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Assessment of Soil Fertility in Smallholder Potato Farms in Rwanda

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ABSTRACT

This study assessed soil fertility in potato farms of Birunga and Buberuka highlands agro-ecological zones (AEZs). It compared nutrients levels (N, P, K, Mg, Ca, Na, S, Mn, Cu, Zn and Fe) and other parameters (pH, organic carbon [OC], cation exchange capacity [CEC], base saturation [BS], bulk density [BD] and texture) of soil samples. ANOVA revealed that pH of soils (5.53-6.50) varied from slightly to moderately acidic, BD fell below optimum for plant growth (< 1.8gcm^{-3}), texture was sandy loam to sand clay loam. Soil fertility for OC (3.33-5.53%), N (0.15-0.31%) and CEC (10.08-18.60 meq/100g) varied from low to medium; and medium to high for BS (34.78-61.91%); was qualified medium for P (5.75-9.20 ppm), K (0.21-0.54 meq/100g), S (6.46 - 8.15 ppm) and majority of micronutrients. Values from Birunga AEZ were higher than ones from Buberuka AEZ except for BD, CEC, clay, silt, Na and Fe. There were significant differences between farms within locations for all parameters and significant differences between locations for all parameters except Na and Mn.

Key words: Potato, Rwanda, Soil fertility, Soil properties.

INTRODUCTION

Agriculture contributes one third of the Rwanda's GDP but is characterized by low productivity resulting from soil fertility decline (MINECOFIN, 2012). In permanent agriculture, soil fertility is maintained through application of fertilizers (IFDC, 2009). It is important to evaluate soil quality, because land uses depend on healthy soil functions (De la Rosa, 2005). Soil properties change in time and space (Rogerio, *et al.,* 2006). Heterogeneity in soil fertility may occur at a large or small scale (Du Feng, *et al.,* 2008). Soil has variability inherent to how the soil formation factors interact within the landscape; variability can also be induced by anthropogenic activities (Wang and Shao, 2013). Spatial variability in soil fertility can help to explain the spatial distribution of crop yield and quality (Vanlauwe *et al.*, 2006; Tittonell *et al.*, 2008). Potatoes need adequate supply of nutrients throughout their growth period (Zelalem *et al.,* 2009). Potato is an important crop for food and income generation in Rwanda; its cultivation is intensively carried out year round in Birunga and Buberuka highlands AEZs where conditions are potentially favorable (MINAGRI, 2011). Continuous cropping for enhanced yields removes substantial amounts of nutrients from soil. Imbalanced and inadequate use of chemical fertilizer and various cultural practices also degrade the soil quality (Medhe *et al.,* 2012). Hence, evaluation of fertility status of the soils of an agro-ecosystem is an important aspect in the context of sustainable agriculture (Singh and Mishra, 2012). It is the most basic decision making tool in order to impose appropriate nutrient management strategies (Brady and Weil, 2002). Due to continuous cultivation of potato in Birunga and Buberuka highlands AEZs without adequate addition of external nutrient inputs, there is incessant uptake of nutrients which may lead to soil fertility gradients at different spatial scales or cause the soil to become deficient in certain nutrients. Therefore, this research aimed at assessing soil fertility in potato farms of Birunga and Buberuka highlands AEZs.

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MATERIALS AND METHODS

Study sites: The study was conducted in two locations; Rubavu (Mudende site/L_1) and Burera (Rwerere site/L_2) districts, located in Birunga and Buberuka AEZs, respectively. Both locations are characterized by steeply sloping hills, tropical-temperate climate and a bimodal rainfall pattern. Their soils are dominated by volcanic soils being in association with lesser areas of other soils such as alisols identified in part of Burera (MINIRENA, 2004). The

volcanic soils of Rwanda contain volcanic ash and belongs to Andisols order (Birasa *et al.,* 1990). Burera district is located at 1°28′26.18′′S of latitude and 29°50′4.85′′E of longitude, at 2100 m above sea level. It is part of Buberuka and Birunga AEZs. It receives about 1400 mm of rainfall and has temperature ranging from 9°C to 29°C (Burera district, 2013). The study was conducted in part of Buberuka AEZ. Rubavu district is located at 1°40′52.54′′S of the latitude and 29°19′45.55′′E of longitude and at 1600 m above sea level. The district is part of Birunga AEZ. It receives about 1200 mm to 1350 mm of rainfall and has a mean temperature of 21°C (Rubavu district, 2013).

Soil sampling

Soil samples were collected before the onset of short rainy season (September-December 2016). Twelve composites samples, each replicated three times, were collected across twelve farms representative to potato fields in each location. The farms were identified using a stratified sampling method. Soil sampling and processing were done as described by Okalebo *et al.*(2002). The soil samples were later analyzed for selected nutrients (N, P, K, Mg, Ca, S, Na, Mn, Cu, Zn and Fe) and other soil parameters (pH, OC, CEC, BS, BD and texture).

Soil physical and chemical characterization

Soil texture was determined using hydrometer method, bulk density was measured using core method as outlined by Okalebo *et al*. (2002). Soil pH (1:2.5 soil- water ratio), was determined using glass electrode pH meter, OC was determined using Walkley and Black method (Walkley and Black, 1934), total mitrogen (TN) was obtained using Macro kijeldahl method, Cation Exchange Capacity (CEC) was obtained using 1M ammonium acetate saturation method, exchangeabler magnesium (Mg) and calcium (Ca) bases were determined using Atomic Absorption Spectrophotometer (AAS), exchangeable sodium (Na) and potassium (K) were determined using flame photometer, while base saturation (BS) was calculated as the percentage of the ratio between exchangeable bases over CEC. Extractable Sulphur (S) was determined using turbidimetric method; extractable micronutrients (copper [Cu], iron [Fe], manganese [Mn] and zinc [Zn]) were determined using DTPA extraction method and extracts were subjected to AAS, as outlined by Okaleb *et al.* (2002). Available P was determined using Mehlich 3 method.

Data analysis

Data related to soil characterization were subjected to analysis of variance using SAS version 9.2 (SAS Institute Inc., 2008). Treatment effects were tested for significance using ANOVA F-test at 5%. An F-protected Least Significant Difference (P=0.05) was used for mean separation.

RESULTS AND DISCUSSION

Soil physical characteristics

The particle size distribution was dominated by sand fraction. 100% of the soil samples of Mudende [L_1] and Rwerere [L_2] locations fell in sandy loam and sand clay loam textural classes, respectively. There were significant differences ($p < 0.05$) between locations (Table 5) in terms of clay, silt and sand content; significant differences ($p < 0.05$) for silt and

Table 1: Statistical analysis of soil properties-Birunga Highlands Agro-Ecological Zone (BRHAEZ) [L_1].

Treatment	pH	OC (%)	Clay (%)	Silt (%)	Sand (%)	BD (gcm^{-3})	TN (%)	AP (ppm)	Ca (meq/100g)	Mg (meq/100g)
Farm (F)1	6.39 ± 0.17^{a}	4.61 ± 0.11^{c}	18.17 ± 0.03^{a}	13.57 ± 0.30^{d}	68.26 ± 0.33^{a}	1.45d ± 0.00^{e}	0.27 ± 0.00^{b}	6.00 ± 0.00^{c}	7.39 ± 0.31^{b}	2.05 ± 0.00^{ab}
F2	6.05 ± 0.03^{b}	3.86 ± 0.02^{e}	18.13 ± 0.01^{ab}	14.28 ± 0.01^{c}	67.59 ± 0.01^{b}	1.47 ± 0.00^{cd}	0.21 ± 0.00^{cde}	6.33 ± 0.08^{c}	7.05 ± 0.00^{b}	1.96 ± 0.00^{b}
F3	5.83 ± 0.20^{bcd}	3.50 ± 0.02^{f}	18.09 ± 0.03^{b}	14.32 ± 0.03^{bc}	67.59 ± 0.01^{b}	1.47 ± 0.00^{cd}	0.21 ± 0.00^{cde}	8.50 ± 0.14^{ab}	7.04 ± 0.00^{b}	1.99 ± 0.00^{b}
F4	5.72 ± 0.11^{cd}	3.45 ± 0.03^{f}	18.09 ± 0.03^{b}	14.33 ± 0.04^{bc}	67.59 ± 0.01^{b}	1.50 ± 0.00^{bc}	0.19 ± 0.01^{def}	8.75 ± 0.14^{ab}	3.76 ± 0.17^{c}	0.49 ± 0.00^{c}
F5	6.01 ± 0.02^{bc}	3.88 ± 0.00^{e}	18.13 ± 0.01^{ab}	14.28 ± 0.00^{c}	67.59 ± 0.01^{b}	1.45 ± 0.00^{de}	0.23 ± 0.00^{c}	8.00 ± 0.29^{b}	7.04 ± 0.01^{b}	1.97 ± 0.00^{b}
F6	6.42 ± 0.16^{a}	5.33 ± 0.12^{a}	18.17 ± 0.03^{a}	14.90 ± 0.32^{ab}	66.93 ± 0.34^{c}	1.42± 0.02^{e}	0.28 ± 0.00^{b}	9.00 ± 0.29^{a}	8.44 ± 0.24^{a}	2.24 ± 0.10^{a}
F7	5.70 ± 0.03^{cd}	3.36 ± 0.09^{f}	18.09 ± 0.03^{b}	13.66 ± 0.37^{d}	68.25 ± 0.34^{a}	1.55 ± 0.00^{a}	0.19 ± 0.01^{ef}	8.25 ± 0.38^{ab}	3.62 ± 0.18^{c}	0.45 ± 0.00^{c}
F8	6.06 ± 0.02^{b}	4.26 ± 0.07^{d}	18.13 ± 0.01^{ab}	13.95 ± 0.34^{cd}	68.25 ± 0.34^{a}	1.45 ± 0.00^{de}	0.23 ± 0.00^{c}	6.42 ± 0.08^{c}	7.05 ± 0.00^{b}	1.96 ± 0.01^{b}
F9	5.58 ± 0.19^{cd}	3.43 ± 0.02^{f}	18.13 ± 0.01^{ab}	14.28 ± 0.00^{c}	67.59 ± 0.01^{b}	1.53 ± 0.02^{b}	0.17 ± 0.01^{f}	8.08 ± 0.51^{b}	3.73 ± 0.06^{c}	0.42 ± 0.01^{c}
F10	6.13 ± 0.02^{ab}	4.43 ± 0.00^{cd}	18.13 ± 0.01^{ab}	14.95 ± 0.33^{a}	66.92 ± 0.33^{c}	1.47 ± 0.02^{cd}	0.21 ± 0.01^{cde}	8.67 ± 0.08^{ab}	7.06 ± 0.06^{b}	1.96 ± 0.01^{b}
F11	6.07± 0.12^{b}	4.26 ± 0.07^{d}	18.13 ± 0.01^{ab}	14.27 ± 0.01^{c}	67.59 ± 0.01^{b}	1.47 ± 0.02^{cd}	0.22 ± 0.00^{cd}	8.58 ± 0.08^{ab}	7.08 ± 0.05^{b}	2.06 ± 0.00^{ab}
F12	6.42 ± 0.17^{a}	5.01 ± 0.11^{b}	18.17 ± 0.03^{a}	14.91 ± 0.32^{ab}	66.92 ± 0.34^{c}	1.45 ± 0.03^{de}	0.31 ± 0.03^{a}	8.50 ± 0.50^{ab}	8.12 ± 0.06^{a}	2.24 ± 0.10^{a}
Maximum	6.42	5.33	18.17	14.95	68.26	1.55	0.28	9.00	8.44	2.23
Minimum	5.58	3.36	18.09	13.57	66.92	1.42	0.17	6.00	3.62	0.42
Mean	6.03	4.11	18.13	14.31	67.59	1.47	0.22	7.92	6.45	1.65
LSD	0.31	0.20	0.07	0.61	0.5757	0.04	0.01	0.83	0.41	0.19
CV (%)	3.07	2.86	0.24	2.25	0.5	1.50	3.76	6.17	3.78	6.95

Mean followed by the same letter(s) within each column do not differ statistically (p= 0.05).
pH: potential of hydrogen, OC: organic carbon, BD: bulk density, TN: total nitrogen, AP: available phosphorus, Ca: calcium, Mg: magnesium.

sand content and no significant differences ($p > 0.05$) for clay content between farms of L_1 (Table 1). There were also significant differences ($p< 0.05$) between farms for clay content at L_2 while no significant ($p > 0.05$) differences were detected between them for sand and silt content (Table 3). The bulk density of soils varied from 1.42 to 1.55 gcm^{-3} [L_1] and from1.52 to1.69 gcm^{-3}[L_2]. The mean value was high at L_2 (1.61 gcm^{-3}) and low at L_1 (1.47 gcm^{-3}) (Tables 1 and 3). Bulk density depicted significant differences ($p < 0.05$) between farms within location and between locations. All recorded values of bulk density were less than the general critical value (< 1.80 gcm^{-3}) for plant growth at which roots penetration is likely to be severely restricted (Brady and Weil, 2008).

Soil chemical characteristics

The pH mean values were 6.03 [L_1] and 5.92 [L_2]. pH of 33.33 % [L_1] and 66.67% [L_2] soil samples ranged from 5.50 to 6.00 whereas pH of the rest samples fall in the range of 6.00-6.50 (Tables 1 & 3); the two pH classes are qualified moderately acidic and slightly acidic, respectively (Bruce and Rayment, 1982). The acidic pH might be attributed to basic cations leaching and their incessant uptake by crop (Brady and Weil, 2008). The mean values of OC were 4.11% [L_1] and 3.71% [L_2]. OC of 50% [L_1] and 75% [L_2] soil samples fell in the range of (2.0-4.0) % whereas OC of the rest samples oscillated within the range of (4.0-10.0) %. The mean values of total nitrogen were 0.22% [L_1] and 0.20% [L_2]. Total nitrogen of 25% [L_1] and 75% [L_2] soils fell within the range of (0.10-0.20) % while total nitrogen of the rest samples ranged from 0.20% to 0.50% (Tables 1 & 3). According to Landon (1991), the first classes of soil OC and TN were graded as low while the second ones were qualified as medium. Low and medium ratings of soil OC and TN may be attributed to the removal of biomass from the field, limited organic inputs application, rapid rate of organic matter mineralization and leaching process of NO^{-3} (Laekemariam, 2015; Laekemariam, 2016). The mean values of available P were 7.92 ppm [L_1] and 7.68 ppm [L_2]. Available P of the total soil samples fell in the range of (5.00-15.00) ppm. Available S of all samples fell within the range of (6.00-10.00) ppm with the mean values of 7.61 ppm [L_1] and 7.44 ppm [L_2] (Tables 1-4). Available P and S were classified medium (Landon, 1991). The medium rating of available P and S can be explained by the prevailing acidic pH, their relationship with OM content, limited to moderated P and S fertilizer application and continuous mining of the nutrients from the field (Laekemariam, 2015; Laekemariam, 2016).

The mean values of exchangeable Ca were 6.45 meq/100g [L_1] and 6.22 meq/100g [L_2]. Exchangeable Ca of 25.00 % samples were below 4.0 meq/100g whereas it fluctuated within the range of (4.00-10.00) meq/100g for the rest. The mean values of exchangeable Mg were 1.65 meq/100g [L_1] and 1.58 meq/100g [L_2]. Mg content of 25.00 % of soil samples fell below 0.50 meq/100g whereas it oscillated within the range of (0.50-4.00) meq/100g for the rest. The mean values of K were 0.35 meq/100g [L_1] and 0.33 meq/100g [L_2]. K content of all soil samples fluctuated within the range of (0.20-0.60) meq/100g. The mean values of Na were 0.30 meq/100g [L_1] and 0.31 meq/100g [L_2]. Na content of 58.33% and 41.67% of soil samples fell in the ranges of (0.10-0.30) meq/100g and (0.30-0.70) meq/100g,

Table 2: Statistical analysis of soil properties- Birunga Highlands Agro-Ecological Zone (BRHAEZ) [L_1] (Cont'd).

Treatment	K (meq/100g)	Na (meq/100g)	CEC (meq/100g)	BS (%)	AS (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)
Farm (F)1	0.28 ± 0.01^{cd}	0.33± 0.02^{abc}	18.27 ± 0.42^{a}	55.68 ± 0.60^{cd}	8.28 ± 0.35^{ab}	0.39 ± 0.02^{a}	5.55 ± 0.21^{ab}	3.47 ± 0.04^{a}	1.08 ± 0.03^{b}
F2	0.28 ± 0.02^{d}	0.30 ± 0.00^{def}	15.90 ± 0.06^{c}	60.53 ± 0.22^{a}	7.53 ± 0.02^{cde}	0.34 ± 0.00^{bcd}	5.03 ± 0.01^{cde}	2.97 ± 0.02^{cd}	0.94e ± 0.01^{f}
F3	0.32 ±0.00^{bcd}	0.28 ± 0.00^{efg}	15.77 ± 0.07^{c}	61.13 ± 0.25^{a}	7.29 ± 0.02^{edf}	0.34 ± 0.00^{cd}	4.95 ± 0.01^{de}	2.87 ± 0.02^{de}	0.90 ± 0.00^{fg}
F4	0.32 ± 0.00^{bcd}	0.27± 0.01^{g}	11.50 ± 0.29^{d}	41.21 ± 0.87^{f}	7.20 ± 0.00^{ef}	0.32 ± 0.01^{d}	4.94 ± 0.01^{e}	2.52 ± 0.02^{f}	0.85 ± 0.00^{hi}
F5	0.31 ± 0.00^{bcd}	0.30 ± 0.00^{cdef}	16.80 ± 0.06^{b}	57.30 ± 0.24^{bc}	7.37 ± 0.01^{edf}	0.35 ± 0.00^{bc}	5.25 ± 0.01^{dc}	3.00 ± 0.05^{bcd}	0.95 ± 0.01^{def}
F6	0.55 ± 0.03^{a}	0.36 ± 0.02^{a}	18.53 ± 0.38^{a}	61.91 ± 0.99^{a}	8.34 ± 0.35^{a}	0.39 ± 0.02^{a}	5.63 ± 0.21^{a}	3.62 ± 0.07^{a}	1.12 ± 0.03^{ab}
F7	0.28 ± 0.01^{cd}	0.26 ± 0.01^{g}	11.00 ± 0.29^{d}	41.40 ± 0.92^{f}	6.96 ± 0.17^{f}	0.32 ± 0.00^{d}	4.83 ± 0.06^{e}	2.50 ± 0.14^{f}	0.88 ± 0.01^{gh}
F8	0.28 ± 0.02^{d}	0.31 ± 0.00^{cde}	15.97 ± 0.09^{c}	60.72 ± 0.39^{a}	7.32 ± 0.06^{edf}	0.35 ± 0.00^{bc}	5.05 ± 0.01^{cde}	3.07 ± 0.02^{bc}	0.98 ± 0.01^{cde}
F9	0.36 ± 0.00^{b}	0.28 ± 0.00^{fg}	10.00 ± 0.22^{e}	46.56 ± 1.05^{e}	6.94 ± 0.15^{f}	0.32 ± 0.00^{d}	4.85 ± 0.06^{e}	2.72 ± 0.06^{e}	0.82 ± 0.01^{i}
F10	0.32 ± 0.00^{bcd}	0.31 ± 0.00^{bcd}	18.00 ± 0.40^{a}	53.80 ± 0.91^{d}	7.93 ± 0.03^{abc}	0.37 ± 0.00^{ab}	5.31 ± 0.01^{bc}	3.47 ± 0.02^{a}	1.00 ± 0.01^{cd}
F11	0.33 ± 0.00^{bc}	0.31 ± 0.00^{bcd}	16.90 ± 0.12^{b}	57.76 ± 0.66^{b}	7.80 ± 0.02^{bcd}	0.35 ± 0.00^{bcd}	5.29 ± 0.01^{bc}	3.17 ± 0.09^{b}	1.00 ± 0.00^{c}
F12	0.55 ± 0.03^{a}	0.34 ± 0.02^{ab}	18.60 ± 0.40^{a}	59.85 ± 0.27^{a}	8.40 ± 0.34^{a}	0.39 ± 0.02^{a}	5.61 ± 0.21^{a}	3.50 ± 0.03^{a}	1.14 ± 0.04^{a}
Maximum	0.55	0.36	18.60	61.91	8.40	0.39	5.63	3.62	1.14
Minimum	0.28	0.26	10.08	41.21	6.94	0.32	4.83	2.50	0.82
Mean	0.35	0.30	15.61	54.82	7.61	0.35	5.19	3.07	0.97
LSD	0.04	0.03	0.77	2.079	0.53	0.02	0.30	0.18	0.05
CV **(%)**	7.40	5.27	2.92	2.24	4.15	4.53	3.38	3.45	3.06

Mean followed by the same letter(s) within each column do not differ statistically ($p= 0.05$).
K: potassium, Na: sodium, CEC: cation exchange capacity, BS: base saturation, AS: available sulfur, Cu: copper, Fe: iron, Mn: manganese, Zn: zinc.

Table 3: Statistical analysis of soil properties- Buberuka Highlands Agro-Ecological Zone (BUHAEZ) [L_2].

Treatment	pH	OC (%)	Clay (%)	Silt (%)	Sand (%)	BD (gcm^{-3})	TN (%)	AP	Ca (meq/100g)	Mg (meq/100g)
Farm (F)1	5.53 ± 0.17^{ed}	3.32d ± 0.03	20.26 ± 0.01^{bc}	15.73 ± 0.34^{b}	64.01± 0.33^{a}	1.69 ± 0.01^{a}	0.15 ± 0.00^{e}	8.75 ± 0.14^{ab}	3.74 ± 0.16^{e}	0.47 ± 0.00^{d}
F2	5.55 ± 0.03^{ed}	3.33d ± 0.00	20.25 ± 0.01^{c}	16.09 ± 0.01^{ab}	63.66± 0.01^{ab}	1.69 ± 0.01^{a}	0.015± 0.00^{e}	7.75 ± 0.14^{d}	3.99 ± 0.00^{e}	0.47 ± 0.00^{d}
F3	5.83 ± 0.01^{cd}	3.52c ± 0.05	20.29 ± 0.01^{bc}	16.08 ± 0.00^{ab}	63.63 ± 0.01^{ab}	1.62 ± 0.01^{bc}	0.19 ± 0.01^{c}	7.83 ± 0.36^{d}	7.08 ± 0.00^{c}	1.98 ± 0.00^{b}
F4	6.13 ± 0.17^{bc}	3.88b ± 0.05	20.42 ± 0.07^{a}	16.00 ± 0.06^{ab}	63.59 ± 0.01^{ab}	1.60 ± 0.01^{cd}	0.18± 0.01^{cd}	6.58 ± 0.22^{e}	7.16b± 0.08^{c}	2.02 ± 0.00^{b}
F5	5.87 ± 0.01^{bcd}	3.56c ± 0.03	20.27 ± 0.01^{bc}	16.09 ± 0.01^{ab}	63.65 ± 0.01^{ab}	1.62 ± 0.01^{bc}	0.19 ± 0.01^{c}	7.83 ± 0.08^{d}	7.02± 0.01^{c}	1.98 ± 0.00^{b}
F6	6.50 ± 0.03^{a}	4.23a ± 0.06	20.41 ± 0.06^{a}	16.08 ± 0.08^{ab}	63.51 ± 0.02^{b}	1.52 ± 0.02^{e}	0.28 ± 0.00^{a}	9.20 ± 0.23^{a}	7.67± 0.34^{a}	2.22 ± 0.17^{a}
F7	5.57 ± 0.19^{ed}	3.41cd ± 0.05	20.2 5± 0.01^{c}	15.75 ± 0.34^{ab}	64.00± 0.34^{a}	1.65 ± 0.01^{b}	0.15 ± 0.01^{de}	6.08 ± 0.08^{ef}	3.73 ± 0.17^{e}	0.47± 0.00^{d}
F8	5.58 ± 0.19^{ed}	3.47cd ± 0.05	20.25 ± 0.01^{c}	15.75± 0.32^{ab}	64.00 ± 0.33^{a}	1.65 ± 0.01^{b}	0.15 ± 0.02^{de}	7.75 ± 0.14^{d}	4.99 ± 0.00^{d}	1.07 ± 0.01^{c}
F9	6.18 ± 0.17^{b}	4.01a ± 0.03	20.29 ± 0.01^{bc}	16.07 ± 0.01^{ab}	63.63 ± 0.01^{ab}	1.57 ± 0.00^{d}	0.24 ± 0.01^{b}	5.75 ± 0.38^{f}	7.45 ± 0.27^{abc}	2.22 ± 0.17^{a}
F10	5.93 ± 0.01^{bc}	3.89b ± 0.02	20.4 1± 0.06^{a}	16.01 ± 0.07^{ab}	63.57 ± 0.01^{ab}	1.57 ± 0.00^{d}	0.20 ± 0.02^{c}	8.08 ± 0.22^{bcd}	7.18 ± 0.00^{abc}	2.02 ± 0.00^{b}
F11	5.92 ± 0.01^{bc}	3.79b ± 0.10	20.27 ± 0.01^{bc}	16.08 ± 0.00^{ab}	63.65 ± 0.01^{ab}	1.60± 0.01^{cd}	0.20 ± 0.01^{c}	8.02 ± 0.13^{cd}	7.03 ± 0.00^{c}	1.98 ± 0.00^{b}
F12	6.40 ± 0.10^{a}	4.09a ± 0.04	20.35 ± 0.01^{ab}	16.16± 0.00^{a}	63.49 ± 0.01 ^{b}	1.52 ± 0.02^{e}	0.28 ± 0.02^{a}	8.58 ± 0.36^{abc}	7.62 ± 0.28^{ab}	2.05 ± 0.00^{ab}
Maximum	6.50	4.23	20.42	16.16	64.01	1.69	0.28	9.20	7.67	2.22
Minimum	5.53	3.33	20.25	15.73	63.49	1.52	0.15	5.75	3.73	0.47
Mean	5.92	3.71	20.31	16.00	63.70	1.61	0.20	7.68	6.22	1.58
LSD	0.33	0.12	0.09	0.42	0.44	0.034	0.03	0.69	0.49	0.19
CV (%)	3.26	1.89	0.26	1.56	0.41	1.24	8.73	5.28	4.64	7.16

Mean followed by the same letter(s) within each column do not differ statistically (p= 0.05).
pH: potential of hydrogen, OC: organic carbon, BD: bulk density, TN: total nitrogen, AP: available phosphorus, Ca: calcium, Mg: magnesium.

Table 4: Statistical analysis of soil properties-Buberuka Highlands Agro-Ecological Zone (BUHAEZ) [L_2] (Cont'd).

Treatment	K (meq/100g)	Na (meq/100g)	CEC (meq/100g)	BS (%)	AS (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)
F(arm)1	0.40 ± 0.00^{bc}	0.26 ± 0.00^{e}	12.66 ± 0.44^{d}	37.76 ± 0.83^{d}	6.46 ± 0.16^{e}	0.30 ± 0.00^{c}	4.82 ± 0.06^{d}	2.75± 0.01^{ef}	0.68 ± 0.02^{gh}
F2	0.32 ± 0.00^{d}	0.27± 0.00^{de}	13.00 ± 0.29^{cd}	38.57 ± 1.00^{cd}	6.48 ± 0.22^{e}	0.30 ± 0.00^{c}	4.81 ± 0.07^{d}	2.65 ± 0.10^{f}	0.64 ± 0.02^{h}
F3	0.32 ± 0.00 d	0.29 ± 0.00^{d}	17.03 ± 0.09^{b}	56.74 ± 0.30^{ab}	7.48 ± 0.03^{cd}	0.33 ± 0.01^{b}	5.40 ± 0.01^{ab}	3.05± 0.00^{dc}	0.78 ± 0.01^{def}
F4	0.22 ± 0.00^{e}	0.28± 0.00^{de}	17.20 ± 0.06^{b}	56.88 ± 0.31^{ab}	7.50 ± 0.00^{cd}	0.34 ± 0.00^{b}	5.40 ± 0.01^{ab}	2.90 ± 0.00^{de}	0.84 ± 0.01^{c}
F5	0.32 ± 0.00^{d}	0.28 ± 0.00^{de}	17.00 ± 0.12^{b}	56.40 ± 0.3 4^{b}	7.50 ± 0.00^{cd}	0.32 ± 0.00^{bc}	5.29 ± 0.01^{bc}	3.05± 0.00^{dc}	0.80 ± 0.00^{cde}
F6	0.47 ± 0.03^{a}	0.38± 0.02^{a}	18.57 ± 0.52^{a}	58.20 ± 1.06^{a}	8.15 ± 0.23^{a}	0.39 ± 0.02^{a}	5.69 ± 0.21^{a}	3.49 ± 0.09^{a}	1.07 ± 0.03^{a}
F7	0.21± 0.00^{e}	0.27± 0.00^{de}	13.67 ± 0.44^{c}	34.78 ± 0.81^{e}	7.28 ± 0.13^{d}	0.32 ± 0.00^{bc}	4.99 ± 0.01^{d}	2.65 ± 0.10^{f}	0.73 ± 0.01^{fg}
F8	0.38 ± 0.00^{c}	0.28 ± 0.00^{de}	16.57 ± 0.09^{b}	39.91 ± 0.20^{c}	7.39 ± 0.03^{cd}	0.32 ± 0.00^{bc}	5.01 ± 0.01^{cd}	2.75e ± 0.00^{f}	0.74 ± 0.01^{ef}
F9	0.22 ± 0.00^{e}	0.37 ± 0.02^{a}	18.40 ± 0.50^{a}	56.43 ± 0.99^{ab}	7.56 ± 0.03^{bcd}	0.37 ± 0.00^{a}	5.41 ± 0.01^{ab}	3.47 ± 0.02^{b}	0.94 ± 0.00^{b}
F10	0.34 ± 0.00^{d}	0.31 ± 0.00^{c}	17.40 ± 0.06^{b}	56.56 ± 0.19^{ab}	7.89 ± 0.33^{abc}	0.39 ± 0.02^{a}	5.62 ± 0.21^{a}	3.06 ± 0.00^{dc}	0.98 ± 0.03^{b}
F11	0.32 ± 0.00^{d}	0.35 ± 0.00^{b}	17.27 ± 0.07^{b}	56.07 ± 0.23^{b}	7.51 ± 0.00^{cd}	0.32 ± 0.00^{bc}	5.31 ± 0.01^{b}	3.24 ± 0.10^{c}	0.81 ± 0.01^{cd}
F12	0.43 ± 0.03^{b}	0.38 ± 0.02^{a}	19.77 ± 0.18^{a}	55.87 ± 1.00^{b}	8.04 ± 0.29^{ab}	0.39 ± 0.02 a	5.67 ± 0.21^{a}	3.50 ±0.10^{a}	1.06 ± 0.03^{a}
Maximum	0.47	0.38	18.97	58.20	8.15	0.39	5.69	3.50	1.07
Minimum	0.21	0.26	12.67	34.78	6.46	0.30	4.81	2.65	0.64
Mean	0.33	0.31	16.48	50.35	7.44	0.34	5.28	3.05	0.84
LSD	0.04	0.03	0.84	1.78	0.51	0.024	0.30	0.19	0.57
CV (%)	6.91	5.03	3.02	2.09	4.06	4.23	3.32	3.70	3.99

Mean followed by the same letter(s) within each column do not differ statistically (p= 0.05).
K: potassium, Na: sodium, CEC: cation exchange capacity, BS: base saturation, AS: available sulfur, Cu: copper, Fe: iron, Mn: manganese, Zn: zinc.

Table 5: Statistical analysis of soil properties-BRHAEZ and BUHAEZ.

Treatment	pH	OC (%)	Clay (%)	Silt (%)	Sand (%)	BD (gcm^{-3})	TN (%)	AP (ppm)	Ca (meq/100g)	Mg (meq/100g)
L_1	6.03 ± 0.05^a	4.11 ±0.11^a	18.13 ± 0.01^b	14.31 ± 0.09^b	67.59 ± 0.10^a	1.47 ± 0.07^b	0.22 ± 0.006^a	7.92 ± 0.18^a	6.45± 0.28^a	1.65± 0.12^a
L_2	5.92 ± 0.06^b	3.71 ± 0.05^b	20.31 ± 0.01^a	15.99 ± 0.05^a	63.70 ± 0.05^b	1.61 ± 0.10^a	0.20± 0.008^b	7.68 ± 0.18^b	6.22 ± 0.26^b	1.58 ± 0.12^b
Mean	5.97	3.91	19.22	15.15	65.64	1.54	0.21	7.80	6.33	1.61
LSD	0.09	0.05	0.02	0.17	0.17	0.01	0.006	0.21	0.12	0.05
CV (%)	3.11	2.51	0.26	2.39	0.54	1.40	6.49	5.65	4.13	6.90

Mean followed by the same letter(s) within each column do not differ statistically (p= 0.05).
pH: potential of hydrogen, OC: organic carbon, BD: bulk density, TN: total nitrogen, AP: available phosphorus, Ca: calcium, Mg: magnesium.

Table 6: Statistical analysis of soil properties- BRHAEZ and BUHAEZ (Cont'd).

Treatment	K (meq/100g)	Na (meq/100g)	CEC (meq/100g)	BS (%)	AS (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)
L_1	0.35 ± 0.02^a	0.30± 0.01^a	15.61 ± 0.50^b	54.82± 1.24^a	7.61± 0.10^a	0.35 ± 0.01^a	5.19 ± 0.05^b	3.07 ± 0.01^a	0.97 ± 0.02^a
L_2	0.33 ± 0.01^b	0.31 ± 0.01^a	16.48 ± 0.36^a	50.35 ± 1.53^b	7.44 ± 0.09^b	0.34 ± 0.01^b	5.28 ± 0.06^a	3.05 ± 0.01^a	0.84 ± 0.02^b
Mean	0.34	0.31	16.04	52.58	7.52	0.35	5.24	3.06	0.90
LSD	0.11	0.007	0.23	0.57	0.14	0.007	0.08	0.06	0.01
CV (%)	7.02	5.07	3.00	230	4.04	4.30	3.27	3.57	3.43

Mean followed by the same letter(s) within each column do not differ statistically (p= 0.05).
K: potassium, Na: sodium, CEC: cation exchange capacity, BS: base saturation, AS: available sulfur, Cu: copper, Fe: iron, Mn: manganese, Zn: zinc.

respectively. The mean values of CEC were 15.61 meq/100g [L_1] and 16.48 meq/100g [L_2]. CEC of 25.00 % soil samples fluctuated within the range of (5.00-15.00) meq/100g whereas it fell in the range of (15.00-25.00) meq/100g for the rest of samples. The mean values of base saturation were 54.82% [L_1] and 50.35% [L_2]. Base saturation of 66.67% [L_1] and 100.00% [L_2] of soil samples fell in the range of (20.00-60.00) % while it was greater than 60.00% for the rest of samples (Tables 1-4). According to Landon (1991), Ca, Mg, Na and CEC ratings oscillated from low to medium, BS was graded generally medium and rarely high whereas K was valued medium. Low and medium classes of basic cations, CEC, Na and BS can be attributed to the soil parental material properties, leaching of cation bases, continuous removal of the bases by crops and low OM content (Bezabih *et al.* 2016).

Extractable Cu of all samples fluctuated within the range of (0.30-0.80) ppm with 0.35 ppm [L_1] and 0.34 ppm [L_2] as means and extractable Fe of all samples oscillated within the range of (4.00-6.00) ppm with 5.28 ppm [L_1] and 5.19 ppm [L_2] as means. The mean values of extractable Mn were 3.07 ppm [L_1] and 3.05 ppm [L_2]. Mn of 91.67% [L_1] and 100% [L_2] soil samples fluctuated within the range of (1.20-3.5) ppm while it oscillated within the range of (3.50-6.00) ppm for the rest. The mean values of extractable Zn were 0.97 ppm [L_1] and 0.84 ppm [L_2]. Zn of 75.00% [L_1] and 83.33% [L_2] soil samples ranged from 0.51 to 1.00 ppm whereas it fluctuated in the range of (1.00-3.00) ppm for the rest of samples (Tables 2 and 4). According to Landon (1991), Cu and Fe were qualified medium, Zn varied from low to medium whereas Mn varied from medium to high. The low to medium content of soil micronutrients may be attributed to low and medium soil. Usually the greater the content of active soil organic matter (SOM) the greater their availability. This is due to the release of the micronutrients through decomposition of SOM and chelating compounds (Brady and Weil, 2002, Nazif *et al.*, 2006). Statistical analysis revealed that there were significant differences between farms within sites for all parameters and significant differences between sites for all parameters except Na and Mn (Tables 5 & 6). The results of the present research are in accordance with findings of Tittonell *et al.* (2010) highlighting heterogeneity in soil fertility within and between farms.

CONCLUSION

The results revealed that the soil pH varied from slightly to moderately acidic, bulk density fell below the optimum range to allow root penetration, soil textural classes were sandy loam to sandy clay loam. Soil fertility was rated either low or medium, or varied from low to medium for the majority of selected chemical parameters. The values recorded from Birunga Highhlands AEZ (L_1) were higher than ones recorded from Buberuka highlands AEZ (L_2) except for BD, clay and silt content, CEC, Na and Fe. In general Birunga Highlands AEZ was more fertile than Buberuka Highlanda AEZ, there were significant differences between farms within locations and significant differences between locations with regard to the selected parameters. Adoption of a site specific nutrient management approach is needed in order to

guarantee sustainable soil resource management, profitable farming system and healthy environment.

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