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

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Authors' contributions

This work was carried out in collaboration between all authors. Author JJT designed the study, managed the literature searches and all laboratory analyses, performed the statistical analysis and wrote the first draft of the manuscript. Authors JMRS, ES and BMM edited the data, reviewed and edited study design and the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Intensive farming practised in the agro-ecological zones of Makonde plateau (C2) and Inland plain (E5) of south-eastern Tanzania without proper soil management has led to nutrient depletion. The objective of the study was to assess the fertility status of soils in Bambara groundnut growing areas of south-eastern Tanzania. Twenty-two farmers' field sites were sampled and composite samples of top soil at 0 – 20 cm depth were collected for physical and chemical analysis. The results indicate that 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 (≥ 6.0) in the C2 and E5 agro-ecological zones, respectively. Total N was very low (< 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 zone was very low to low (< 0.05 cmol(+)/kg) while E5

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zone had medium K level. The calcium level of C2 was low to medium (0.2 – 2.5 cmol(+)/kg) whereas that of E5 was medium to high (0.6 – 5.0 cmol(+)/kg). The exchangeable Mg^{2+} levels were very low to low (< 0.2 cmol(+)/kg) while Na^+ was < 0.30 cmol(+)/kg soil indicating no sodicity problem. For > 90% of the studied soils extractable Zn was below critical level of 0.6 mg/kg. All soils had adequate extractable Fe whereas > 70% of the soils had high (> 5 mg/kg) extractable Mn. The study area generally indicated low fertility status in terms of N, P, K, S, Mg and Zn, calling for proper management for improving 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 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 the 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 soils. These practices are widespread particularly in Sub-Sahara African countries [3,4]. Nutrient depletion has been recognized as a constraint that contributes to low food crop production and incomes, thus affecting livelihood in Sub-Sahara African 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. Tenga et al. [7] reported that population pressure and expansion of human settlements have reduced the 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 reduce the soil organic matter content, and continuous cropping leads to nutrient mining responsible for soil fertility degradation [8]. Most of the soils in south-eastern Tanzania are highly weathered 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 current 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 soils for Bambara groundnut growing areas in south-eastern Tanzania.

2. MATERIALS 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 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 [7], classified as Equatorial savannah with dry winter (Aw) [14]. The area comprises two agro-ecological zones identified by De Pauw [15]. The zones are:

i) Coastal zone (C2), which comprises the Makonde plateau, characterised by an 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 subsoils [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.

2.2 Site Selection and Soil Sampling

The selection of the sites was aimed at assessing the 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 1 km 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 the representative spots 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.

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). 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

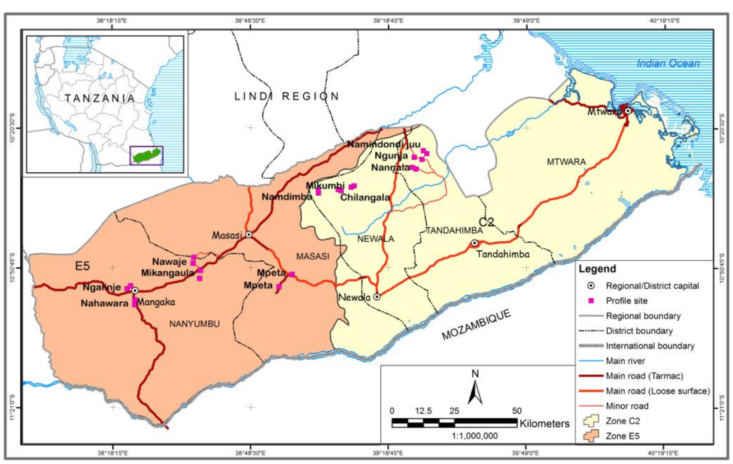

Fig. 1. Map showing the selected study villages under Bambara production in the study area

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

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]. Available P was extracted using Bray-1 method [18] and determined by spectrophotometer following colour developed by molybdenum blue method [20]. Exchangeable bases in ammonium acetate filtrates were measured by atomic absorption spectrophotometer and cation exchange capacity was determined from NH_4^+ saturated soil residues 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 Moberg [16]. Extractable Fe was extracted by acidified ammonium oxalate solution $(COONH_4)_2$ as described by Moberg [16]. Zn and Mn were extracted by Diethylene triamine pentacetic acid (DTPA) as described by Lindsay and Norvell [22]. Contents of Fe, Zn and Mn were determined by atomic absorption spectrophotometer. Total exchangeable bases (TEB) were calculated as the sum of exchangeable bases Ca, Mg, K and Na whereas nutrient ratios were mathematically calculated using the exchangeable bases.

2.4 Statistical Analysis

Correlations showing relationships between pairs of soil parameters were performed using GenStat Release 10.3 DE, 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) had 16.7% sandy clay loam texture 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 Landon [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.

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 Landon [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 Brady and Weil [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 Landon [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 Makonde plateau and Inland plain soils have low levels of soil available P for the growth of most crops. According to Mhango et al. [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.

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**

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 Landon [24], a level of 6 mg/kg is critical, below that response of most tropical crops to S is expected. Mhango et al. [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 soil 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 Landon [24], 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 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. According to [24], the soils of Makonde plateau (C2) were rated as having low to medium (0.2 – 2.5 cmol(+)/kg soil) and those of Inland plain as having medium to high (0.6 – 5.0 cmol(+)/kg soil) Ca levels. Horneck et al. [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 is low in soluble bases and having a coarse texture which facilitates leaching, especially in Makonde plateau (C2).

Exchangeable Mg in soils of Makonde plateau (C2) ranged between 0.06 and 0.5 cmol(+)/kg soil and in soils of Inland plains (E5) between

0.20 and 1.01 cmol(+)/kg soil as presented in Table 4. According to Landon [24] and EUROCONSULT [25] the soil Mg values of Makonde plateau were rated 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].

3.2.5 Cation exchange capacity and percent base saturation

Cation exchange capacity (CEC) values of soils of Makonde plateau and Inland plains are presented in Table 4. They ranged from 1.30 to 3.38 and from 2.10 to 5.66 cmol(+)/kg soil, respectively. According to Brady and Weil [26], 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 Hazelton and Murphy [28], the CEC of Makonde plateau and Inland plain soils are were rated as very low (< 6 cmol(+)/kg soil). Over 90% of the soils had very low CEC. This could be attributed to low organic matter content and low clay content in the soil which imply that the soils would be marginally suitable for crop production. The percent base saturation (Table 4) of soils of Makonde plateau and Inland plains ranged from 41 to 75% and from 50 to 87%, respectively which indicates that the Inland plains are better than Makonde plateau soils for pH and P. According to IUSS [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 was estimated that 28% of the soils of the study area are marginally favourable soils; thus there is need for 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 Alloway [29],

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 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. Sims and Johnson [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.

Extractable Mn values in the study area ranged from 0.72 to 72.38 mg/kg. Sillanpää [31] reported that the critical range for most crops ranged from 2.0 to 5 mg/kg, which provides an indication that more than 70% of the soils of the study area had high soil Mn (>5 mg/kg).

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 Landon [24] and Msanya et al. [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 80% of the Makonde plateau soils the ratios were higher than the favourable levels. Landon [24] and Hazelton and Murphy [28] reported that a high ratio of Ca/Mg exceeding 5:1 limits plant availability of Mg and P.

For Makonde plateau and Inland plains soils, Ca/TEB ratios ranged from 0.65 to 0.80 and from 0.63 to 0.77, respectively (Table 6). Landon [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 Makonde plateau and Inland plains ranged from 1.67 to 12.50 and from 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 of 1 to 4 for nutrient uptake by plants ([24], [32]. The percentage K/TEB ratio of soils in the study area ranged from 1.60 to 8.57%. According to Karuma et al. [33], the K/TEB ratio favourable for most of the 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) are desirable in such areas to improve the lost soil nutrients [34, 35,36].

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, where Bambara groundnuts are cultivated are presented in Table 7. In Makonde plateau, the soil available P correlated positively and significantly with Ca (r = .67; *P* =.017) and was 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 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 anions are 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 their availability for plant uptake [37]. Similar finding was reported by Abreu et al. [38] 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 Cao et al. [40], indicating that OC significantly correlated with N in the degraded alpine meadow soils in central Tibet. In 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 Mwango et al. [41] indicating a significant correlation of pH with Mg.

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**

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

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.

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

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 [42] 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 impact on soil reaction thereby limiting 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; $P = .02$).

4. CONCLUSION AND RECOMMENDATIONS

The study on 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, will likely limit the availability of some nutrients including nitrogen, available P, potassium, calcium and magnesium for crop production. This situation necessitates 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 the utilization of available organic materials and increase their awareness of combining inorganic and organic plant nutrient sources for improving soil fertility for crop production.

CONSENT

All authors declare that ‘written informed consent’ was obtained from the farmers for publication of this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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