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 (< 1.8g/cm3), 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.

MATERIALS AND METHODS

Study sites: The study was conducted in two locations; Rubavu (Mudende site/L1) and Burera (Rwerere site/L2) 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 allisols 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 (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 nitroge (TN) was obtained using Macro kjeldahl method, Cation Exchange Capacity (CEC) was obtained using 1M ammonium acetate saturation method, exchangeable 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 Okalebo 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] and Rwerere [L] 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 sand fraction, respectively. There were significant differences (p < 0.05) 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) using ANOVA F-test at 5%. An F-protected Least Significant Difference (P=0.05) was used for mean separation.
sand content and no significant differences (p > 0.05) for clay content between farms of L2 (Table 1). There were also significant differences (p < 0.05) between farms for clay content at L2, while no significant (p > 0.05) differences were detected between them for silt content (Table 2). The bulk density of soils varied from 1.42 to 1.55 g cm⁻³. The mean value was high at L1 (1.61 g cm⁻³) and low at L5 (1.47 g cm⁻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 g cm⁻³) for plant growth at which root penetration is likely to be severely restricted (Brady and Weil, 2008).

### Soil chemical characteristics

The pH mean values were 6.03 [L1] and 5.92 [L1]. The pH of 33.33 % [L1] and 66.67 % [L1] 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 (Brady 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 % [L1] and 3.71 % [L1]. OC of 50% [L1] and 75% [L1] soil samples fell in the range of (2.0-4.0) % whereas the rest of the samples oscillated within the range of (4.0-10.0). The mean values of total nitrogen were 0.22 % [L1] and 0.20 % [L1]. Total nitrogen of 25% [L1] and 75% [L1] soils fell within the range of (0.10-0.20) % while total nitrogen of the rest samples ranged from 0.20% to 0.50% (Table 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 NO₃ (Laekeamiriam, 2015; Laekemariam, 2016). The mean values of available P were 7.92 ppm [L1] and 7.68 ppm [L1]. 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 [L1] and 7.44 ppm [L1] (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 moderately P and S fertilizer application and continuous mining of the nutrients from the field; (Laekeamiriam, 2015; Laekemariam, 2016).

The mean values of exchangeable Ca were 6.45 meq/100g [L1] and 6.22 meq/100g [L1]. 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 [L1] and 1.58 meq/100g [L1]. 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 [L1] and 0.33 meq/100g [L1]. K content of all soil samples fluctuated within the range of (0.20-6.0) meq/100g. The mean values of Na were 0.30 meq/100g [L1] and 0.31 meq/100g [L1]. 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.
| Treatment (F1) | pH | OC (%) | CEC (meq/100g) | K (meq/100g) | Na (meq/100g) | C | Mn (ppm) | Cu (ppm) | Zn (ppm) |
|---------------|----|--------|----------------|---------------|---------------|---|--------|--------|---------|
| Minimum       | 6.50±0.19 | 3.41±0.03 | 63.45±0.04 | 5.75±0.01 | 5.89±0.01 | a | 5.87±0.01 | 3.05±0.00 | 5.93±0.01 |
| Mean          | 6.52±0.19 | 3.43±0.03 | 63.47±0.04 | 5.78±0.01 | 5.90±0.01 | a | 5.88±0.01 | 3.06±0.00 | 5.94±0.01 |
| LSD           | 0.03 | 0.04 | 0.04 | 0.01 | 0.01 | a | 0.03 | 0.00 | 0.01 |
| CV (%)        | 3.26 | 2.66 | 2.66 | 0.67 | 0.67 | a | 0.44 | 1.24 | 0.41 |

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

Means followed by the same letter(s) within each column do not differ statistically (p= 0.05).

| Treatment (F1) | Silt (%) | Sand (%) | Ca (mg/100g) | Mg (mg/100g) | AP | OC (%) | pH | CEC (meq/100g) | K (meq/100g) | Na (meq/100g) | C | Mn (ppm) | Cu (ppm) | Zn (ppm) |
|---------------|----------|----------|---------------|---------------|----|--------|----|----------------|---------------|---------------|---|--------|--------|---------|
| Minimum       | 6.60±0.10 | 20.25±0.03 | 36.45±0.04 | 29.75±0.01 | 12.75±0.01 | a | 12.65±0.01 | 4.03±0.00 | 12.76±0.01 |
| Mean          | 6.62±0.10 | 20.26±0.03 | 36.47±0.04 | 29.76±0.01 | 12.77±0.01 | a | 12.66±0.01 | 4.04±0.00 | 12.78±0.01 |
| LSD           | 0.01 | 0.04 | 0.04 | 0.01 | 0.01 | a | 0.01 | 0.00 | 0.02 |
| CV (%)        | 3.26 | 2.66 | 2.66 | 0.67 | 0.67 | a | 0.44 | 1.24 | 0.41 |

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

Means followed by the same letter(s) within each column do not differ statistically (p= 0.05).
Table 5: Statistical analysis of soil properties—BRHAEZ and BUHAEZ.

| Treatment | Clay (%) | Sand (%) | Silt (%) | Ca (ppm) | Mg (meq/100g) | AP | K (ppm) | Fe (ppm) | Mn (ppm) | Cu (ppm) | Zn (ppm) | OC (%) |
|-----------|----------|----------|----------|----------|--------------|----|---------|----------|----------|----------|----------|--------|
| L         | 2.39     | 0.54     | 0.34     | 4.04     | 0.20 ± 0.008 | 2  | 0.97    | 1.47 ± 0.17 | 0.22 ± 0.009 | 7.52 ± 0.19 | 6.45 ± 0.28 | 14.31 ± 0.10 |
| Mean      | 2.39     | 0.55     | 0.34     | 4.04     | 0.20 ± 0.008 | 2  | 0.97    | 1.47 ± 0.17 | 0.22 ± 0.009 | 7.52 ± 0.19 | 6.45 ± 0.28 | 14.31 ± 0.10 |
| LSD       | 0.31     | 0.17     | 0.17     | 0.31     | 0.02 ± 0.000 | 2  | 0.97    | 1.47 ± 0.17 | 0.22 ± 0.009 | 7.52 ± 0.19 | 6.45 ± 0.28 | 14.31 ± 0.10 |
| CV (%)    | 13.62    | 33.92    | 33.92    | 13.62    | 11.11        | 2  | 15.15   | 20.31 ± 0.01 | 6.759 ± 0.009 | 7.82 ± 0.18 | 6.45 ± 0.28 | 14.51 ± 0.10 |

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

| Treatment | pH | CEC (meq/100g) | BD (g/cm³) | TN | Total Nitrogen | AP | Available phosphorus | Ca, magnesium |
|-----------|----|----------------|------------|----|---------------|----|----------------------|--------------|
| L         | 6.92 ± 0.02 | 15.61 ± 0.05 | 0.49 ± 0.01 | 9.03 ± 0.12 | 5.65 ± 0.05 | 4.49 ± 0.02 | 0.97 ± 0.02 | 0.11 ± 0.008 |
| Mean      | 6.92 ± 0.02 | 15.61 ± 0.05 | 0.49 ± 0.01 | 9.03 ± 0.12 | 5.65 ± 0.05 | 4.49 ± 0.02 | 0.97 ± 0.02 | 0.11 ± 0.008 |
| LSD       | 0.34     | 0.33 ± 0.01   | 0.02 ± 0.00 | 0.34     | 0.02 ± 0.00   | 0.02 ± 0.00 | 0.34     | 0.02 ± 0.00 |
| CV (%)    | 5.28 ± 0.06| 6.33 ± 0.05   | 2.39 ± 0.02| 5.28 ± 0.06| 4.11 ± 0.11  | 5.28 ± 0.06| 5.28 ± 0.06| 5.28 ± 0.06|

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 Highlands AEZ (L₁) were higher than ones recorded from Buberuka highlands AEZ (L₂) except for BD, clay and silt content, CEC, Na and Fe. In general Birunga Highlands AEZ was more fertile than Buberuka Highland 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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