agro-ecological zones of Makonde plateau (C2) and Inland plain (E5) of the south eastern Tanzania without proper soil management had led to nutrients depletion. The objective of the study was to assess the soil fertility status of soils in Bambara groundnut growing areas of the south eastern Tanzania. Twenty two farmer's field sites were sampled and a composite sample of top soil at 0 – 20 cm depth was collected for physical and chemical analysis of soil. The results indicate that most of the soils in the study area are sandy loam (64%), loamy sand (27%) and sandy clay loam (9%). About 28% of the soils in the study area had very low CEC values (< 6 cmol (+) kg soil). Soil pH was strongly acidic to moderately acidic (≤ 5.5) and slightly acidic soils (≥ 6.0) in the C2 and E5, respectively. Total N was very low level (< 0.1%) and organic carbon was very low to low (< 0.6%). Low levels of available P (<10 mg/kg), inadequate S (SO_4-S) levels (< 10 mg/kg) were observed. The exchangeable K in the C2 was very low to low (< 0.05 cmol(+)/kg) while E5 had medium K level. The calcium level of C2 was low to medium (0.2 – 2.5 cmol (+)/kg) whereas E5 was medium to high (0.6 – 5.0 cmol (+)/kg). The exchangeable Mg^+ levels were very low to low (< 0.2 cmol(+)/kg) and Na^+ less than 0.30 cmol (+) kg soil which indicate no sodicity problem. Extractable Zn in the soil was < 0.6 mg/kg with adequate Fe whereas >30% had inadequate Mn < 5 mg/kg. The study area indicate low fertility status especially with respect to N, P, K, S, Mg and Zn, that needs proper management to improve soil fertility for crop production

Keywords: Soil fertility, physical and chemical properties, soil fertility management, south eastern Tanzania

1. INTRODUCTION

Soil fertility decline is a major constraint affecting agricultural production and livelihoods of people in south-eastern Tanzania. Continuous farming on the same area piece of land has been the practice used by farmers in crop production, without replenishing the soil fertility removed by crops. Soil fertility can be maintained through use of organic materials, manures, inorganic fertilizers, lime and crop rotation practices in combination with leguminous crops [1]. It has been reported that agriculture intensification and expansion of crop cultivation to marginal soils is responsible for lowering the productivity of many soils [2].

Human activities, including over cultivation of croplands, shifting cultivation, slash and burn of crop residues are some of the factors which can cause nutrient depletion in the soils, and they are widespread particularly in Sub Sahara Africa countries [3], [4]. Nutrient depletion has been recognized as a constraint that contributes to low food crop production and incomes, thus affecting livelihood in deleted Sub-Sahara Africa including Tanzania. Some serious land degradation has been observed in many parts of Tanzania, particularly in the semi-arid areas [5], [6].

In South Eastern Tanzania, particularly in the Makonde plateau and plains, traditional farming practices including clean weeding, removal and burning of crop residues, shortening and elimination of fallow periods have resulted in increased soil nutrient depletion. [7] reported that population pressure and expansion of human settlements has reduced fallow period to less than three years and led most farmers to practice seasonal fallows and/or continuous cultivation system. Poor soil management including clean weeding, removal and burning of crop residues reduces the soil organic matter content, continuous cropping leads to nutrient mining leading to soil fertility degradation [8]. Most of the soils in the South Eastern Tanzania are highly weathered deleted with very low soil fertility status, leading to low crop yields; thus they need proper soil management [9]. In those areas, research has addressed soil acidity amelioration [10], soil erosion [11], [12], soil acidification due to use of sulphur [9], and extent and severity of acidification [13], with less attention to soil fertility status.

This investigation of assessing the status of soil fertility would provide valuable information that will help to establish appropriate soil fertility management strategies for farmers, extension workers and policy makers in efforts to improve soil fertility and productivity of the study area. Research on assessing soil fertility is important as the results obtained could also be used as baseline to monitor changes of soil fertility and its productivity due to various interventions. Therefore, this study intended to assess the fertility status of the soil for Bambara groundnut growing areas in south eastern Tanzania.

2. MATERIAL AND METHODS

2.1 Description of the study area

The study was conducted in Mtwara region known to be a potential area for Bambara groundnut production in the south eastern Tanzania. The area is located within longitude 38° 03' and 40° 30' E and latitude 10° 05' and 11° 25' S, at an altitude range of 110 - 900 m above sea level (Fig 1). The area is characterised by a uni-modal rainfall pattern that occurs from December to April. The rainfall distribution is erratic, and is often interrupted by a dry spell of one to two weeks at the end of January or at the beginning of February. The mean annual rainfall deleted varies with altitude from 820 mm at around 100 meters above sea level (m.a.s.l) to 1245 mm at 870 m.a.s.l. The lowest mean monthly temperature is 24.3° C in July and the highest is 27.5° C in December. The mean annual temperature is 26° C in the coastal area and 24° C in the inland area [14], classified as Equatorial savannah with dry winter (Aw) [43].

The area comprises two agro-ecological zones identified by [15]. The zones are:

i) Coastal zone (C2), which comprises the Makonde plateau, characterised by undulating plateau and slightly dissected. The undulating plateau is characterised by a flat topped surface rising gently from the Makonde Dissected Plateau in the east toward a steep scarp slopes face in the western edges. Soils found on the plateau are deep, highly weathered, well drained with loamy sand top soils and sandy loam or sandy clay loam sub soils [9]. The area covered by the Makonde plateau is about 550,000 ha.

ii) Eastern plateaux and mountain block (E5), found in slightly dissected, gently undulating plain characterised as a scarp-foot-plain slope toward the west and southwest to Ruvuma valley. There are few isolated hills rising prominently from this plain, with steep or near vertical rock faces. The soils are moderately deep coarse sandy loam with occasionally finer sand clay loam subsoils [9]. About 650,000 ha of land is covered by Inland plains.

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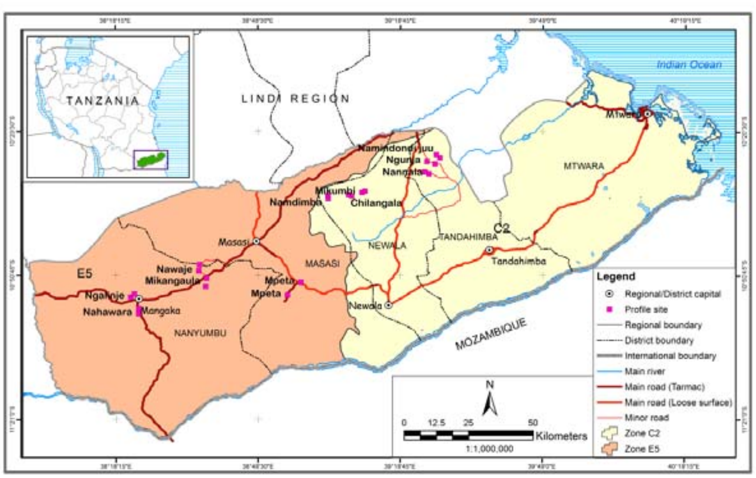

Fig. 1. Map showing the selected study villages under Bambara production in the study area

2.2 Site selection and soil sampling

The selection of the sites was aimed at assessing soil fertility status of the areas for Bambara groundnut production. Two government village leaders, four to six farmers who were members of the village committee and one village extension officer were used to identify the representative farmers at the village level. Two representative Bambara groundnut fields were selected for assessing soil fertility status in each village (Table 1). Selection of the study fields considered Bambara groundnut based farming system in the village, topography, cropping system and crop management. The fields selected were far apart; with the closest fields within a village being about 1km apart while the farthest were 7 km apart. Soil samples (0 – 20 cm depth) were taken from representative farmers' fields of about 2,000 m^2 to 4,000 m^2 in each village. Composite soil samples were derived from ten soil sub-samples collected randomly using an auger from representative spot and mixed to form the composite. One kg each of composite samples was air dried and sieved through 2 mm sieve for laboratory analysis. A Global positioning system (GPS) and clinometer were used to locate the geographical positions and slopes, respectively, of the selected fields.

Table 1. Geographical location of the selected villages under Bambara groundnut production in south-eastern Tanzania where soil samples were taken

District	Village	Geographical location/ coordinates	
Tandahimba	Namindondi juu 1	10°25.997' S	039°27.148' E
	Namindondi juu 2	10°25.394' S	039°26.383' E
	Ngunja 1	10°26.780' S	039°24.409' E
	Ngunja2	10°27.274' S	039°26.110' E
	Namnala 1	10°29.267' S	039°24.596' E
	Namnala 2	10°28.995' S	039°23.953' E
Newala	Mikumbi 1	10°33.128' S	039°10.897' E
	Mikumbi 2	10°33.009' S	039°11.248' E
	Chilangala 1	10°33.854' S	039°07.891' E
	Chilangala 2	10°33.793' S	039°07.760' E
	Namdimba 1	10°34.077' S	039°03.398' E
	Namdimba 2	10°34.382' S	039°03.149' E
Nanyumbu	Nawaje 1	10°49.462' S	038°35.928' E
	Nawaje 2	10°48.605' S	038°36.057' E
	Mikangaula 1	10°51.354' S	038°37.540' E
	Mikangaula 2	10°52.723' S	038°37.359' E
	Nahawara 1	10°58.746' S	038°23.076' E
	Nahawara 2	10°57.674' S	038°23.134' E
	Ngalinje 1	10°54.986' S	038°21.693' E
	Ngalinje 2	10°54.612' S	038°22.198' E
Masasi	Mpeta 1	10°54.883' S	038°54.761' E
	Mpeta 2	10°52.168' S	038°57.643' E

2.3 Laboratory analysis

The physio-chemical analysis was carried out at the laboratories of Mlingano Agriculture Research Institute and Sokoine University of Agriculture using standard laboratory procedures. The parameters analysed were particle size distribution, soil pH, organic carbon (OC), total nitrogen (TN), available P, exchangeable bases (Ca, Mg, K and Na), and cation exchange capacity (CEC). Other parameters include extractable sulphur (S), iron (Fe), manganese (Mn) and zinc (Zn). The pH was measured electrometrically in 1:2.5 soil: water suspensions while particle size distribution was determined by the Bouyoucos hydrometer method [16]. Textural classes were determined using the USDA textural classes triangle [17]. Organic carbon was determined by the Walkley-Black wet oxidation method [18] and total nitrogen was determined by the micro-Kjedahl procedure [19]. The available P was extracted using Bray-1 method [18] and determined by spectrophotometer following colour developed by molybdenum blue method [20]. The exchangeable bases in the ammonium acetate filtrates were measured by atomic absorption spectrophotometer and cation exchange capacity was determined from NH_4^+ saturated soil residue and displaced using 1 M KCl, then determined by Kjeldahl distillation method for estimation of CEC of the soil [21}. Extractable Sulphur (SO_4^{2+}-S) was extracted using calcium monophosphate [$Ca(H_2PO_4)_2.H_2O$], then determined by the turbidimetric method as described by [16]. Extractable Fe was extracted by acidified ammonium oxalate solution $(COONH_4)_2$ as described by [16]. The Zn and Mn were extracted by Diethylene triamine pentacetic acid (DTPA) as described by [22]. The Fe, Zn and Mn were determined by atomic absorption spectrophotometer. Total exchangeable bases (TEB) were calculated as sum of exchangeable bases Ca, Mg, K and Na whereas nutrient balance ratio was mathematically calculated using the exchangeable bases.

2.4 Statistical Analysis

Correlations showing relationships between pairs of soil parameters were performed using GenStat Release 10.3DE, VSN International Ltd. (Rothamsted Experimental Station) Discovery Edition 4.

3. RESULTS AND DISCUSSION

3.1 Selected physical properties of the soils

The study area comprised textural classes which are sandy loam, loamy sand and sandy clay loam (Table 2). Analytical results of soil samples collected showed that the Makonde plateau (agro-ecological zone C2) and Inland plains (agro-ecological zone E5) had sandy loam soils to the tune of 66.7% and 60%, respectively. Loamy sands covered 16.7% and 40%, respectively, of the soil samples collected in C2 and E5 zones. The Makonde plateau (C2) shown 16.7% sandy clay loam whereas Inland plain (E) had no sandy clay loam in the samples collected. Thus, the soils of the study area are predominantly, coarse textured. This points to a generally low soil fertility status in the area.

Table 2. Particle size distribution profiles of soils in the study area

Agroecological zone	Soil sampling site	Slopes (%)	Sand (%)	Silt (%)	Clay (%)	Soil types
Makonde plateau	Namindondi juu 1	1	86	4	10	LS
	Namindondi juu 2	1	86	4	10	LS
	Ngunja 1	2	76	6	18	SL
	Ngunja2	1	78	4	18	SL
	Namnala 1	2	80	6	14	SL
	Namnala 2	2	82	4	14	SL
	Mikumbi 1	1	80	4	16	SL
	Mikumbi 2	1	78	4	18	SL
	Chilangala 1	3	74	4	22	SCL
	Chilangala 2	3	76	4	20	SCL
	Namdimba 1	1	74	8	18	SL
	Namdimba 2	1	74	8	18	SL
Inland plains	Nawaje 1	1	80	8	12	SL
	Nawaje 2	1	76	8	16	SL
	Mikangaula 1	2	82	8	10	LS
	Mikangaula 2	2	80	10	10	SL
	Nahawara 1	3	78	10	12	SL
	Nahawara 2	3	80	8	12	SL
	Ngalinje 1	1	82	8	10	LS
	Ngalinje 2	2	84	6	10	LS
	Mpeta 1	2	86	4	10	LS
	Mpeta 2	2	82	6	12	SL

Key: LS=Loamy sand, SL=Sandy loam, SCL=Sandy clay loam

3.2 Soil chemical properties

3.2.1 Soil pH

The results of soil pH in water (Table 3) varied considerably among the sampling sites in the study area with a range from 5.0 to 6.0 and 6.0 to 6.3 for Makonde plateau and Inland plains, respectively.

[23] considered this soil pH range as very strong acidic to moderate acidic and slightly acidic soils in C2 and E5, respectively. About 92% of the soil sampled sites in the Makonde plateau had strong acidity to moderate acidity (pH: ≤ 5.5) whereas inland plain had slight acidity (pH: ≥ 6.0). According to [24], at pH less than 5.5, phosphate ions normally combine with iron and aluminium ions to form compounds which P is not readily available to plants.

Table 3. Some chemical properties and fertility status of the soils in the Makonde plateau and Inland plains

Agro-ecological zone	Soil sampling site	Soil pH 1:2.5	OC (%)	Total N (%)	Bray – 1 P mg/kg	Sulphur mg/kg
Makonde plateau	Namindondi juu 1	5.2	0.60	0.05	1.07	4.86
	Namindondi juu 2	5.3	0.27	0.04	1.34	10.94
	Ngunja 1	5.4	0.37	0.06	2.60	3.99
	Ngunja 2	5.2	0.14	0.04	2.51	13.54
	Namnala 1	5.4	0.45	0.04	3.13	9.20
	Namnala 2	6.0	0.57	0.08	6.45	9.20
	Mikumbi 1	5.3	0.30	0.05	1.97	20.49
	Mikumbi 2	5.0	0.39	0.05	1.79	7.47
	Chilangala 1	5.0	0.49	0.05	1.88	17.01
	Chilangala 2	5.0	0.60	0.05	1.70	6.60
	Namdimba 1	5.4	0.66	0.08	2.96	10.07
	Namdimba 2	5.3	0.79	0.06	2.78	6.60
Range		**5.0 - 6.0**	**0.14 - 0.79**	**0.04 - 0.08**	**1.07 - 6.45**	**3.99 - 20.49**
Inland plain	Nawaje 1	6.0	0.45	0.04	8.24	3.99
	Nawaje 2	6.2	0.28	0.02	6.72	6.60
	Mikangaula 1	6.1	0.37	0.03	7.08	7.47
	Mikangaula 2	6.0	0.65	0.04	6.9	11.81
	Nahawara 1	6.2	0.40	0.05	5.73	7.47
	Nahawara 2	6.1	0.30	0.03	7.52	8.33
	Ngalinje 1	6.3	0.20	0.03	8.87	3.13
	Ngalinje 2	6.3	0.40	0.03	6.54	9.20
	Mpeta 1	6.2	0.20	0.03	7.79	5.73
	Mpeta 2	6.0	0.50	0.03	6.99	5.73
Range		**5.0 -6.3**	**0.20– 0.65**	**0.02– 0.05**	**5.73 - 8.87**	**3.13 - 11.81**

3.2.2 Total Nitrogen and Organic Carbon

Total nitrogen values ranged from 0.04 to 0.08% and 0.02 to 0.05% for Makonde plateau and Inland plains, respectively (Table 3). These values for the soil samples collected in the study area are rated by [24] as being very low level (< 0.1%). More than 90% of the study areas are rated very low levels of total N, indicating nitrogen deficiency for most crops in the area. Organic carbon (OC) values were very low (0.14 to 0.79% for Makonde plateau and 0.20 to 0.65% for Inland plain). It is estimated that about 66.6% of the sites in the Makonde plateau had very low organic carbon whereas 90% of the samples sites in the Inland plain had very low range (< 0.6%) [25]. Generally the study area indicates very low to low range of OC. According to [26], OC plays a vital role as store of the plant nutrients phosphorus and sulphur. Low soil N and organic matter in this area could be attributed to prevailing farming practices mainly slash and burn and removal of crop residues during land preparation that lead to a decrease in the amounts of organic matter in the soils.

3.2.3 Available Phosphorus and Sulphur

Table 3 presents extractable P (Bray 1) levels in the soils. They ranged from 1.07 to 6.45 mg/kg and 6.54 to 8.87 mg/kg of P for Makonde plateau and Inland plains, respectively. According to [24], response to P application in plants could be unveiled when soil available P is less than 15 mg kg^{-1} soil. The present results indicate that the Makonde plateau and the Inland plain soils have low levels of soil available P for the growth of most crops. According to [27], the critical P level for optimum growth of Bambara groundnut is 10 mg/kg. This critical level indicates that the soils of the study area have low levels of extractable P for Bambara production, and thus they need supplemental P fertilizer. Exchangeable S (SO_4-S) levels of the soil ranged from 3.99 to 20.49 mg/kg and 3.13 to 11.81 mg/kg for Makonde plateau and Inland plains, respectively (Table 3). According to [24], a level of 6 mg/kg is critical, below that response of most tropical crops to S is expected. [27] reported that critical level of soil S (SO_4-S) for optimal growth of Bambara groundnut is 10 mg/kg. Based on this critical level, over 70 % of soils of the study area had inadequate levels of sulphur (< 10 mg/kg) for Bambara groundnut production.

3.2.4 Exchangeable Potassium, Calcium, Magnesium and Sodium

Exchangeable Potassium (K) levels of soils samples in the Makonde plateau and Inland plains ranged from 0.02 to 0.09 and 0.02 to 0.39 cmol (+)/kg, respectively (Table 4). According to [24] the response to K fertilizer is likely when the exchangeable K in clay, loamy and sandy soils is less than 0.2 to 0.4, 0.13 to 0.25 and 0.05 to 0.10 cmol (+)/kg, respectively. This categorization indicates that soils from the Makonde plateau (C2) were rated as being very low to low (< 0.05) whereas Inland plains (E5) were rated as being medium. These results imply that K fertilizer is required for optimum production of crops in the study area.

The values of exchangeable Ca in the Makonde plateau (C2) and Inland plains (E5) are presented in Table 4. They ranged between 0.45 and 1.98 and 1.13 and 3.54 cmol (+)/kg soil, for soils of C2 and E5, respectively. [24] rates the soils of Makonde plateau (C2) as having low to medium (0.2 – 2.5 cmol (+)/kg soil) and the Inland plain as having medium to high (0.6 – 5.0 cmol (+)/kg soil) Ca levels, respectively. [23] reported that calcium deficiency usually occurs on very acidic soils. The data from the study area indicate that 92% of the Makonde plateau (C2) soils are strongly acidic (pH 5.0 – 5.5) whereas Inland plains (E5) had slightly acidic soils. Low pH could dominate in soils developed over sandstone parent material which are low in soluble bases and have coarse texture which facilitates leaching, especially in Makonde plateau (C2**).**

Exchangeable Mg in soils of Makonde plateau (C2) ranged between 0.06 to 0.5 cmol (+)/kg soil and in soils of Inland plains (E5) 0.20 to 1.01 cmol (+)/kg soil as presented in Table 4. [24] and [25] rated the soil Mg values of Makonde plateau as very low to low and in Inland plains as low to medium. About, 58% of the Makonde plateau had very low Mg in soil whereas 60 % of the Inland plains had low Mg levels, hence the need for supplemental Mg to improve plant growth.
For exchangeable sodium the soils had low values (< 0.30 cmol (+) kg soil), indicating no sodicity problem in the studied soils [25].

Table 4. Levels of exchangeable bases and CEC of the soils in the Makonde plateau and Inland plains

Agro-ecological zones (AEZ)	Soil sampling site	Ca	Mg	K	Na	CEC	BS %
Makonde plateau	Namindondi juu 1	1.08	0.22	0.04	0.21	2.66	50
	Namindondi juu 2	0.61	0.07	0.03	0.12	1.50	47
	Ngunja 1	1.86	0.22	0.09	0.16	3.38	64
	Ngunja 2	0.81	0.15	0.09	0.07	2.02	52
	Namnala 1	0.67	0.12	0.04	0.12	1.73	48
	Namnala 2	1.98	0.34	0.05	0.12	3.17	75
	Mikumbi 1	0.56	0.11	0.02	0.16	1.50	46
	Mikumbi 2	0.45	0.06	0.02	0.09	1.30	41
	Chilangala 1	0.53	0.12	0.03	0.14	1.62	42
	Chilangala 2	0.66	0.07	0.04	0.11	1.60	48
	Namdimba 1	1.40	0.50	0.04	0.16	3.06	63
	Namdimba 2	1.48	0.27	0.03	0.09	2.74	65
Range		**0.45 – 1.98**	**0.06 – 0.50**	**0.02 – 0.09**	**0.09 – 0.21**	**1.30 – 3.38**	**41– 75**
Inland plain	Nawaje 1	2.58	0.78	0.24	0.21	4.58	79
	Nawaje 2	1.54	0.39	0.14	0.09	2.69	77
	Mikangaula 1	1.67	0.47	0.14	0.16	3.10	74
	Mikangaula 2	3.54	1.01	0.39	0.07	5.66	87
	Nahawara 1	1.91	0.52	0.14	0.18	3.30	78

	Nahawara 2	1.35	0.20	0.15	0.05	2.42	70
	Ngalinje 1	1.77	0.30	0.20	0.16	3.02	75
	Ngalinje 2	1.56	0.27	0.18	0.14	2.69	75
	Mpeta 1	1.14	0.20	0.12	0.04	2.10	70
	Mpeta 2	1.13	0.52	0.09	0.05	2.50	50
Range		**1.13 - 3.54**	**0.20 – 1.01**	**0.02 – 0.39**	**0.04 – 0.21**	**2.10 – 5.66**	**50 - 87**

Key: CEC= Cation exchange capacity, BS=Base saturation

3.2.5 Cation exchange capacity and percent base saturation

The cation exchange capacities of soils of Makonde plateau and Inland plains are presented in Table 4: they ranged from 1.30 to 3.38 and 2.10 to 5.66 cmol (+) kg soil, respectively. According to [26], the CEC determines the ability of the soil to bind or hold nutrients against leaching and it is usually influenced by clay mineral and organic matter components. According to [28], the CEC of Makonde plateau and Inland plain soils are rated as very low (< 6 cmol (+) kg soil). Over 90% of the soils had very low CEC. This could be attributed to the low organic matter content and low clay content in the soil which imply that the soils would be marginally suitable for crop production. The per cent base saturation (Table 4) of soils of Makonde plateau and Inland plains ranged from 41 to 75% and 50 to 87%, respectively which indicates that the Inland plains are better than Makonde plateau soils for pH and P. According to [17], soils having less than 50% base saturation are considered as less favourable soils and those with more than 50% base saturation are considered as favourable soils. It is estimated that 28% of the soils of the study area are categorized to be less favourable soils; thus need appropriate soil management to improve the bases for improved crop production.

3.2.6 Micronutrients

The DTPA extractable Zn in the soils of Makonde plateau and Inland plains ranged from 0.06 to 0.67 mg/kg (Table 5). According to [29], responses of crops to Zn for most crops are obtained when soil Zn is 0.1 to 1.0 mg/kg, but a critical limit of 0.6 mg/kg is considered a desirable limit for a range of crops. Based on this value, over 90% of the soils of the study area had < 0.6 mg/kg; thus crop response to Zn application is expected. Extractable Fe values of soils ranged from 12.88 to 76.63 mg/kg. [30] reported that the critical level of Fe for some crops was in the range of 2.5 to 5.0 mg/kg. Based on this critical range, all sample sites had adequate Fe for crop production.
The extractable Mn values in the study area ranged from 0.72 to 72.38 mg/kg. [31] reported that the critical range for most crops ranged from 2.0 to 5 mg/kg, which provide indication that more than 70% of the soils of the study area had high soil Mn (>5 mg/kg).

Table 5. Levels of selected micronutrient in soils of the study area

Agro-ecological zone	Soil sampling site	Zn	Fe	Mn
		mg/kg		
Makonde plateau	Namindondi juu 1	0.11	36.63	5.72
	Namindondi juu 2	0.26	49.13	2.89
	Ngunja 1	0.06	24.13	11.15
	Ngunja 2	0.06	27.88	5.93
	Namnala 1	0.31	41.63	7.67
	Namnala 2	0.21	20.38	5.93
	Mikumbi 1	0.11	49.13	2.67
	Mikumbi 2	0.06	65.38	0.72
	Chilangala 1	0.06	46.63	1.59
	Chilangala 2	0.26	76.63	1.15
	Namdimba 1	0.16	40.38	4.20
	Namdimba 2	0.11	35.38	3.98
Range		**0.06 – 0.26**	**20.13 – 76.63**	**0.72 – 11.15**
Inland plain	Nawaje 1	0.62	26.63	44.13
	Nawaje 2	0.11	16.63	39.78
	Mikangaula 1	0.31	15.38	22.39
	Mikangaula 2	0.57	16.63	35.43
	Nahawara 1	0.26	17.88	28.91
	Nahawara 2	0.31	17.88	44.13

	Ngalinje 1	0.67	22.88	72.39
	Ngalinje 2	0.31	20.38	52.83
	Mpeta 1	0.21	14.13	37.61
	Mpeta 2	0.21	12.88	35.43
Range		**0.11 – 0.67**	**12. 88 – 26.63**	**22.39 – 72.39**

3.2.7 Nutrient balances in the Makonde plateau and Inland plain area

The nutrient ratios of the soil in the study area are presented in Table 6. The ratio of Ca/Mg ranged between 2.80 to 9.43 and 2.17 to 6.75 in the Makonde plateau and Inland plain, respectively. According to [24] and [32], the optimum range of Ca/Mg ratio for a wide range of crops is 2 to 4. Approximately 60% of the Ca/Mg ratios observed in the Inland plains soils were within the optimum range while the remaining part as well as in the Makonde plateau 80% of the soils had ratios higher than the favourable levels. [24] and [28] reported that a high ratio of Ca/Mg exceeding 5:1 limits plant availability of Mg and P.

For the Makonde plateau and Inland plains soils, Ca/TEB ratios ranged from 0.65 to 0.80 and 0.63 to 0.77, respectively (Table 6). [24] reported that a Ca/TEB ratio greater than 5 may affect the uptake of other bases, particularly Mg and /or K. The soils in the study area had favourable levels (<5) of Ca/TEB ratio.

The Mg/K ratios in soils of the Makonde plateau and Inland plains ranged from 1.67 to 12.50 and 1.33 to 5.78, respectively. About 58% of Makonde plateau and 90% of Inland plains soils had Mg/K ratios which are within the optimum range 1 to 4 for nutrient uptake by plant ([24], [32]. This finding indicates that there is Mg imbalance in these soils and this could be associated with low soil pH. The percentage K/TEB ratio of soils in the study area ranged between 1.60 to 8.57%. According to [33], the K/TEB ratio favourable for most of tropical crops is above 2%. Over 90% of soils in the study area had K/TEB >2%, suggesting that the area is favourable for most tropical crops. Generally, the nutrient imbalance observed in some areas in the Makonde plateau and Inland plains could negatively affect nutrient availability to plants. Therefore, use of inorganic fertilizers containing these nutrients, and soil amendments such as lime, phosphate rock, and organic manures (crop residues, compost and green manure) is desirable in such areas to improve the lost soil nutrients [34], [35], [36].

Table 6. Nutrient balance in the Makonde plateau (C2) and Inland plain (E5) in the South eastern Tanzania

Agro-ecological zone	Soil sampling site	Ca:Mg	Ca:TEB	Mg:K	%(K/TEB)
Makonde plateau	Namindondi juu 1	4.91	0.70	5.50	2.58
	Namindondi juu 2	8.71	0.73	2.33	3.61
	Ngunja 1	8.45	0.80	2.44	3.86
	Ngunja 2	5.40	0.72	1.67	8.04
	Namnala 1	5.58	0.71	3.00	4.21
	Namnala 2	5.82	0.80	6.80	2.01
	Mikumbi 1	5.09	0.66	5.50	2.35
	Mikumbi 2	7.50	0.73	3.00	3.23
	Chilangala 1	4.42	0.65	4.00	3.66
	Chilangala 2	9.43	0.75	1.75	4.55
	Namdimba 1	2.80	0.67	12.50	1.90
	Namdimba 2	5.48	0.79	9.00	1.60
Range		**2.80 - 9.43**	**0.65 - 0.80**	**1.67 - 12.50**	**1.60 - 8.04**
Inland plain	Nawaje 1	3.31	0.68	3.25	6.30
	Nawaje 2	3.50	0.71	2.59	7.78
	Mikangaula 1	3.95	0.71	2.79	6.48
	Mikangaula 2	3.55	0.68	3.36	5.74
	Nahawara 1	5.90	0.73	1.50	8.23
	Nahawara 2	5.78	0.73	1.50	8.37
	Ngalinje 1	5.70	0.76	1.67	8.00
	Ngalinje 2	2.17	0.63	5.78	5.03
	Mpeta 1	3.67	0.69	3.71	5.09
	Mpeta 2	6.75	0.77	1.33	8.57
Range		**2.17 - 6.75**	**0.63 - 0.77**	**1.33 - 5.78**	**5.03 - 8.57**

Key: TEB= Total Exchangeable bases

3.2.8 Correlation among some soil chemical properties

Pearson's correlations of some chemical properties of the soils from Makonde plateau and Inland plains, areas where Bambara groundnut is cultivated, are presented in Table 7. In the Makonde plateau, the soil available P correlated positively and significantly with Ca (r = .67; *P* =.017) and very highly significant with soil pH (r = .88; *P* < .001). This finding suggests that as soil pH increases within the limits of the present data, the availability of P also increases and the vice-versa. It has, in most studies, been reported that at the low pH levels where the soil reaction is classified as acidic (pH <4.5) phosphate ion is likely to be vulnerable to fixation reactions associated with acid forming cations (e.g. Fe^{3+}, Al^{3+} and H^{+}) and/or Mn^{2+} , which ultimately decrease its availability for plant uptake [37]. Similar finding was reported by [38] in indicating correlation between pH and P. Organic carbon was observed to correlate positively and significantly with total N (r = .59; *P* = .046). This correlation suggests that decomposition of soil organic matter releases some essential soil nutrients (e.g. N) for plant uptake. The increase of OM in the soil creates a soil nutrient pool for plant nutrients [39]. Similar findings were reported by [40], indicating that OC significantly correlated with N in the degraded alpine meadow soils in central Tibet. In the Makonde plateau, Mg was also observed to correlate positively and significantly with pH (r =.58; *P* = .047) and highly significantly with total N (r = .87; *P* < .001) (Table 7), indicating the aid of the pH on the availability of N and Mg in the soils. Similar findings were reported by [41] indicating significant correlation of pH with Mg.

Table 7. Correlations among some chemical properties of the soil in the Makonde plateau

		Measured variables and their corresponding correlations											
		1	2	3	4	5	6	7	8	9	10	11	12
P	(1)	-											
Ca	(2)	0.67*	-										
Fe	(3)	-0.57	-0.73**	-									
K	(4)	0.23	0.48	- 0.6**	-								
Mg	(5)	0.54	0.76**	-0.56	0.19	-							
Mn	(6)	0.35	0.64*	- 0.77*	0.75**	0.34	-						
Na	(7)	-0.2	0.19	-0.16	-0.1	0.3	0.25	-					
Org. C	(8)	0.22	0.42	0.04	-0.35	0.54	-0.11	0.21	-				
Soil pH	(9)	0.88***	0.74**	-0.7	0.23	0.58*	0.52	0.09	0.14	-			
Sulphur	(10)	-0.06	-0.48	0.07	-0.26	-0.2	-0.39	-0.05	-0.44	-0.1	-		
Total N	(11)	0.66	0.77	-0.37	0.04	0.87***	0.15	0.23	0.59*	0.62*	-0.2	-	
Zn	(12)	0.22	-0.08	0.23	-.0.23	-0.1	-0.01	-0.07	0.16	0.31	-0.14	-0.06	-

*Pearson's correlation at 95% confidence level, *P< .05, **P< .01, *** P< .001.*
Key: P = phosphorus, Ca = calcium, Fe = iron, K = potassium, Mn = manganese, Na = sodium, OC = organic carbon, Zn = zinc.

Correlations between soil parameters in the Inland plains are presented in Table 8. Positive and very highly significant correlation (r = .98; *P* < .001) was obtained between Ca and K. Calcium also showed similar correlations with magnesium (r = .88; *P* < .001), significantly with organic carbon (r = .68; *P* = .029) and zinc (r = .67; *P* = .034). Apart from manganese and soil pH, which showed insignificant negative correlations with calcium, these findings suggest that calcium is important in increasing availability and/or solubility of most other nutrient elements in these soils and probably for their susceptibility for plant uptake. Calcium weathers relatively quickly and can become unavailable to plants via leaching in highly weathered (mature) soils compared with other basic cations [44] increasing impact of low pH to soil reactions. Fe shows positive and significant correlations with Na (r = .73; *P* = .016) and Zn (r = .72; *P* = .019). This finding suggests that increase in Na will (delete) impact on soil reaction thereby limits for solubility of Fe and Zn in soils. Mg correlated positively and significantly with potassium (r = .75; *P* = .013) and highly significant with organic carbon (r = .85; *P* = .002). Potassium also correlated positively and significantly with zinc (r = .72; *P* = .02).

Table 8. Correlations among some chemical properties of the soil in the Inland plains

		Measured variables and their corresponding correlations											
		1	2	3	4	5	6	7	8	9	10	11	12
P	(1)	-											
Ca	(2)	-0.00	-										
Fe	(3)	0.47	0.38	-									
K	(4)	0.13	0.95***	0.37	-								
Mg	(5)	-0.13	0.88***	0.16	0.75*	-							
Mn	(6)	0.63	-0.06	0.6	0.15	-0.32	-						
Na	(7)	0.06	0.29	0.73*	0.13	0.22	0.14	-					
OC	(8)	-0.41	0.68*	-0.06	0.59	0.85**	-0.4	0.01	-				
Soil pH	(9)	0.00	-0.42	0.15	-0.31	-0.70*	0.53	0.18	-0.69*	-			
Sulphur	(10)	-0.64*	0.41	-0.38	0.45	0.31	-0.41	-0.33	0.58	-0.18	-		
Total N	(11)	-0.28	0.54	0.26	0.37	0.54	-0.26	0.45	0.48	-0.25	0.18	-	
Zn	(12)	0.62	0.67*	0.72*	0.72**	0.47	0.52	0.46	0.23	-0.14	-0.17	0.37	-

*Pearson's correlation at 95% confidence level, *signifies P<0.05, ** signifies P<0.01, ***signifies P<0.001.*
Key: P = phosphorus, Ca = calcium, Fe = iron, K = potassium, Mn = manganese, Na = sodium, OC = organic carbon, Zn = zinc

4. CONCLUSION AND RECOMMENDATIONS

The study of soil fertility status in the Makonde plateau and Inland plains revealed that soils are acidic, ranging from strongly acidic to slightly acid. Strong soil acidity, especially in the Makonde plateau areas, low pH is likely to limit availability of some nutrients include nitrogen, available P, potassium, calcium and magnesium for crop production. These alarmingly situations necessitate immediate attention to replenishing the depleted nutrients in the soil. Therefore, to achieve sustainable crop production in the studied area, use of inorganic fertilizers, liming, use of organic materials (manure, compost etc.) and/or crop rotation should be adopted to alleviate this low soil fertility. Farmers should be trained on utilization of available organic materials and increase their awareness of combining inorganic and organic plant nutrient source for improving soil fertility for cop production.

CONSENT (WHERE EVER APPLICABLE)

All authors declare that 'written informed consent was obtained from the farmers field for publication of this study. A copy of the written consent is available for review by the Editorial office/Chief Editor/Editorial Board members of this journal.

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