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Soil Nutrient Status of Smallholder Cassava Farms in Southern Ethiopia

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Abstract
This study investigates the soil nutrient status of cassava farms in Wolaita, Southern Ethiopia. Soil samples were randomly collected form 12 cassava farms and soil management practices on the farm were also recorded. The samples were analyzed for physical and chemical properties. The result reveled that cassava in the study sites was cultivated under low to no fertilizer application in which farmers applied phosphorous (P) and nitrogen(N) fertilizer ranging from nil to 32.2 kg/ha P_2O_5 and nil to 19.2 kg/ha, respectively. Non- use of organic fertilizer and complete removal of crop residues from the field were also common farm practices. The physico-chemical properties of cassava farms revealed clay textural class with an ideal bulk density (1.06 to1.35 gcm^{-3}). The soil pH was strong to moderate acidity (pH 5.0–6.1). The farms were very low to low in their organic carbon (1.2–2.5%) and total N content was low (< 0.2%). The soil available P was below the critical level (< 30 mg kg^{-1}) in 100% of the cassava farms, while 92% of the studied soils showed sulfur (S) deficiency (< 20 mg kg^{-1}). Exchangeable calcium (Ca) on 83% of farms was low (< 5 Cmol (+) kg^{-1}), while magnesium (Mg) was under medium category. Potassium (K) to Mg varied from 0.4:1 to 0.9:1. Thus, Mg induced K deficiency was speculated on 75% of cassava farms. The result regarding micronutrient status indicated that boron (B) and copper (Cu) in 100% of the cassava farms were deficient. Lower content of iron (Fe) on 33% and zinc (Zn) on 17% farms was also recorded. All soil samples were adequate in manganese. Regardless of their share, about 57% essential elements derived from soil (N, P, K, S, B, Cu, Fe and Zn) were found limiting nutrients to cassava production in the study area. Thus, correcting the limitation through balanced fertilizer application is needed. Further study is suggested in order to have firm conclusion.
Keywords: Cassava, Ethiopia, Nutrient, Soil, Wolaita

1. INTRODUCTION

Cassava has become very significant crop globally for generating income and food security (Abah and Petja, 2016). Cassava is an important source of calories for millions of people in the world. It can grow on a wide variety of soils within a temperature of between 25 and 29°C, and with a rainfall range of 500 to 1500 mm. Cassava can grow on level to moderate slope and does not require much water for growth (Titus *et al*., 2011).

Woliata area in southern region of Ethiopia is known for the production of a varied number of agricultural produce such as grains crops, roots and tuber crops, legumes, and fruits. In some districts of Wolaita zone, cassava is among widely cultivated crops. It is cultivated by smallholder farmers' holdings including marginal lands. Meanwhile, farmers around Wolaita area are experiencing lower yield of different crops than the national average and potential productivity (Fanuel, 2015). The limited use of modern inputs is a major characteristic of crop production in Ethiopia and it seems to be a major explanation for its current low productivity (EIAR, 2015). In addition, continuous cropping without adequate restorative practices may also cause soil fertility decline or nutrient depletion and have resulted in low yields.

Nevertheless, the existing soil management practices and soil nutrient status in the cassava fields of Wolaita are not well documented. It is, therefore, necessary to evaluate the soil nutrient status of cassava farms. This is because crop productions in these areas are highly intensified due to small land sizes; and received inadequate management practices. Accordingly, the fields are expected to prone to physical and chemical degradation due to aforementioned farm practices. Hence, assessing the soil fertility status is imperative to identify yield limiting nutrients, design better soil management practices and thus to solve the problem of low productivity. Thus, the following study aimed at investigation farm management practices and soil fertility status of cassava fields was conducted.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The study was conducted in selected 12 *Kebeles* (small administrative units) of Sodo Zuria district, Wolaita zone, Southern Nations', Nationalities' and Peoples' Regional State (SNNPRS) of Ethiopia during 2013. The study district has minimum and maximum average annual temperature of 14.3 and 25.6 ^{0}C, respectively; with the average annual rainfall of 1200 mm (NMA, 2013). The area has a bimodal rainfall pattern with mean annual precipitation of 1355 mm. Eutric Nitisols associated with Humic Nitisols are the most prevalent soils (Tesfaye, 2003). Agriculture in the study area is predominantly small-scale mixed subsistence farming. The farming system is mainly based on continuous cultivation without any fallow periods. The location, *Kebeles,* elevation, slope and topographic categories of study sites are listed in Table 1. Location was recorded using the GPS (geographical positioning system) receiver (model Garmin GPSMAP 60Cx) whereas slope was measured using a clinometer.

Table 1: Location of cassava growing farms

Kebele	Long	Lat	Elevation (m.a.s.l)	Slope (up) (%)	Slope (down) (%)	Topography
Bukema Fekeka	37.63214	6.81617	1821	9	11	SL
Bukema Fekeka	37.61879	6.80106	1786	5	5	GS
Bukema Fekeka	37.62642	6.80423	1801	2	4	GS
Tome Gerera	37.61896	6.77331	1709	3	5	GS
Tome Gerera	37.65974	6.77197	1791	6	8	GS
Tome Gerera	37.67070	6.77002	1818	4	5	GS
Mante Gerera	37.62083	6.77858	1721	9	10	SL
Mante Gerera	37.63532	6.78528	1752	10	12	SL
Mante Gerera	37.65805	6.78249	1811	4	6	GS
Kodo Gawle	37.66803	6.81104	1842	10	12	SL
Kodo Gawle	37.64147	6.81385	1827	11	12	SL
Woyde Mesena	37.64331	6.83802	1859	11	12	SL

SL= strongly slopping, GS=Gentle Slope

2.2. Soil Sampling Procedure and Laboratory Analysis

A total of 12 soil samples were collected randomly from cassava farms of five *Kebeles.* These farms belonged to smallholder farmers of the study area. From each field, relevant information regarding topography, cropping history, soil fertility management practices and estimated yield was recorded using a short structured questionnaire. Sampling fields were georeferenced using the Geographical Positioning System (GPS). The survey was conducted during 2013.

Soil samples were taken from 0-20 cm depth. The disturbed and undisturbed soil samples were taken using augur and core sampler, respectively. About 10 to 15 sub-samples from each field were taken to form one kg composite sample. After soil processing (drying, grinding and sieving), soil physicochemical properties like texture, pH, soil organic carbon (OC), macro and micronutrient contents and cation exchange capacity (CEC) were analyzed.

The soil air-dry color was described using Munsell soil color chart (KIC, 2000). Particle size distribution (PSD) was analyzed by laser diffraction method using laser scattering particle size distribution analyzer (Horiba- Partica LA-950V2) (Stefano *et al*., 2010). Soil bulk density (BD) was determined using the core method as described by Anderson and Ingram (1993).

Soil pH (1:2 soil: water suspension) was measured with a glass electrode (model CP-501) (Mylavarapu, 2009). Available phosphorous (P), available sulfur (S), exchangeable basic cations (calcium (Ca), potassium (K), magnesium (Mg) and sodium (Na)) and extractable micronutrients (boron (B), copper (Cu), iron (Fe_, manganese (Mn) and zinc (Zn)) were determined using Mehlich-III multi-nutrient extraction method (Mehlich, 1984). The concentration of elements in the supernatant was measured using inductively coupled plasma (ICP) spectrometer. Mid-infrared diffused reflectance spectral analysis was also used to determine the amount of soil organic carbon (OC), total nitrogen (N) and cation exchange capacity (CEC). The available soil Mn content was determined using manganese activity index (MnAI) as described by Karltun*et al.* (2013).

MnAI=101.7-(15.2*pH) +3.75*Mn_soil

where: pH is pH(H_2O) and Mnsoil is the concentration of Mehlich-III extracted manganese.

Particle size distribution, pH, OC, TN, CEC were analyzed at the National Soil Testing Center (NSTC), Addis Ababa, Ethiopia while Ca, Mg, K, Na, B, Cu, Fe, Mn and Zn were analyzed in Altic B.V., Dronten, The Netherlands.

2.3. Statistical Analysis

Descriptive statistics such as mean, standard deviation, minimum, maximum and median was employed. Variation in soil properties was determined using the coefficient of variation (CV) and rated as low (< 20%), moderate (20 - 50%) and highly variable (> 50%) according to Aweto (1982) *cited in* Amuyou *et al.* (2013). Data analysis was carried out using Statistical Package for Social Sciences (SPSS) software version 20.

3. RESULTS AND DISCUSSION

3.1. Soil Management Practices of Cassava Farms

Information regarding soil management practices of farmers at the sampling sites is presented in Table 2. Cassava growing farmers have been using only two types of inorganic fertilizers supplying N and P in the form of di-ammonium phosphate (DAP) (18 % N, 46 % P_2O_5) and urea (46 % N). The amount of P-in P_2O_5 varied from nil to 32.2 with mean value of 6.12 kg/ha, while, the N application varied from nil to 19.2 kg/ha with average amount of 3.6 kg/ha. The result in general suggested the limited use of fertilizer (organic and inorganic) for cassava production (Table 2). Furthermore, complete removal of crop residues from the farm has been commonly practiced (Table 2). Consequently, estimated cassava yield varied form 6-10 ton/ha (Table 2). This might be liked to inadequate soil management practices. This is in line with Fanuel *et al.* (2016) who associated lower yield with inadequate soil management practices.

Table 2: Soil Management Practices and Yield of cassava growing farms

Sample Site	Inorganic Fertilizer			Organic Fertilizer		Residue Mag't	Estimated Yield (ton/ha)
	Received	**P_2O_5 (kg/ha)**	**N (kg/ha)**	**Received**	**FYM (ton/ha)**		
Bukema Fekeka	Yes	13.8	19.2	No	0	C	6.0
Bukema Fekeka	No	0	0	No	0	C	10.0
Bukema Fekeka	No	0	0	No	0	C	6.0
Tome Gerera	No	0	0	No	0	C	10.0
Tome Gerera	Yes	27.6	10.8	No	0	C	NA
Tome Gerera	No	0	0	No	0	C	NA
Mante Gerera	No	0	0	No	0	C	NA
Mante Gerera	Yes	32.2	12.6	No	0	C	NA
Mante Gerera	No	0	0	Yes	0.6	C	NA
Kodo Gawle	No	0	0	No	0	C	NA
Kodo Gawle	No	0	0	No	0	C	NA
Woyde Mesena	No	0	0	No	0	C	NA
	Mean	**6.12**	**3.6**	**Mean**	**0.1**	**Mean**	8.00

C= Complete removal

3.2. Physical Properties

The results of soil texture, as presented in Table 3, revealed that the particle size distribution of samples from cassava farms was dominated by clay fraction (above 68%). The clay fraction of soils ranged from 68 to 96% with a mean of 82%. Thus the farms are categorized under clay textural classes (Table 2). This is supported by Fanuel (2015) who reported high clay contents in Sodo Zuria district of southern Ethiopia.

The hue index of soils indicated 2.5YR, 5YR and 10R, while the value and chroma of soils varied from (3-4) and (3-6), respectively (Table 3). The soil colors of cassava farms have dominantly reddish color. Soil bulk density (BD) of cassava farms ranged from 1.06 to1.35 gcm^{-3} with an average value of 1.18 g cm^{-3} (Table 2). The effect of soil BD for plant root growth depends on soil texture. Hazelton and Murphy (2007) indicated 1.4 g cm^{-3} as critical BD value for clay texture soils. Thus, cassava farms in the present study were ideal for proper root development.

Table 3: Physical Parameters of cassava growing farms

Sample Site	Sand (%)	Silt (%)	Clay (%)	Texture	Hoe	Value	Croma	Color	Bulk density ($gmcm^{-3}$)
Bukema Fekeka	6	11	83	Clay	2.5YR	3	6	Dark Red	1.10
Bukema Fekeka	9	14	77	Clay	10R	3	4	Duskey Red	NA
Bukema Fekeka	7	14	79	Clay	2.5YR	3	4	Dark Reddish Brown	NA
Tome Gerera	12	14	74	Clay	10R	3	4	Duskey Red	NA
Tome Gerera	6	10	83	clay	2.5YR	3	4	Dark Reddish Brown	1.06
Tome Gerera	14	18	68	clay	5YR	4	4	Reddish Brown	1.20
Mante Gerera	1	3	96	clay	2.5YR	3	4	Dark Reddish Brown	NA
Mante Gerera	5	9	86	clay	2.5YR	3	3	Dark Reddish Brown	NA
Mante Gerera	7	12	81	clay	2.5YR	3	4	Dark Reddish Brown	1.19
Kodo Gawle	3	5	92	Clay	2.5YR	4	4	Reddish Brown	1.35
Kodo Gawle	7	11	82	clay	2.5YR	3	4	Dark Reddish Brown	1.19
Woyde Mesena	6	11	83	clay	5YR	4	4	Reddish Brown	1.20
Mean	**7.0**	**11.0**	**82.0**			**3.3**	**4.1**		**1.18**
SD	**3.0**	**4.0**	**7.0**			**0.5**	**0.7**		**0.09**
CV (%)	**48**	**37**	**9**			**14**	**16**		**8**

NA= Data not taken

3.2. Chemical Properties

Soil pH

Variability of soil pH among cassava farms was found under low (CV < 20%) category. Thus, the pH ranged from 5.0 to 6.1 with a mean and median 5.4 and 5.5, respectively (Table 4). The pH of soils collected from cassava farms were qualified under strongly acidity (pH < 5.5) for 67% farms and moderate acidity (5.6 – 6.5) for 33% of farms (EthioSIS, 2014). According to Titus *et al*., (2011) cassava tolerates wider soil pH ranges (4.0 to 8.0); however, the best pH range for growing cassava is 5.5 to 6.5. In this regards, majority of farms growing cassava in the study area needs reclamation. The observed pH in the study area might be associated with removal of bases through crop harvest and leaching of basic cations. This is supported by Yihenew *et al.* (2015), Fanuel (2015) and Abah and Petja (2016).

Soil organic carbon (OC) and total N (TN)

The OC content of cassava farms in the study sites showed moderate variability (20-50%). Accordingly, OC was found in the range of 1.2– 2.5% with a mean and median 1.8 and 1.8%, respectively (Table 4). These values fall under low to very low (< 2%) to low (2 - 4%) range based on the ratings of soil test values established by Landon (2014). Total nitrogen levels vary between 0.1 and 0.2%. The mean and median values were 0.1 and 0.13, respectively (Table 2). In terms of total N, cassava growing farms were rated as very low to low (< 0.2%) considering the ratings of Landon (2014) for tropical soils. The OC and TN values are similar to most cultivated soils of Ethiopia (Hillete *et al.,* 2015; Fanuel *et al.*, 2016) which is attributed to complete removal of biomass from the field, lower organic input application, and rapid rate of mineralization.

Available P

The soil available P content in the cassava farms varied from 0.05 to 4.30 mg kg^{-1}with a mean value of 2.0 ± 1.2 mg kg^{-1} in which higher variability of available P among cassava farms was recorded (Table 4). In the study sites, higher variability may be attributed to differences in management e.g. varied P fertilizer application (Table 2). Available P levels are below the critical level (30 mg kg^{-1}) suggested by EthioSIS (2014) that limits cassava production. This recalls the need for enhancing the level through fertilizers. The low content of available P can be explained by the presence of low pH, low P fertilizer application rate and continues losses from the field. This result is in agreement with the findings of (Tekalign *et al*., 2002 and Teshome *et al.,* 2013; Fanuel *et al.*, 2016).

Available Sulfur

Mehlich 3 extractable sulfur (sulfate-S) in the cassava farms ranged from 8.6 to 24.3 mg kg^{-1}. It showed moderate variability with mean and median of 14.5 and 13.4 mg kg^{-1} (Table 4). Almost all of cassava farms were found deficient assuming the critical level adopted in Ethiopia (20 mgkg^{-1}) (EthioSIS, 2014). Lower soil organic matter content, non-use of external S application, soil acidity and up take by crops attributed to deficiency of S in the study area. In confirmation with this study Solomon *et al.* (2001), Habtamu *et al.* (2015), Hillete *et al.,* (2015) and Fanuel *et al.* (2016) reported deficiency of S on the cultivated fields of different parts of Ethiopia. This was further supported by Fanuel (2015) and Fanuel *et al.* (2016) who reported deficiency of S in the study area.

Table 4. Chemical Parameters of cassava growing farms

Sample Site	pH-H_2O	OC	TN	P	S	Ca	Mg	K	Na	K:Mg	CEC
		%	%	mg kg^{-1}	mg kg^{-1}		Cmol kg^{-1}			-	Cmol kg^{-1}
Bukema Fekeka	5.2	1.8	0.12	0.05	24.3	2.2	0.8	0.5	2.3	0.6	18
Bukema Fekeka	5.8	1.7	0.11	1.80	8.6	5.4	1.8	1.0	0.4	0.6	19
Bukema Fekeka	5.7	1.6	0.11	2.10	11.5	4.7	1.7	0.9	0.6	0.5	19
Tome Gerera	5.5	1.2	0.07	3.00	16.9	3.6	1.3	0.6	1.5	0.5	17
Tome Gerera	5.5	1.8	0.15	3.50	11.1	4.6	1.4	0.8	0.5	0.6	18
Tome Gerera	5.5	1.6	0.13	4.30	11.6	4.6	1.3	0.8	0.6	0.6	17
Mante Gerera	5.6	2.4	0.19	0.80	11.9	3.2	1.2	0.9	0.5	0.8	17
Mante Gerera	5.0	1.8	0.13	3.00	16.0	2.5	0.9	0.7	0.5	0.8	17
Mante Gerera	5.2	2.5	0.22	1.80	19.5	3.6	1.4	1.2	1.7	0.9	18
Kodo Gawle	6.1	1.2	0.10	1.40	10.4	5.1	1.9	0.8	0.6	0.4	18
Kodo Gawle	5.1	2.0	0.17	1.20	17.2	2.7	0.9	0.4	0.8	0.4	19
Woyde Mesena	5.1	1.8	0.14	1.20	14.8	1.9	0.6	0.3	0.5	0.5	17
Mean	**5.4**	**1.8**	**0.1**	**2.0**	**14.5**	**3.7**	**1.3**	**0.7**	**0.9**	**0.6**	**17.8**
SD	**0.3**	**0.4**	**0.04**	**1.2**	**4.5**	**1.2**	**0.4**	**0.3**	**0.6**	**0.1**	**0.8**
Median	**5.5**	**1.8**	**0.13**	**1.8**	**13.4**	**3.6**	**1.3**	**0.8**	**0.6**	**0.6**	**18.0**
CV%	**6**	**22**	**30**	**61**	**31**	**32**	**32**	**35**	**70**	**24**	**5**

Exchangeable bases and cation exchange capacity

Exchangeable bases except Na among cassava farms showed moderate variability. The exchange site was dominantly occupied by Ca followed by Mg. The range of exchangeable Ca was 1.9-5.4 Cmol (+) kg^{-1}, Mg (0.6-1.8 Cmol (+) kg^{-1}), K (0.3-1.2 Cmol (+) kg^{-1}) and Na (0.4-2.3 Cmol (+) kg^{-1}) with mean values of 3.7, 1.3, 0.7 and 0.9 Cmol (+) kg^{-1}, respectively (Table 4). Majority of cassava farms (83%) were found low in exchangeable Ca (2–5 Cmol (+) kg^{-1}) and medium (1.0 - 3.0 Cmol (+) kg^{-1}) in exchangeable Mg (Landon, 2014); while exchangeable K was rated as optimum (0.51-1.5 Cmol (+) kg^{-1}) (EthioSIS, 2014). The exchangeable sodium percentage (ESP) was below 15% and too low to cause sodicity.

It has been suggested that the proportions of the basic cations of the effective cation exchange capacity are more relevant to plant performance than the actual levels (Hazelton and Murphy, 2007 and Landon, 2014).

This is important to identify antagonistic effects existed due to disproportionate quantities of exchangeable cations in the soil. In the present study, K to Mg ratio varied from 0.4:1 to 0.9:1 (Table 4), in which Mg induced K deficiency was speculated on 75% of cassava farms when considering 0.7:1 for clay soils (Loide, 2004). Similar findings in Ethiopia were reported by Hillete *et al.*, 2015; Fanuel *et al.* (2016). The Mg induced K deficiency may be due to K adsorption to cation exchange sites, K fixation capacity of clay mineral and continuous K removal without application of K containing fertilizers (Dobermann *et al.,* 1996; Hillete *et al.*, 2015; Fanuel *et al.* (2016). These soils however require fertility enhancement with organic/inorganic fertilizers for optimal crop production.

Data regarding cation exchange capacity (CEC) showed lower variability among cassava farms (Table 4). It varied from 17-19 Cmol (+) kg^{-1} with mean and median value of 17.8 and 18.0 Cmol (+) kg^{-1}. According to the rating of Landon (2014), CEC of the cassava farms were under moderate (15-25) category.

Micronutrients

The range, mean and median (mg kg^{-1}) values of micronutrients for cassava farms in their order are as follows (Table 5): B ([0.3-0.6], 0.4, 0.4), Cu ([0.01-0.5], 0.3, 0.35), Fe ([45-107], 84, 84), MnAI ([514-904], 643.0, 611) and Zn ([1.3-4.8], 2.8.2.6). In this study, Fe, Mn were found to be low in their variability (CV=20-50%), whereas, B, Cu and Zn showed moderate variability (CV > 50%). Considering the ratings proposed for Ethiopian soils by EthioSIS (2014), cassava farms were grouped under very low (< 0.5) and low (0.5 – 0.8) level of B; and very low (< 0.5) and low (0.5 – 0.9) category of Cu. The content of Fe was qualified under low level (< 80 mg kg^{-1}) for 33% of cassava farms, while the remaining farms showed optimum (80 – 300) level (EthioSIS, 2014). All farms showed Mn content above 25 mg kg^{-1}, which is a critical level for Ethiopian soils (EthioSIS, 2014). Zinc level (mgkg^{-1}) varied from low (1-1.5) to optimum (1.5–10) levels, however, the lower Zn content was recorded on two cassava farms (i.e. 17%). Regardless of distribution, cassava growing farms in the present study were limited by B, Cu, Fe and Zn deficiencies. This recalls the need for immediate intervention to improve cassava production. In confirmation with this study deficiency of B (Tegbaru, 2014; EthioSIS, 2014; Eyob *et al.* 2015; Fanuel *et al.*, 2016), Cu (Fanuel, 2015; EthioSIS, 2014), Fe (EthioSIS, 2014) and Zn (Tegbaru, 2014; EthioSIS, 2014; Hillete *et al.*, 2015) in Ethiopia were reported. The deficiency might be attributed to low level of soil OM, nutrient mining, and non-use of Cu containing fertilizer.

.Table 5. Micronutrient status of cassava growing farms

Sample Site	B	Cu	Fe	Mn	MnAI	Zn
			mg kg^{-1}			
Bukema Fekeka	0.3	0.1	79	131	514	1.8
Bukema Fekeka	0.3	0.4	86	170	651	4.4
Bukema Fekeka	0.6	0.4	82	143	551	2.8
Tome Gerera	0.4	0.2	103	198	761	4.8
Tome Gerera	0.5	0.5	96	193	743	3.2
Tome Gerera	0.4	0.5	107	176	678	4.1
Mante Gerera	0.4	0.3	45	144	557	1.4
Mante Gerera	0.6	0.3	82	234	904	2.1
Mante Gerera	0.4	0.4	86	158	615	3.2
Kodo Gawle	0.5	0.3	71	159	606	2.3
Kodo Gawle	0.4	0.3	76	138	542	1.3
Woyde Mesena	0.3	0.4	92	151	591	2.0
Mean	**0.4**	**0.3**	**83.8**	**166.3**	**642.8**	**2.8**
SD	**0.1**	**0.1**	**16.2**	**29.9**	**113.2**	**1.2**
Median	**0.4**	**0.35**	**84.0**	**158.5**	**610.5**	**2.6**
CV (%)	**24**	**34**	**19**	**18**	**18**	**42**

4. CONCLUSION

From the present study, it can be concluded that the soil analysis result of cassava farms in Southern Ethiopia showed an acidic soil pH, low level of soil organic carbon, deficiency in the levels of N, P, S, K, B and Cu. Furthermore, the deficiency of Fe and Zn on some cassava farms were also recorded. The problems in the study sites could be linked to acidic pH, impact of continues and intensive cropping, inadequate soil management practices and low/no fertilizer application. Thus, further studies in calibrating the response of cassava under balanced fertilization containing macro and micro nutrients are needed. For sound conclusion, soil survey considering a number of cassava growing farms is suggested.

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