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Evaluation of Soil Fertility Status and Land Suitability for Smallholder Farmers' Groundnut and Maize Production in Chisamba District, Zambia

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Authors' contributions

This work was carried out in collaboration between all authors. Author MC designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors JPM, PWM, AKK and OIL critically reviewed the manuscript and managed the literature reviews. All authors read and approved the final manuscript.

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ABSTRACT

A study was conducted to determine the soil fertility status and the suitability of land for the smallholder farmers' sustainable production of groundnut and maize in Chisamba District of Zambia. Composite soil samples (0 – 30 cm) were collected from the fields of 18 randomly selected major groundnut producing villages. The soils were analysed for various chemical and physical properties. Then focused group discussions as instruments of data collection were used to capture information on market availability for groundnuts. The simple limitation method was used to compute land suitability. The results showed that most (63.63%) of the soils were strongly acidic, with the mean pH of 4.95±0.35. The mean of CEC was 3.63±2.73 cmol / kg. There was a highly significant and positive relationship between pH_{CaCl2} and the concentration of Ca (r = 0.653,

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P = .000), Mg (r = 0.614, *P* = .000) and K (r = 0.651, *P* = .000). There was also a positive highly significant relationship between N and SOM (r = 0.487, *P* = .004). A positive and highly significant relationship between gender of the smallholder farmer and sale of groundnuts at markets of nearest towns (r = 0.202, *P* = .005) was observed. It was observed that 72.22% of the groundnuts producing areas of Chisamba District were marginally suitable (S3) for groundnut production. It was also observed that 68.75 % of the soils in the study area were marginally suitable for maize production. It was concluded that the major soil fertility limiting factors were soil acidity, low CEC, SOM, Ca, Mg, K and N. The major socio-economic limiting factor was the non-availability of stable markets.

Keywords: Smallholder groundnut farmers; fertility status; market; land suitability.

1. INTRODUCTION

The increase in food insecurity in semi-arid Africa has been attributed to the decline in soil fertility (13.2%), strong soil acidity (16.9%), P fixation (6.8%) [1] and generally land degradation [2]. This is exacerbated by continuous cultivation [3,4] without replenishment of nutrients [3,5] which has depleted soil P and many other nutrients from smallholder farms [4]. Similarly, Thierfelder et al. [6] attributed the low fertility status of smallholder farmers' fields in sub-Saharan Africa to continued mining of nutrients through crop harvests and removal of crop residues. The removal of crop residues reduces substrates for microbes and results in loss of soil organic matter (SOM) with a corresponding reduction in nutrient cycling [7]. In Zambia, this is compounded by the widespread of acidic soils which are inherently low in N and P [8]. This has resulted in low grain yields of maize and groundnuts causing widespread food insecurity in Zambia [8,9,10].

Therefore, studies to determine the fertility status of soils especially in regions dominated by smallholder farmers are vital in improving crop productivity of the rural poor [11]. Fertility status assessments of soils are essential [11] for correct fertilizer recommendations [12]. It is a tool not only for developing guidelines vital in land management [13] but also for land use planning [13,14]. Fertility status assessments are also very important for determining both the site specific suitability of an area for a particular crop to be grown [15,16,14,17] critical for sustainable crop production [16]. Soil fertility status can be evaluated by monitoring soil physical and chemical properties [16,18] and also by assessing the differences between nutrient inputs and outputs, commonly called nutrient balance [18]. Soil physical and chemical properties provide a framework for determining the fertility status of soils [14].

It is essential however, that land suitability evaluations integrate both the physical environment and socio-economic factors [19,20]. The FAO [19] framework recommends that crop specific requirements be identified and then subsequently matched with land characteristics to define suitability ratings and determine classes. In this study, suitability classes were determined by the simple limitation method [19,20]. The simple limitation method is based on identifying land limitations [20]. Land limitations are defined as deviations of land characteristics from optimal conditions for a specific land use [19]. Land use type in this study was defined as subsistence rain fed groundnut and maize production by smallholder farmers in Chisamba District.

The livelihood of smallholder farmers in Chisamba District depend on rain fed groundnut and maize production [10,21]. However, poor kernel yields as low as 642 kg / ha [9] and stagnant yields of maize of 1000 kg / ha [10] deprive the rural poor of the much needed food and cash [10,21]. Therefore, improving the soil fertility status of groundnut producing areas of Chisamba District, is the cornerstone for sustainable crop production essential in combating widespread food insecurity in Zambia. Up-to-date and site specific information on the fertility status of soils in the groundnut-based cropping systems is indispensable in making the correct fertiliser recommendations. Fertility status assessments of soils in the groundnut-based cropping systems of Chisamba District are very important for determining the site specific suitability of these areas for both groundnut and maize production. This is a fertility management tool critical in the sustainable production of groundnuts and maize. Therefore, a study was commissioned to determine the fertility status of the soils and the suitability of the smallholder farmers' fields for groundnut and maize production in Chisamba District.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

Chisamba District is located about 50 km North of Lusaka, in the Central Province of Zambia [8]. The District is dominated by smallholder farmers whose livelihoods depend on rain fed groundnut and maize production [10]. The District covers 2 978.5 km^2 and is located between latitude 14^o 30' and 15º 00' S and longitudes 28^{o}00' and 28^o 30' E. It is 1 138 m above sea level. The District is in agro-ecological zone II a (AEZ II a) which receives annual rainfall of 800 – 1 000 mm [22]. The daily mean minimum and maximum temperature ranges from 14.31ºC to 27.31ºC [8].

2.2 Study Design and Approach

Chisamba District has been stratified into two agricultural blocks and 11 camps [10,22]. The camps have further been subdivided into 49 agricultural zones (Table 1). Multistage sampling was used to select the major groundnut producing villages. In the first step, two agricultural blocks and 11 agricultural camps were purposively selected. This was subsequently followed by random selection of 11 agricultural zones. From these 11 agricultural zones, 18 major groundnut producing villages were then randomly selected. The study used the two stage approach of land suitability assessments [19] whereby the physical potential of soils in the groundnut producing areas of Chisamba District were analysed first, and, market availability and prices were then used to determine socio-economic factors [19].

2.2.1 Soil sampling and laboratory analysis

Top soil samples (0-30 cm) from the fields of the 18 randomly selected smallholder groundnut farmers representing 18 major groundnut producing villages were collected immediately after harvesting of both their groundnuts and maize crops of 2013 / 2014 agricultural season. This was done prior to incorporation and burning of the crop residues. Groundnut fields were generally small and therefore, a 5 x 5 m quadrant was used to avoid sampling the edges, while a 10 x 10 m quadrant was used to collect composite soil samples from harvested maize fields. Five soil samples were collected at the depth of 0 – 30 cm using a soil auger, four at the apexes and one at the middle of the quadrant. The samples were thoroughly mixed in a bucket to make one composite sample per field, and then packed in a clearly labelled bag. Seventeen soils were collected from groundnut fields while 15 from maize fields. An additional control soil sample was purposively collected at GART, from a field which had not been cultivated for 4 years. This gave a total of 33 soils. The collected soil samples were air dried, cleaned free of roots and debris, passed through 2 mm sieve and analysed for various soil characteristics.

Table 1. Sampling stratum for smallholder farmers' groundnut producing areas of Chisamba District

Block	Agricultural camp	Agricultural zone	Selected zone
	Chankumba	Chankumba, Kampekete, Kamulombwe, Liteta, Luamabwe, Malombe, Mwanang'ombe, Nalutwi	Chankumba
	Chipembi	Chamuka, Chipembi, Kaputi, Moombe, Mwantaya	Chipembi
Chisamba	Chisamba Central	Chibonde, Chisamba central, Kamano, Momboshi	Momboshi
	Kanakantampa	Kachangwa, Kanakantapa, Mupelekese, Mwapula, Nyakanga	Kachangwa
	Ploughman's	Chisamba ranch, Mupamapamo, Mwansuka	Mupamapamo
	Bombwe	Bombwe, Lombwa,Munema	Bombwe
	Chinkokomene	Chinkokomene, Chungu, Kabanga, Mukobola	Chinkokomene
Muswishi	Chowa	Chowa, Kizito, Kasosolo	Chowa
	Lifwambula	Kabukombo, Libukoshi, Lifwambula	Lifwambula
	Mulungushi	Bulaya, Kachisenga, Kasholola, Kasosolo, Phase 1, Phase 2	Phase 1
	Muswishi	Zone1, Zone 2, Zone 3, Zone 4, Zone 5	Zone 1
2 blocks	11 Camps	49 Zones	11 selected zones

(Source: CSO and MACO 2011, Chisamba District Council Office, Chisamba District Office for Ministry Agriculture and Cooperatives)

The soil pH was measured in a 1:2.5 (w/v) ratio of soil to 0.01 M $CaCl_2$ solution using a glass electrode [23]. Soil texture was determined by sedimentation using the hydrometer [24]. Cation exchange capacity (CEC), was determined by leaching 5 g soil sample with 150 ml 1 M NH_4OAc buffered at pH 7; this was followed by steam distillation and then titration of the distillate with 0.1 N HCl [23]. The Walkley and Black (1934) method was used to estimate the organic carbon of the soils [25]. Organic carbon was then converted to soil organic matter by multiplying by a factor of 1.72 [23]. Total N was measured using the Kjeldhal digestion method [23]. The Bray 1 method was used to determine P [26]. Three grams of the soil sample was extracted in 20 ml 0.025 M HCl and 0.03 M NH_4F in triplicate [26]. The colour developed was then read on the UV-VIS spectrophotometer (Model: Genesys 10 UV). The trace elements Fe, Zn, Cu and Mn were extracted using DTPA [23]. Twenty grams of the soil was weighed and extracted in 40 ml DTPA in triplicate [23]. To determine calcium, magnesium, potassium and sodium, ten grams of the soil sample was weighed into 100 ml plastic bottles and 50 ml ammonium acetate added. The mixture was shaken for 30 minutes and then filtered. For magnesium and calcium, 1 ml of the filtrate was transferred to 25 ml volumetric flasks, 5 ml strontium chloride added and diluted to volume [23]. Both trace elements and cations were determined by the atomic absorption spectrophotometer (AAS), Analyst 400 Perkin Elmer. Total exchangeable bases and exchangeable sodium percentage was computed [23].

Three clods were also sampled per field. These were moistened with a few drops of water to prevent them from breaking, wrapped in tissue and packed in labelled 250 ml plastic bottles. Bulk density was then determined using the clod method where molten wax was used to coat the clod before being suspended in water [23]. Porosity was computed [23,35].

2.2.2 Participatory approach

The second step used focused group discussions as instruments of data collection. Data was collected only for groundnuts. With the help of the District Agricultural Officer, extension officers and traditional zone leaders, smallholder groundnut farmers were convened at the meeting place of an agricultural zone and focused group discussions were held. These were conducted from May 15th to July 15th, 2014. Questions to capture information on the form in which groundnuts were sold, the availability of markets, and contract and credit facilities were asked. The focussed group discussions also captured information on prices, when the smallholder farmers sold their groundnuts and amounts realised from sales.

2.2.3 Use of limitation approach for evaluation of soils for groundnut and maize production

The simple limitation approach was used to determine the suitability of the soils in Chisamba District for groundnut and maize production [20]. In this study, depending on the level of limitations, the land characteristics were assigned numbers ranging from 0 to 5 (Table 2). If a land characteristic was optimal for groundnut production, it had no limitation and it was assigned zero (0). If unfavourable for crop growth and was extremely severe, it was assigned five (5). The FAO [19] framework was then used to define land classes whereby if the land characteristic was optimal, it was assigned S1, and if the limitation was extremely severe, N2 (Table 2). The soil fertility characteristics were first considered alone and then their aggregated score was used to determine the suitability classes as guided by Sys et al. [20].

Market assessment was only determined for groundnuts. If parastatal markets and contracts with seed companies existed, market availability

Table 2. Rating of limitation levels and land suitability classes

	Limitation levels		Land class
0	No limitation	S1	Very suitable
1	Slight limitation		
2	Moderate limitations	S2	Moderately suitable
3	Severe limitations	S3	Marginally suitable
4	Very severe limitations	N1	Unsuitable but susceptible to correction
5	Extremely severe limitations	N2	Unsuitable and non-susceptible to correction

(Source: FAO, 1976; Sys et al., 1991)

was assigned S1. If only contracts with seed companies existed, market availability was assigned S2. If both parastatal markets and contracts with seed companies did not exist, market availability was assigned S3 (Table 2).

2.3 Statistical Analysis

Measure of central tendencies and dispersion and the Pearson's correlation analysis were conducted on the data using SPSS.

3. RESULTS AND DISCUSSION

3.1 Fertility Status of Soils in the Smallholder Farmers' Groundnut Producing Areas of Chisamba District

3.1.1 Soil chemical characteristics

The pH of the soils in groundnut producing areas of Chisamba District ranged from 4.45 to 5.84, with the mean value of 4.95±0.35 (Table 3). According to indices given by Nweke [27] and Haby et al. [28], soils with pH ranging from 4 – 4.99 are ranked as strongly acidic. While pH values of 5 – 5.84 are classed medium acidity. Therefore, most (63.63%) of the soils in the groundnut producing areas were strongly acidic. While 36.37% were of medium acidity. Strong acid soils limit crop production because of toxicity [8,29] induced by Mn^{2+} and exchangeable Al^{3+} [8]. At pH < 5.5, the most labile form of Mn is Mn^{2+} which is phytotoxic [30]. It was also observed that all the soils in the study area had Al^{3+} (Table 4) above the acceptable threshold of 0.011 cmol / kg index given by Haby et al. [28]. Aluminum phytotoxicity in acid soils is one of the major limiting factors in groundnut production [31]. The inhibition of root elongation [32] and subsequent death of the groundnut root tips under Al^{3+} stress prevents the crop to take up water and nutrients [33,32]. This is the reason why acid soils impede crop production [34,35]. Therefore, strong acid soils were one of the limiting factors for groundnut and maize production in the study area.

According to Musinguzi et al. [36], sustainable crop production can only be attained when soils contained 3.44% SOM. The sustainability is achieved because SOM above 3.4% [37], stabilises the soil structure, decreases bulk density and promotes heightened nutrient cycling [37]. Musinguzi et al. [38] later reported that soils with SOM content of 2.06% were susceptible to degradation. Only 15.15% soils had SOM above 3.44%. It follows therefore that only 15.15% of the soils in the study area can be used for sustainable crop production. It was also observed that only 45.45% of the soils had SOM above the threshold of 2.06% [38]. The rest (39.40%) of the soils had SOM below the threshold and were therefore susceptible to soil degradation [38]. Smallholder farmers in the study area practice low external input agriculture [39] and depend on the mineralisation of SOM for crop production [36,38]. Therefore, when low, SOM limited crop production [38].

The Cation Exchange Capacity (CEC) of soils in the groundnut producing areas of Chisamba ranged from 1.20 to 13.60 cmol / kg. The mean of CEC was 3.63±2.73 cmol / kg (Table 3). The CEC can be classified as low because the values were less than 15 cmol / kg [40]. Low CEC is a limiting factor to crop production because the buffering capacity of the soil reduces [41]. When this happens, soluble nutrients tend to leach out of the root zone [29]. The low CEC can be attributed to the high sand (Table 7) and low organic matter content [42,43] of the soils in the study area. Namakka et al. [44] and Czarnecki and Düring [45] reported that high SOM resulted in a corresponding high CEC, giving a positive linear relationship. This explanation can be extended to the low SOM and the corresponding low CEC observed in soils of the study area.

According to Sys et al. [20], total N less than 0.1% was marginally suitable for both groundnut and maize production. Most (84.85%) of the soils in the study area had total N less than 0.1%, with a mean of 0.09±0.04% (Table 3). Therefore, the soils were rated as containing very low total N [20]. The available soil P ranged from 0.0 to 42.91 mg / kg with a mean of 6.62 ± 9.21 mg / kg (Table 3). The critical limit of the soil available P for groundnut production is 10 mg / kg [46]. This means that most (75.76%) of the soils contained P below the critical limit. Therefore, low N and P were other major limiting soil fertility factors hampering groundnut and maize production in Chisamba District. This is in agreement with GART [8] and MAL [22] who reported that inherently low N and P impeded crop production in Zambia. The mean exchangeable Ca^{2+} was observed to be 2.86±2.25 cmol / kg (Table 3). Sys et al. [20] classified Ca2+ to be high (> 10 cmol / kg), medium (5 – 10 cmol / kg) and low (<5 cmol / kg). This means

Table 3. Some chemical properties of soils in the groundnut-producing areas of Chisamba District, Zambia

Field	pH	OM	N	CEC	Na	K	Ca	Mg	P	S
		%				cmol/kg			mg/kg	
Maize	4.86	1.44	0.07	2.80	0.04	0.11	2.40	0.29	7.77	0.49
Peanut	5.05	1.92	0.07	2.70	0.04	0.12	2.31	0.28	1.66	0.42
Maize	5.24	1.60	0.08	4.10	0.03	0.11	6.14	0.55	<0.04	0.60
Peanut	4.99	1.44	0.08	2.90	0.03	0.09	2.70	0.24	0.31	0.48
Maize	4.79	1.84	0.08	4.40	0.04	0.06	2.26	0.19	9.53	0.36
Peanut	4.45	2.00	0.10	1.80	0.03	0.05	2.39	0.14	9.08	0.38
Maize	4.55	1.60	0.06	7.30	0.08	0.05	5.03	0.58	4.99	0.40
Peanut	4.5	2.08	0.07	2.60	0.03	0.05	1.87	0.14	2.43	0.44
Peanut	4.92	3.76	0.20	7.20	0.03	0.16	4.51	0.94	<0.04	0.89
Maize	4.46	2.48	0.20	1.20	0.03	0.06	1.75	0.13	<0.04	1.26
Peanut	4.75	2.32	0.03	2.10	0.03	0.07	1.98	0.14	<0.04	0.61
Peanut	4.57	1.68	0.08	1.90	0.03	0.05	2.14	0.11	1.84	0.37
Maize	4.74	2.48	0.08	2.60	0.03	0.06	1.77	0.18	19.50	0.54
Peanut	4.76	0.40	0.08	3.00	0.04	0.10	2.17	0.29	9.35	0.49
Maize	4.79	0.56	0.07	1.90	0.03	0.06	2.14	0.18	16.98	0.48
Peanut	5.1	1.76	0.08	2.30	0.03	0.07	2.80	0.33	14.15	0.63
Maize	4.91	0.48	0.10	2.50	0.03	0.06	1.62	0.17	<0.04	0.37
Peanut	4.97	1.68	0.08	1.80	0.03	0.04	1.59	0.16	2.52	0.34
Maize	5.34	2.16	0.10	1.90	0.03	0.05	2.05	0.24	2.97	0.40
Peanut	5.06	2.64	0.08	4.80	0.04	0.07	2.46	0.37	10.56	0.49
Maize	4.95	2.08	0.07	2.50	0.03	0.05	3.59	0.34	12.22	0.29
Peanut	4.66	1.84	0.07	3.10	0.02	0.05	2.20	0.15	10.78	0.40
Maize	4.97	2.24	0.08	4.20	0.03	0.10	2.19	0.52	<0.04	0.40
Peanut	4.92	2.24	0.10	11.90	0.03	0.08	2.12	0.46	<0.04	0.38
Maize	5.8	5.76	0.20	13.60	0.04	0.58	6.63	1.38	<0.04	0.93
Peanut	5.84	5.84	0.07	3.20	0.03	0.40	7.20	1.20	<0.04	0.75
Maize	5.4	2.16	0.10	2.80	0.03	0.07	3.12	0.19	4.90	0.41
Peanut	5.29	2.24	0.11	3.00	0.03	0.04	4.73	0.21	6.42	0.45
Maize	5.25	2.00	0.10	2.60	0.02	0.06	2.49	0.22	42.91	0.37
Peanut	5.19	2.08	0.08	2.60	0.04	0.06	2.64	0.29	25.12	0.42
Maize	4.55	1.92	0.08	2.60	0.03	0.07	1.40	0.18	2.47	0.57
Peanut	4.5	2.08	0.07	1.80	0.03	0.06	1.40	0.19	0.09	0.40
Fallow	5.14	4.48	0.14	3.00	0.02	0.21	2.63	1.06	0.04	0.40
Minimum	4.45	0.40	0.03	1.20	0.02	0.04	1.40	0.11	<0.04	0.29
Maximum	5.84	5.84	0.20	13.60	0.08	0.58	7.20	1.38	42.91	1.26
Mean	4.95	2.22	0.09	3.60	0.03	0.10	2.86	0.36	6.62	0.51
Standard deviation	0.35	1.20	0.04	2.73	0.01	0.11	1.50	0.32	9.21	0.20
Method	GE [23]	W & B [25]	MK [23]	1M NH_4Ac [23]	Extraction with neutral NH_4Ac [23]				Bray I [26]	TD [23]

Key: GE = (0.01M CaCl2) Glass Electrode; TD = Turbidimetric Method; W & B = Walkley and Black; MK = Micro-Kjeldhl

that most (87.88%) of the soils had low Ca^{2+} content which impeded groundnut and maize production. The contents of exchangeable Mg^{2+} ranged from 0.11 to 1.38 cmol / kg (Table 3). The distribution of exchangeable Mg^{2+} in the study area was assigned S3 (21.21%) and N1 (57.57%). While the distribution of K^+ was assigned N1 (75.76%) and S3 (18.18%). The limiting fertility contribution level of K^+ and Mg^{2+} towards the assigning of the suitability of the soils in the groundnut producing areas was severe. While the contribution of Ca^{2+}, total N, P and S was marginally suitable.

Table 4. Exchangeable acidity, total exchangeable bases and exchangeable sodium percentage of soils in the groundnut-producing areas of Chisamba District, Zambia

Farm/Village	Field	ESP	TEB	Al^{3+}	H^+	$Al^{3+} + H^+$
		%		cmol /kg		
F. Ndlovu	Maize	1.31	2.72	0.44	0.32	0.76
	Peanut	1.43	2.62	0.60	0.64	1.24
N. M. Chitanga	Maize	0.78	6.72	0.28	0.84	1.12
	Peanut	1.01	2.97	0.16	0.68	0.84
B. Malambo	Maize	0.88	2.49	0.16	0.68	0.84
	Peanut	1.65	2.56	0.16	0.76	0.92
M. Tagwere	Maize	1.09	5.68	0.08	0.80	0.88
	Peanut	1.18	2.04	0.08	0.60	0.68
A. Bwalya	Peanut	0.48	5.48	0.20	0.92	1.12
I. Nyambe	Maize	2.55	1.91	0.04	0.60	0.64
G. Meleki	Peanut	1.60	2.15	0.16	0.64	0.80
H. Chilondola	Peanut	1.64	2.28	0.16	0.80	0.96
M.Nzala	Maize	1.27	1.98	0.02	0.68	0.70
	Peanut	1.18	2.50	0.04	0.52	0.56
D. Siampongo	Maize	1.39	2.35	0.02	0.60	0.62
	Peanut	1.30	3.16	0.08	0.60	0.68
G. Nkomanga	Maize	1.35	1.82	0.20	0.76	0.96
	Peanut	1.75	1.79	0.36	0.76	1.12
I. Munyangwa	Maize	1.58	2.32	0.04	0.64	0.68
	Peanut	0.86	2.86	0.20	0.60	0.80
F. Sakalunda	Maize	1.06	3.95	0.20	0.80	1.00
	Peanut	0.78	2.38	0.60	0.52	1.12
S. Njovu	Maize	0.81	2.75	0.02	1.04	1.06
	Peanut	0.26	2.61	0.56	0.72	1.28
I. Musialela	Maize	0.29	8.04	0.24	0.84	1.08
	Peanut	1.01	8.43	0.28	0.80	1.08
T. Ndlovu	Maize	0.97	3.34	0.28	0.96	1.24
	Peanut	0.90	4.97	0.28	0.88	1.16
M. Banda	Maize	0.92	2.73	0.32	0.44	0.76
	Peanut	1.44	2.96	0.44	0.80	1.24
Mugwagwa	Maize	1.05	1.61	0.32	0.80	1.12
	Peanut	1.65	1.62	1.08	0.36	1.44
GART	Fallow	0.63	3.71	0.64	0.48	1.12
Minimum		0.26	16.10	0.02	0.32	
Maximum		2.55	84.30	1.08	1.04	
Mean		1.15	32.58	0.26	0.69	
Standard deviation		0.46	17.58	0.23	0.17	
Method		Computed		Extracted with 1M KCl [23]		

Key: Al3+ + H+ = Exchangeable acidity; ESP = Exchangeable sodium percentage; TEB = Total exchangeable bases

The distribution of B in the groundnut producing areas of Chisamba District ranged from 0.0 to 2.29 mg / kg, with a mean concentration of 0.58±0.59 mg / kg. The critical limit of water extractable B in soils for groundnut production is 0.5 mg / kg [47]. It was observed that 51.52% soils had B above the critical limit while 48.48% were below. The levels of DTPA extractable Zn ranged from 0.13 to 4.25 mg / kg, with a mean concentration of 0.59±0.76 mg / kg (Table 5). The critical level of DTPA extractable Zn is 0.7 mg / kg [48]. This means that most (72.73%) of the soils in Chisamba District had Zn below the critical limit. Therefore, B and Zn were the micronutrients which were observed to be limiting for both groundnut and maize production.

3.1.2 Correlation analysis of some limiting fertility factors

The relationships between pH_{CaCl2}, CEC, SOM and the concentration of nutrients in the soils of the groundnut producing areas of Chisamba District were reported in Table 6. There was a highly significant and positive relationship between pH_{CaCl2} and the concentration of Ca (r = 0.653, *P* = .000), Mg (r = 0.614, *P* = .000) and K (r = 0.651, *P* = .000). The relationships between CEC and Ca, Mg and K were also positive and highly significant. Since the correlations of Ca, Mg and K concentration with CEC and SOM were positive and highly significant (Table 6), it follows that high CEC and SOM increases the availability of these base cations. On the contrary, Tsozué et al. [49] evaluated acid soils in Cameroon and documented that the correlation between Ca and K with SOM was non-significant. They reported that SOM was not a major factor in the availability of Ca and K in the acid soils of Cameroon. However, in this study, the availability of Ca, Mg and K in the acid soils of Chisamba District depended on SOM and also on pH and CEC. Similarly, Kebeney et al. [29] analysed strongly acid soils in Kenya and reported that there was a positive correlation between Ca, Mg and SOM. They also reported that SOM was a major factor in the availability of Ca and Mg.

Table 5. Micronutrients in the soils of the groundnut-producing areas of Chisamba District, Zambia

Farm/Village	Field	B	Cu	Fe	Mn	Zn
				mg/kg		
F. Ndlovu	Maize	0.00	0.61	26.24	24.74	0.72
	Peanut	0.00	0.57	18.18	39.54	0.48
N. Mukanachitanga	Maize	0.00	0.44	10.72	27.34	0.39
	Peanut	0.17	0.42	17.84	16.14	0.43
B. Malambo	Maize	2.29	0.50	12.10	18.61	0.39
	Peanut	0.00	0.30	11.01	33.59	0.32
M. Tagwere	Maize	0.81	0.52	12.61	64.14	0.24
	Peanut	0.00	0.37	13.42	31.14	0.38
A. Bwalya	Peanut	1.15	2.54	32.38	63.36	0.43
I. Nyambe	Maize	0.08	0.69	26.38	13.09	0.15
G. Meleki	Peanut	0.63	1.39	15.27	17.98	0.24
H. Chilondola	Peanut	0.39	0.24	10.20	10.81	0.16
M. Nzala	Maize	0.23	0.61	40.64	22.78	1.12
	Peanut	0.52	0.54	23.76	62.52	0.85
D. Siampongo	Maize	0.88	1.00	31.32	28.28	1.14
	Peanut	1.14	0.59	13.66	23.66	0.86
G. Nkomanga	Maize	1.94	0.97	11.35	15.38	0.27
	Peanut	1.84	0.75	6.60	21.50	0.16
I. Munyangwa	Maize	0.60	0.59	11.49	19.49	0.63
	Peanut	0.79	0.54	31.86	53.89	0.75
F. Sakalunda	Maize	0.25	0.75	15.60	10.80	0.13
	Peanut	0.23	0.38	7.11	10.73	0.16
S. Njovu	Maize	0.44	0.94	16.28	50.00	0.36
	Peanut	0.54	1.09	22.82	44.20	0.32
I. Musialela	Maize	0.77	4.16	10.56	84.88	4.25
	Peanut	0.68	3.72	9.71	12.48	2.04
T. Ndlovu	Maize	0.78	0.25	8.06	11.90	0.22
	Peanut	0.00	0.29	9.82	6.63	0.23
M. Banda	Maize	0.98	0.21	18.11	10.89	0.18
	Peanut	0.30	0.37	16.00	1.27	0.19
Mugwagwa	Maize	0.60	2.14	13.07	58.88	0.37
	Peanut	0.00	0.97	10.43	23.08	0.27
GART	Fallow	0.00	2.68	19.04	21.00	0.76
Minimum		0.00	0.21	6.60	1.27	0.13
Maximum		2.29	4.16	40.64	84.88	4.25
Mean		0.58	0.97	16.78	28.93	0.59
Standard deviation		0.59	0.98	8.35	20.39	0.76
Method		Extraction with water [23]	Extracted with DTPA then AAS [23]			

Despite the correlation between soil pH_{CaCl2} and total soil N being positive, it was non-significant. It is plausible that pH was not the only factor affecting N availability. The availability of total N depends on CEC and SOM. This is because there was a positive highly significant relationship between CEC and total N (r = 0.404, P = .020). There was also a positive and highly significant correlation between total N (r = 0.487, P = .004) and SOM (Table 6). Similarly, Tsozué et al. [49] reported that total N was significantly correlated with SOM. This means that high SOM increases total N availability. The same explanation can be extended to the relationship between CEC and total N. It follows therefore, that the low SOM and CEC observed in the soils of the smallholder farmers' groundnut producing areas of Chisamba District contributed to the low total N levels documented.

There was a positive non-significant relationship between B (r = 0.128, P = - .181), Zn (r = 0.235, P = .189) and pH_{CaCl2} (Table 6). There was however, a positive highly significant relationship between pH_{CaCl2} and concentration of Cu (r = 0.467, P = .006). All the micronutrients were positively correlated with CEC. The relationships of Cu (P = .004), Mn (P = .000) and Zn (P = .001) with CEC were highly significant. The relationship of SOM with B was negative and non-significant (Table 6). However, the correlation between Cu (r = 0.819, P = .000), Zn (r = 0.646, P = .000) and SOM was positive and highly significant. Therefore, CEC and SOM were factors in the availability of micronutrients in soils of the study area [41].

3.1.3 Soil physical characteristics

The site-specific USDA soil textural classes of soils in the study area were presented in Table 7. It was observed that most (63.64%) of the soils in the study area were loamy sand. Given that groundnuts perform better in sandy loams or loamy sands [50], the soils in the study area were assigned S1 (very suitable) with regard to soil texture class. The bulk density of soils in Chisamba District ranged from 1.24 to 1.69 Mg / m^3, with the mean of 1.61±0.11 Mg / m^3. While the estimated porosity ranged from 36.23 to 53.06%, with a mean of 39.39±4.10%.The bulk densities observed in the study area were lower than 1.82 Mg / m^3 which was reported to impede root growth [51] due to compaction and poor aeration [51,52]. It was observed that there was a strong positive relationship (r = 0.78) between porosity and SOM (Fig. 1b). There was a strong negative correlation (r = -0.78) between SOM and bulk density (Fig. 1a). This is in agreement with Chaudhari et al. [53] who reported that there was a strong negative correlation (r = -0.88) between bulk density and SOM. Keller and Håkansson [54] reported that bulk density decreased with high SOM. Therefore, due to restored SOM, low bulk density was observed in a field that was fallow for 8 years [55]. This is in agreement with the current study where it was observed that the control field (GART which was fallow for 4 years) had SOM content of 4.48±1.20% with a corresponding low bulk density of 1.24±0.11 Mg / m^3.

Fig. 2 showed that there was a negative relationship between bulk density and clay (r = -0.64), and silt (r = -0.78). While Fig. 2c showed that there was a positive linear relationship between sand content and bulk density. This means that the higher the sand content the higher the bulk density. It follows therefore, that high clay [56,54] and clay plus silt [56] results in a decrease in bulk density [56,54]. The current results were in agreement with a well documented empirical relationship between bulk density and porosity of a very strong negative correlation (r = -1) [57].

3.2 Land Suitability Evaluation of Smallholder Farmers' Groundnut Producing Areas of Chismaba District

3.2.1 Land suitability evaluation of soils for groundnut and maize production

Crop-specific requirements for groundnuts and maize (Appendix 1) were used to determine land suitability for groundnuts and maize production in Chisamba District [19,20]. Given that optimum yields of groundnuts are obtained when temperature ranges between 22 – 30ºC and that yields are low at temperature below 18 and above 33 [58], the study area was assigned suitable (S2) with regards to temperature. The fertility properties used included SOM, CEC, pH, N, Ca, K and Mg.

Results for land suitability evaluation of groundnut-growing areas of Chisamba District for groundnuts and maize production were presented in Table 8. It was observed that most (72.22%) of the groundnut fields in the study area were marginally suitable (S3) for groundnut production. Only (5.56%) soils in the study area were very suitable (S1) for groundnut production. It was also observed that the soils in the study area were marginally suitable (68.75%), moderately suitable (12.50%) and very suitable (6.25%) for maize production. Some soils in the study area were ranked N1, and therefore, currently not suitable for both groundnuts (5.56%) and maize (12.50%) production but susceptible to correction. The major limiting soil fertility factors included soil acidity, and low CEC, SOM, Ca, Mg, K and N.

3.2.2 Land suitability evaluation of market availability for groundnut production

Market availability in the groundnut producing areas of Chisamba District was assigned S3 because of the non-existence of contracts with seed companies and parastatal markets. The only available markets the farmers exploited were the small-scale traders (37%), fellow famers (35%) and various buyers (28%) at markets in Lusaka and Kabwe (Fig. 3). Small-scale traders were defined by farmers as traders from other districts who went to purchase groundnuts from them. They said the traders can either be stationed at one point and then farmers go to sale to them or mobile whereby the traders go from village to village to buy groundnuts. It was observed that groundnuts are sold virtually throughout the year, with October being the pick month for sales (Fig. 4). The farmers revealed that early maturing varieties were sold from January to May (Fig. 4) as fresh unshelled groundnuts at the markets of nearest towns. While, from June to December, other varieties and shelled groundnuts were sold to available buyers.

Table 6. The Pearson's correlation analysis of fertility factors

Nutrient	pH		Cation exchange capacity		Soil organic matter	
	Pearson's correlation	*P* value	Pearson's correlation	*P* value	Pearson's correlation	*P* value
N	0.224	.209	0.404	.020*	0.487	.004**
P	0.051	.778	-0.211	.238	-0.227	.203
S	0.144	.431	0.22	.227	0.542	.001**
K	0.651	.000**	0.574	.000**	0.814	.000**
Ca	0.653	.000**	0.48	.005**	0.601	.000**
Mg	0.614	.000**	0.628	.000**	0.829	.000**
B	0.128	.181	0.144	.425	-0.098	.587
Cu	0.467	.006*	0.487	.004**	0.819	.000**
Fe	-0.19	.29	0.072	.692	-0.04	.825
Mn	-0.025	.889	0.665	.000**	0.204	.254
Zn	0.235	.189	0.549	.001**	0.646	.000**

*** Correlation is significant at the level of 0.01*
**Correlation is significant at the level of 0.05*

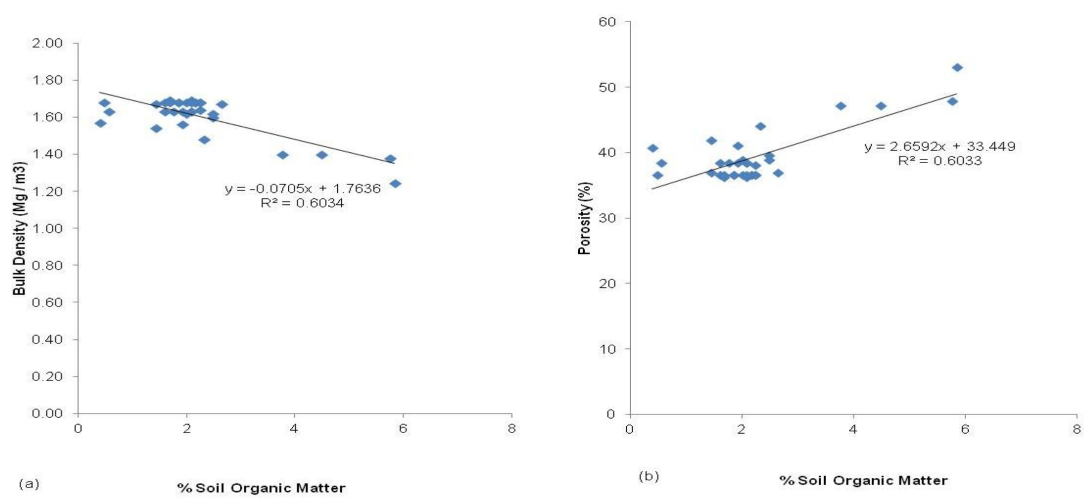

Fig. 1. The relationship between soil organic matter and bulk density and porosity

Table 7. Site-specific physical properties of soils in the groundnut producing areas of Chisamba District

Farm/Village	Field	Coordinates (UTM)		Sand	Clay	Silt	USDA textural
		X	Y		%		Class
F. Ndlovu	Maize			66.4	11.6	22	Sandy Loam
	Peanut	683628	8380378	80.4	11.6	8	Sandy Loam
N. Mukanachitanga	Maize			84.4	5.6	10	Loamy Sand
	Peanut	647811	8368626	80.4	5.6	14	Loamy Sand
B. Malambo	Maize			86.4	5.6	8	Loamy Sand
	Peanut	673612	8404357	86.4	5.6	8	Loamy Sand
M. Tagwere	Maize			84.4	7.6	8	Loamy Sand
	Peanut	678035	8389016	86.4	7.6	6	Loamy Sand
A. Bwalya	Peanut	618009	8372514	56.4	25.6	18	Sandy Clay Loam
I. Nyambe	Maize	629219	8351073	84.4	9.6	6	Loamy Sand
G. Meleki	Peanut	670731	8349000	74.4	19.6	6	Sandy Loam
H. Chilondola	Peanut	662787	8332213	90.4	5.6	4	Sand
M. Nzala	Maize			74.4	7.6	18	Sandy Loam
	Peanut	680998	8380226	68.4	9.6	22	Sandy Loam
D. Siampongo	Maize			84.4	7.6	8	Loamy Sand
	Peanut	673100	8402287	84.4	7.6	8	Loamy Sand
G. Nkomanga	Maize			82.4	5.6	12	Loamy Sand
	Peanut	690964	8378549	84.4	5.6	10	Loamy Sand
I. Munyangwa	Maize			82.4	5.6	12	Loamy Sand
	Peanut	668325	8368466	78.4	5.6	16	Loamy Sand
F. Sakalunda	Maize			90.4	5.6	4	Sand
	Peanut	665573	8330290	86.4	5.6	8	Loamy Sand
S. Njovu	Maize			86.4	7.6	6	Loamy Sand
	Peanut	670552	8349004	86.4	5.6	8	Loamy Sand
I. Musialela	Maize			42.4	25.6	32	Loam
	Peanut			56.4	1.6	42	Sandy Loam
T. Ndlovu	Maize			86.4	5.6	8	Loamy Sand
	Peanut	664994	8332331	86.4	5.6	8	Loamy Sand
M. Banda	Maize			76.4	7.6	16	Sandy Loam
	Peanut			82.4	7.6	10	Loamy Sand
Mugwagwa	Maize			82.4	7.6	10	Loamy Sand
	Peanut			84.4	5.6	10	Loamy Sand
GART	Fallow	618088	8344811	56.4	25.6	18	Sandy Clay Loam

The non-significant relationship between gender and buyers of groundnuts (r = 0.137, *P* = .058) showed that gender was not a factor in choosing the buyer. However, gender was a factor in selling groundnuts in towns near Chisamba District (e.g. Kabwe or Lusaka). This is because there was a positive and highly significant relationship between gender of the smallholder farmer and sale of groundnuts at markets of nearest towns (r = 0.202, *P* = .005). This relationship can be attributed to transport costs incurred when sales are made in nearest towns. Female farmers disclosed that the sale of groundnuts locally minimised transportation costs. There was also a positive and highly significant relationship between sale of groundnuts at markets of nearest towns and the various buyers the farmers sold to at these markets (r = 0.605, *P* = .000). This can be explained by pricing of the commodity. The farmers disclosed that the price of a 50 kg bag of shelled nuts was k 250 ($ 45.45) in 2013. While a 50 kg bag of unshelled nuts was sold at k 100. However, the price of kernels in Lusaka or Kabwe was much higher than in the District. It was concluded therefore, that the socio-economic factor such as poor market availability was also one of limiting factors which influenced the assigning of groundnut producing areas of Chismba District as marginally suitable (S3).

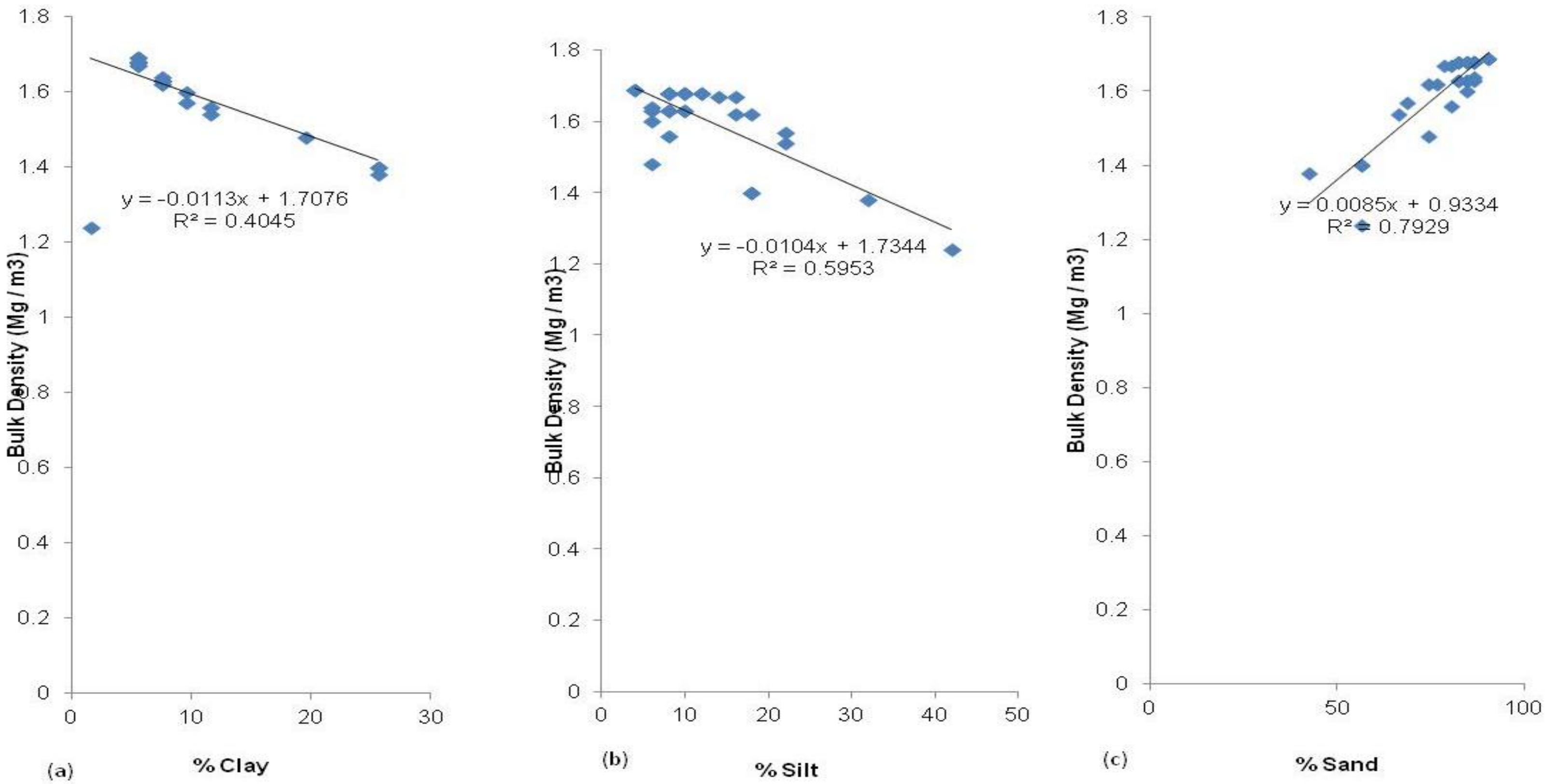

Fig. 2. The relationship between bulk density and clay, silt and sand content of soils in Chisamba

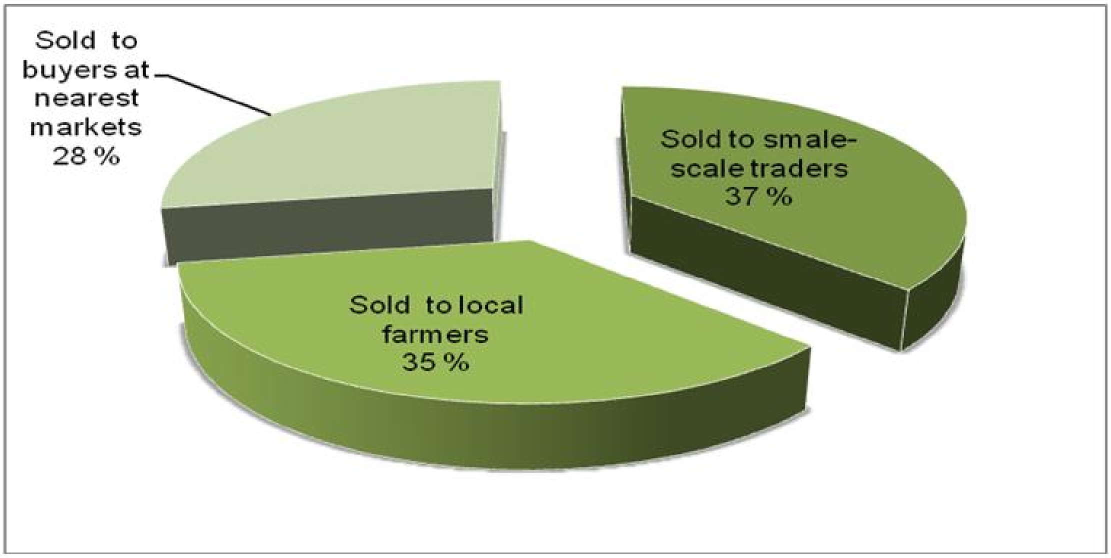

Fig. 3. Buyers of groundnuts produced by smallholder farmers in Chisamba District

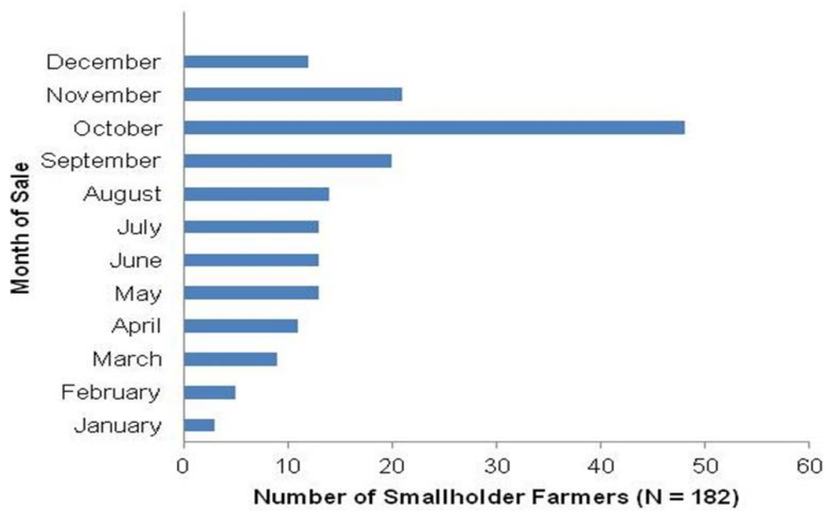

Fig. 4. Period when smallholder farmers in Chisamba District sold groundnuts

3.3 Measures to Improve Soil Suitability for Groundnut and Maize Production in Chisamba District

To improve groundnut and maize production in the smallholder groundnut producing areas liming of acid soils is recommended [8]. Given that 45.45% of the soils had SOM below the threshold of 2.06% [38], it is pertinent to increase SOM levels in the soils [59] of the groundnut producing areas of Chisamba District. Increasing the SOM levels in smallholder farming systems can be achieved by retention of crop residues [60], addition of both green [59] and animal manure [60,61] and minimising tillage of land [62]. Additionally, SOM levels in soils of the study area can be improved by adopting cropping systems that can potentially increase crop residues such as mixed cropping [20], intercropping [63,64] and crop rotation [65]. Fertiliser use can result in improved yields with a corresponding increase in SOM through roots and above ground organic substrates [12]. Given the variability of smallholder farmers in resource endowment, the above recommendations can easily be attained by implementation of integrated soil fertility management [66].

Table 8. Overall soil – site specific fertility suitability for groundnut and maize production in Chisamba District

Village/Farm identity	Field suitability class	
	Groundnut	Maize
Fanwell Ndlovu	S3	S3
Nicolas Mukanachitanga	S3	S2
Beauty Malambo	S3	S3
Misheck Tagwere	S3	S3
Alice Bwalya	S2	fna
Gladys Meleki	S3	fna
Handiya Chilondola	N1	fna
Imasiku Nyambe	fna	S3
Mazuba Nzala	S3	S3
Doris Siampongo	S3	N1
Godwell Nkomanga	S3	N1
Ireen Munyangwa	S3	S3
Francis Sakalunda	S3	S3
Suzen Njovu	S3	S3
Inutu Musialela	S1	S1
Thomas Ndlovu	S2	S3
Maureen Banda	S3	3
Mugwagwa	S3	S3
Gart Fallow Field	S2	S2

Key: fna = Field not available; S1 = Very suitable; S2 = Moderately suitable; S3 = Marginally suitable and N1 = Unsuitable but susceptible to correction

4. CONCLUSION

The site-specific fertility status of the soils was determined to be poor. It was observed that three quarters of the soils in the study area were marginally suitable for both groundnut and maize production. The use of both physical and chemical properties and socio-economic factors to determine land suitability was more rigorous. It revealed a lot of additional information affecting groundnut production. The limiting fertility factors which affected both groundnut and maize production in Chisamba District were soil acidity, low Ca, Mg, K, N, SOM and CEC. Additionally, groundnut production was limited by lack of stable markets.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDICES

Appendix 1. Crop-specific fertility requirements and rating of soil for groundnut and maize production

Crop	Land characteristic	Land class and degree of limitation					
		S1		S2	S3	N1	N2
	Climate	0	1	2	3	4	5
Groundnuts	Rainfall (mm)	1000 - 1200	800 - 999	700 - 799	400 - 699	>400	>200
	Temperature range (ºC)	22 - 30	14 – 27				
	Physical Characteristics						
	Texture (USDA Class)	Sandy loam	loamy sand	Loam	Sandy clay loam	Sand	Clay
	Soil Fertility Characteristics						
	pH 0.01M CaCl2	5.0 - 5.5	4.99 - 5.0	4.79 - 4.98	4.5 - 4.78	4.0 - 4.49	<4
	Organic Matter (%)	>6	4.0 - 6.0	2.0 - 3.99	1.0 - 1.99	<1.0	
	CEC (cmol / kg)	>10	8.0 - 10.0	6.0 - 7.99	3 - 5.99	<3	
	Calcium (cmol / kg)	>10	5.0 - 10.0	3.8 - 4.99	2.6 - 3.79	1.0 - 2.59	<1.0
	Magnesium (cmol / kg)	>1.4	0.9 - 1.4	0.6 - 0.9	0.3 - 0.59	<0.3	
	Potassium (cmol / kg)	>0.5	0.3 - 0.5	0.2 - 0.29	0.1 - 0.19	<0.1	
	Nitrogen (%)	0.3	0.2 - 0.3	0.1 - 0.19	<0.1		
	Salinity: ESP (%)	0.0	0.0 - 10	10.0 - 15.0	15 - 20	20 - 25	>25
Maize	**Soil fertility characteristics**						
	pH 0.01M CaCl2	5.8 - 6.0	5.5 - 5.79	5.2 - 5.49	5.0 - 5.19	4.5 - 4.99	<4
	Organic Matter (%)	>3.4	2.6 - 3.39	1.21 - 2.59	0.86 - 1.20	<0.86	
	CEC (cmol / kg)	>10	8.0 - 10.0	6.0 - 7.99	3 - 5.99	<3	
	Calcium (cmol / kg)	>10	5.0 - 10.0	3.8 - 4.99	2.6 - 3.79	1.0 - 2.59	<1.0
	Magnesium (cmol / kg)	>1.4	0.9 - 1.4	0.6 - 0.9	0.3 - 0.59	<0.3	
	Potassium (cmol / kg)	>0.5	0.3 - 0.5	0.2 - 0.29	0.1 - 0.19	<0.1	
	Nitrogen (%)	0.3	0.2 - 0.3	0.1 - 0.19	<0.1		
	Salinity: ESP (%)	0	0.0 - 10	10.0 - 15.0	15 - 20	>20	

Adapted from FAO 1976; FAO 2009; Sys et al., 1991, and MAFF 2000

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