RESEARCH ARTICLE

Variations in Soil Chemical Properties, Bacteria and Fungi Populations Along Slope Positions and Profile Depths in Terraced and Non-terraced Lands of Rwanda highlands

A. Fashaho[1, 3*], G.M. Ndegwa[2], J.J. Lelei[3], A.O. Musandu[3], S.M. Mwonga[3]

10.18805/ag.D-149

ABSTRACT

The objective of the current study was to evaluate the effect of terracing on soil chemical and biological properties in the Rwanda highlands. The study was done in March 2017. Composite soil samples were collected from the top, middle and bottom slopes of four-year-terraced and non-terraced lands, in three profile depths, in medium and high altitudes. Results showed that, levels of organic carbon (1.35, 1.04%) were significantly ($p < 0.05$) higher in non-terraced than terraced land, and populations of bacteria (3.59, 2.61 $CFU*10^6g^{-1}$) and fungi (2.51, 1.57 $CFU*10^4g^{-1}$) were significantly higher in terraced than non-terraced land, in the medium-altitude, with no significant differences observed in the high altitude. Soil pH, total N, available P, CEC, exchangeable K^+, Mg^{2+} and Ca^{2+} levels in terraced and non-terraced lands were not significantly different in both altitudes. Thus, soil characteristics and fertility of the study areas showed slight changes after four years of terracing.

Keywords: Cation exchange capacity, Exchangeable bases, Nitrogen, Organic carbon, Phosphorus

Agricultural Science Digest (2019)

INTRODUCTION

Land terracing has been promoted as the best management practice for effective soil and water conservation (Dorren and Rey, 2004) in hilly and mountainous regions of many countries (Widomski, 2011). Transformation of soil layers occurs during the construction of bench terraces. This causes changes in soil chemical properties, including organic matter content, which may decrease by 50% (Ramos *et al.*, 2007) and biological properties. Microbiological properties are the most sensitive and rapid indicators of perturbations and land use changes in the surrounding soil (García-Orenes *et al.*, 2013). Bacteria and fungi are the dominant decomposers in soil (Paul, 2007). Changes in soil properties depend on natural characteristics of soil type. Soils with highly developed layers (AEBtC horizons) such as ferralsols, lixisols, and acrisols are mostly susceptible to land transformation (Driessen *et al.*, 2001). These are the major soil types in medium and high altitudes of eastern and northeastern Rwanda (Verdoodt and Van Ranst, 2003).

The objective of the study was to determine variations in soil chemical and biological properties in 4 years terraced and non-terraced lands across slope positions and profile depths in medium and high altitudes of eastern and northeastern Rwanda.

MATERIAL AND METHODS

The study was done in Rwamagana and Gicumbi districts located in the medium and high altitudes of eastern and northeastern Rwanda, respectively, in March 2017. Soils in the medium-altitude (1502–1647 m asl) were dystric regosols/ dystric leptosols in the top slope and haplic (humic) ferralsols/ haplic Lixisols in middle and bottom slopes (Verdoodt and Van Ranst, 2003). In the high altitude (1881–2130 m asl), soils were humic Alisols/humic Acrisols in the top and middle slopes and humic Acrisols/humic (ferralic) Cambisols in bottom slope (Verdoodt and Van Ranst, 2003). The mean annual rainfall received is 950–1500 mm and average temperatures range between 13.2°C and 30°C. Crops grown in the previous season in the medium and high altitudes were common beans and garden peas, respectively, and soils were fertilized with farm yard manure (FYM).

Soil samples were collected in a zigzag pattern using a soil auger at three soil depths (0–30, 30–60 and 60–90 cm), from

---

[1]Department of Crop Science, University of Rwanda, P.O. Box 210, Musanze, Rwanda

[2]Department of Soil Science, University of Rwanda, P.O. Box 210, Musanze, Rwanda

[3]Department of Crops, Horticulture, and Soils, Egerton University, P.O Box 536 – 20115, Egerton, Njoro, Kenya

Corresponding Author: A. Fashaho, Department of Crop Science, University of Rwanda, P.O. Box 210, Musanze, Rwanda, Email: fashaho@yahoo.fr

How to cite this article: Fashaho, A., G.M. Ndegwa, J.J. Lelei, A.O. Musandu, & S.M. Mwonga. (2019). Variations in soil chemical properties and bacteria and fungi populations along slope positions and profile depths in terraced and non- terraced lands of Rwanda highlands. Agri Sci Diges, 39(3):215-219.

Source of support: Research funded by the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM).

Conflict of interest: None

Submitted: 16-04-2019 **Accepted:** 30-05-2019 **Published:** 07-10-2019

the top, middle and bottom slopes of 4 year bench terraced and non-terraced lands. Three replicates were considered during sampling. For biological analysis, only the surface soil (0–30 cm) was considered, and samples were transported to the laboratory in cooled boxes where they were frozen at 4°C for a maximum of 48 hours before analysis.

Soil $pH_{(water)}$ in a 1: 2.5 soil-water solution and $pH_{(KCl)}$ in a 1: 2.5 soil-KCl 1N solution was determined using the glass electrode method (Pal, 2013; Okalebo *et al.*, 2002). Organic carbon was determined using the oxidation method of Walkley and Black (Pal, 2013; Okalebo *et al.*, 2002). Total nitrogen was determined using the Kjeldal method (Pal, 2013; Okalebo *et al.*, 2002). Available phosphorus was determined using Bray II method which is the specific method for acidic soils (Pal, 2013; Okalebo *et al.*, 2002). Cation exchange capacity (CEC) was determined using the ammonium acetate method. Exchangeable potassium (K^+), magnesium (Mg^{2+}) and calcium (Ca^{2+}) were determined using atomic absorption spectrophotometry. Total bacteria population was determined using the plate-count technique (Wallenius, 2011) based on incubating dilutions of soil suspension on plate count agar (PCA) and counting colony-forming units (CFU). For fungi population, the acidified potato dextrose agar (PDA) was used as a medium (Wallenius, 2011). Colony forming units per gram ($CFU\ g^{-1}$) of soil was calculated using the equation of Johnson and Case (2007).

$$CFU\ g^{-1}\ soil = [\text{Number of colonies/Volume plated (mL)}]^* \text{ Dilution factor} \quad ...(1)$$

Data collected were organized using excel datasheet and subjected to Bartlett Chi-square test of homogeneity. Analysis of variance (ANOVA) was performed using a statistical analysis system (SAS), version 9.2 (SAS, 2008). Duncan's Multiple Range Test (DMRT) was performed for means comparison. A total of 5% probability level was used for the significance of all statistical analyses (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Soil reaction (pH)

Soil pH values ranged from very acidic to fairly acidic rating in both study sites (Table 1). Soils were acidic due to leaching of bases resulting from excessive rainfall amounts received in the highlands. Land terracing had a non-significant influence on soil acidity due to limited application of lime in the study areas. Amare *et al.* (2013) similarly reported non-significant differences in the mean values of pH between loss and deposition zones of terraces. Soils in bottom slopes were relatively less acidic (higher pH values) than those in middle and top slopes. This may be probably due to relatively higher contents of basic cations Ca^{2+} and Mg^{2+} in bottom slope soils.

Soil cation exchange capacity and exchangeable bases

Cation exchange capacity (CEC) ranged from 5.80–11.89 $Cmol_{(+)}\ Kg^{-1}$ in medium altitude and from 5.40–9.66 $Cmol_{(+)}\ Kg^{-1}$ in high altitude (Table 1). These weak values (Hazelton and Murphy, 2007) may be attributed to low clay and organic matter contents in addition to land use consisting of continued cultivation with low nutrients replenishment. Clay and organic matter are the main factors that influence CEC in the soil (Adugna and Abegaz, 2015). Soils with a higher clay fraction tend to have a higher CEC. Terracing effect on CEC and exchangeable K^+, Mg^{2+} and Ca^{2+} was non-significant. Along with slope positions, significantly ($p < 0.05$) higher CEC and exchangeable K^+, Mg^{2+} and Ca^{2+} were found in bottom slopes. Across profile depth, higher contents were found in deeper soils (Table 2). Higher CEC and exchangeable K^+, Mg^{2+} and Ca^{2+} levels found in bottom slopes and deeper layers might be attributed to high clay content coupled with eluviation and illuviation processes. These results are in line with findings of Lawal *et al.* (2014).

Organic carbon

Soil organic carbon (SOC) ranged from 0.80–1.51% in medium altitude and from 0.85–2.53% in high altitude (Table 1). These values are ranked as weak (Landon, 1991). Higher SOC was found in non-terraced (1.35%) than terraced land (1.04%), in medium altitude. Terracing slightly reduced soil organic matter (SOM) from 2.32–1.79%. This may be attributed to higher mineralization of organic matter in the latter due to improved microorganism's activity. This reduction of SOM was, however, less than that of 50% reported on terraced lands in northeastern Spain (Ramos *et al.*, 2007). Along with slope positions, significantly ($p < 0.05$) higher SOC contents were found in top slopes in both medium (1.34%) and high altitudes (2.44%). This may be attributed to lower mineralization due to the lower population of decomposers (bacteria and fungi) compared to middle and bottom slopes. Across profile depth, higher SOC contents were found in surface layers than in sub and deeper layers (Table 2). This may be attributed to a greater concentration of organic matter from plant residues and FYM used. Naturally, plant and animal residues are concentrated in surface layers of soil. A similar trend was reported by Eze (2015) and Lawal *et al.*(2014).

Total nitrogen

Total nitrogen contents ranged from 0.06–0.08% in medium altitude and from 0.08–0.11 in high altitude (Table 1). Ratios of carbon to nitrogen (C/N) in soil varied from 13.24 to 20.33 in medium altitude and from 10.90–25.72 in high altitude. The values indicated that mineralization was normal to low (Hazelton and Murphy, 2007; Landon, 1991). Terracing effect on total N was non-significant. Along slope positions, significantly ($p < 0.05$) higher contents in total N were found in top slopes; 0.08% in medium and 0.10% in high altitudes. Across profile depth, higher total N contents were found in surface soils (0.09% N) in medium altitude (Table 2). These may vary due to higher contents of organic matter in top slopes and surface soils. A similar trend was reported by Eze (2015) and Lawal *et al.* (2014).

Available phosphorus

Available p-values ranged from 13.97–18.63%, in medium

Table 1: Soil pH, CEC, exchangeable bases, SOC, total N, available P, and bacteria and fungi populations in terraced and non-terraced lands across the top, middle and bottom slopes of the study areas (means ± Standard error)

Site location	Type of land	Slope position	pH$_{(water)}$	CEC (Cmol$_{(+)}$ Kg^{-1})	Exch. K^{+} (Cmol$_{(+)}$ Kg^{-1})	Exch. Mg^{2+} (Cmol$_{(+)}$ Kg^{-1})	Exch. Ca^{2+} (Cmol$_{(+)}$ Kg^{-1})	SOC (%)	Total N (%)	Available P (ppm)	Bacteria population (CFU*10^{6}g^{-1})	Fungi population (CFU*10^{4}g^{-1})
Medium altitude	Terraced land	Top	5.00 ± 0.05	5.80 ± 0.53	0.20 ± 0.01	1.23 ± 0.11	3.69 ± 0.12^{e}	1.23 ± 0.04	0.08 ± 0.01	15.39 ± 0.79	3.65 ± 0.34	2.27 ± 0.22
		Middle	5.43 ± 0.10	7.12 ± 0.35	0.25 ± 0.01	1.10 ± 0.12	4.55 ± 0.12^{d}	0.80 ± 0.05	0.06 ± 0.00	18.63 ± 1.18	3.10 ± 0.43	2.48 ± 0.76
		Bottom	5.79 ± 0.05	11.08 ± 0.80	0.23 ± 0.02	1.33 ± 0.06	7.77 ± 0.16^{a}	1.09 ± 0.04	0.07 ± 0.01	13.97 ± 0.02	4.03 ± 0.58	2.77 ± 0.26
	Non-terraced land	Top	5.05 ± 0.02	7.23 ± 0.59	0.19 ± 0.01	0.84 ± 0.05	3.41 ± 0.08^{e}	1.51 ± 0.02	0.08 ± 0.00	14.71 ± 0.74	2.68 ± 0.59	1.45 ± 0.40
		Middle	5.28 ± 0.08	5.83 ± 0.39	0.22 ± 0.02	1.01 ± 0.11	5.45 ± 0.35^{c}	1.16 ± 0.11	0.07 ± 0.00	17.84 ± 1.24	2.39 ± 0.43	1.50 ± 0.28
		Bottom	5.62 ± 0.13	11.89 ± 0.90	0.20 ± 0.02	1.13 ± 0.06	7.12 ± 0.31^{b}	1.38 ± 0.03	0.07 ± 0.00	15.31 ± 0.83	2.75 ± 0.24	1.77 ± 0.19
Mean			5.36	8.16	0.22	1.11	5.33	1.19	0.07	15.97	3.10	2.04
CV (%)			4.37	25.49	19.55	25.54	10.55	13.62	15.10	11.74	24.77	34.23
High altitude	Terraced land	Top	4.46 ± 0.04	8.07 ± 0.71	0.18 ± 0.01	0.84 ± 0.09	2.39 ± 0.27^{c}	2.38 ± 0.11	0.10 ± 0.01	19.30 ± 1.83	2.36 ± 0.20	2.07 ± 0.20
		Middle	4.91 ± 0.09	5.81 ± 0.43	0.15 ± 0.01	0.94 ± 0.08	3.30 ± 0.23^{b}	1.90 ± 0.06	0.08 ± 0.00	14.82 ± 1.51	2.03 ± 0.45	2.38 ± 0.30
		Bottom	5.50 ± 0.05	8.94 ± 0.71	0.25 ± 0.01	1.43 ± 0.01	4.35 ± 0.10^{a}	0.85 ± 0.05	0.08 ± 0.00	52.29 ± 1.12	2.72 ± 0.29	1.98 ± 0.29
	Non-terraced land	Top	4.45 ± 0.03	8.84 ± 0.74	0.18 ± 0.01	1.10 ± 0.07	2.70 ± 0.12^{c}	2.53 ± 0.16	0.11 ± 0.01	20.11 ± 0.73	1.69 ± 0.11	1.75 ± 0.26
		Middle	4.78 ± 0.08	5.40 ± 0.41	0.16 ± 0.01	1.00 ± 0.12	2.55 ± 0.25^{c}	1.94 ± 0.08	0.09 ± 0.01	16.04 ± 2.01	2.23 ± 0.57	2.05 ± 0.48
		Bottom	5.38 ± 0.07	9.66 ± 0.51	0.25 ± 0.01	1.43 ± 0.01	4.12 ± 0.14^{a}	0.94 ± 0.10	0.08 ± 0.00	56.43 ± 2.28	2.52 ± 0.28	1.55 ± 0.12
Mean			4.91	7.79	0.20	1.13	3.24	1.75	0.09	29.83	2.43	1.96
CV (%)			4.05	24.10	14.22	17.93	13.84	14.72	26.28	13.87	25.56	23.28

Different letters in the same column indicate significantly different values

Key: CEC = Cation exchange capacity, CV = Coefficient of variation, SOC = Soil organic carbon

Table 2: Variation of soil pH, CEC, exchangeable bases, SOC, total N and available P with profile depths in the study areas (means ± Standard Error)

Site location	Profile depth (cm)	$pH_{(water)}$	CEC ($Cmol_{(+)}$ Kg^{-1})	Exch. K^{+} ($Cmol_{(+)}$ Kg^{-1})	Exch. Mg^{2+} ($Cmol_{(+)}$ Kg^{-1})	Exch. Ca^{2+} ($Cmol_{(+)}$ Kg^{-1})	SOC (%)	Total N (%)	Available P (ppm)
Medium altitude	0–30	5.40 ± 0.09	8.06 ± 0.76	0.19 ± 0.01^{b}	1.10 ± 0.07	5.15 ± 0.45	1.30 ± 0.06^{a}	0.09 ± 0.00^{a}	17.94 ± 0.65^{a}
	30–60	5.33 ± 0.07	8.14 ± 0.70	0.22 ± 0.01^{ab}	1.08 ± 0.07	5.42 ± 0.42	1.19 ± 0.07^{b}	0.07 ± 0.00^{b}	16.10 ± 0.71^{b}
	60–90	5.36 ± 0.10	8.28 ± 0.73	0.24 ± 0.01^{a}	1.14 ± 0.07	5.42 ± 0.40	1.09 ± 0.07^{b}	0.06 ± 0.00^{c}	13.88 ± 0.46^{c}
Mean		5.36	8.16	0.22	1.11	5.33	1.19	0.07	15.97
CV (%)		4.37	25.49	19.55	25.54	10.55	13.62	15.10	11.74
High altitude	0–30	4.94 ± 0.10	7.61 ± 0.63	0.17 ± 0.01^{c}	1.00 ± 0.09^{b}	2.88 ± 0.23^{b}	1.87 ± 0.18^{a}	0.09 ± 0.01	33.47 ± 4.56^{a}
	30–60	4.87 ± 0.11	7.53 ± 0.52	0.20 ± 0.01^{b}	1.12 ± 0.07^{b}	3.14 ± 0.24^{b}	1.76 ± 0.16^{ab}	0.09 ± 0.01	29.07 ± 4.36^{b}
	60–90	4.92 ± 0.11	8.22 ± 0.51	0.22 ± 0.01^{a}	1.26 ± 0.05^{a}	3.69 ± 0.17^{a}	1.63 ± 0.16^{b}	0.08 ± 0.01	26.97 ± 4.09^{b}
Mean		4.91	7.79	0.20	1.13	3.24	1.75	0.09	29.83
CV (%)		4.05	24.10	14.22	17.93	13.84	14.72	26.28	13.87

Different letters in the same column indicate significantly different values

Key: CEC = Cation Exchange Capacity, CV = Coefficient of variation, SOC = Soil Organic Carbon

altitude, which is in the weak to middle rating (Landon, 1991), and from 14.82–56.43%, in high altitude and ranked weak to high (Landon, 1991) (Table 1). Terracing effect on available p was non-significant. Along slope positions, significantly ($p < 0.05$) higher available p contents were found in middle slope (18.23 ppm) of medium and in bottom slope (54.35 ppm) of high altitudes. This is in agreement with findings by Lawal *et al.* (2014) who reported that weathering of P rich parent rock released phosphorus into the soil. Across soil depths, significantly ($p < 0.05$) higher p contents were found in surface soils; 17.94 ppm in medium and 33.47 ppm in high altitude (Table 2). This may be due to applied FYM.

Bacteria population

Bacteria population varied from 2.39*10^{6}–4.03*10^{6}CFU g^{-1} in medium altitude and from 1.66*10^{6} to 2.72*10^{6} CFUg^{-1} in high altitude (Table 1). These values are low compared to those of 10^{8}–10^{9} CFU g^{-1} estimated in 0–15 cm soil depth (Bahattarai *et al.*, 2015). This may have been due to low SOM content and acidity of soils. The abundance and composition of the bacterial community are strongly related to soil pH. Bacteria tend to do better in neutral pH soils than in acid soils (Magdoff & ES, 2009). Significantly ($p < 0.05$) higher bacteria population was observed in terraced (3.59*10^{6} CFU g^{-1}) than non-terraced (2.61*10^{6} CFU g^{-1}) lands of medium altitude. This may due to the improved soil physical properties and enhanced microclimate in terraced lands; these include pore spaces, moisture, aeration and temperature. Microorganism population in the soil is influenced by soil porosity; the more the pore spaces, the higher is the count of microbes (Bahattarai *et al.*, 2015; Magdoff and ES, 2009). Main effect of slope positions on the bacterial population was non-significant.

Fungi population

Fungi population varied from 1.45*10^{4} to 2.77*10^{4} CFU g^{-1} in medium altitude and from 1.55*10^{4} to 2.38*10^{4} CFU g^{-1} in high altitude (Table 1). This population is low compared to the estimated values of 10^{5} – 10^{6} CFU g^{-1} in 0-15 cm soil depth (Bahattarai *et al.,* 2015). This may be attributed to low soil organic matter and nutrient content. Naturally, fungi growth tends to be promoted in undisturbed natural ecosystems (Magdoff and ES, 2009; Paul, 2007) and in high organically fertilized soils (Swer *et al.,* 2011). Significantly ($p < 0.05$) higher fungi population was observed in terraced (2.51*10^{4} CFU g^{-1}) than non-terraced (1.57*10^{4} CFU g^{-1}) lands of medium altitude. This might be attributed to higher aeration (Bahattarai*et al.,* 2015). The main effect of slope positions on fungi population was non-significant.

CONCLUSION

The objective of this study was to determine the effect of land terracing on soil chemical and biological properties across slope positions and profile depths in Rwanda highlands. Results showed that, in medium altitude area, organic carbon was higher in non-terraced than in terraced lands, bacteria and fungi populations were higher in terraced than in non-terraced lands, and non-significant differences in high altitude. Soil pH, contents in total N, available P, CEC, exchangeable K^+, Mg^{2+} and Ca^{2+} were not significantly different in terraced and non-terraced lands in both study areas. Along slope positions, top slope soils had higher contents in organic C and total N, while bottom slopes had higher contents in CEC, Mg^{2+} and Ca^{2+}. Across profile depths, SOC, total N, available P were higher in surface soils, while CEC, exchangeable K^+, Mg^{2+}, Ca^{2+} were higher in deeper layers. Therefore, soil chemical and biological properties of the study areas showed variations along slope positions and profile depth, but slight changes were due to terracing.

ACKNOWLEDGMENTS

Authors would like to acknowledge the Carnegie Cooperation of New York and the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) for funding. We thank the University of Rwanda and Egerton University, for providing research facilities, including laboratory and libraries.

REFERENCES

Adugna, A., Abegaz, A. (2015). Effects of soil depth on the dynamics of selected soil properties among the highlands resources of Northeast Wollega , Ethiopia : are these sign of degradation? Soil Earth, 1: 2011–2035. DOI: 10.5194/sed-7-2011-2015.

Amare, T., Terefe, A., Selassie, Y. G., *et al,* (2013). Soil Properties and Crop Yields along the Terraces and Toposequece of Anjeni Watershed, Central Highlands of Ethiopia. Journal of Agricultural Science, 5(2): 134–144. DOI: 10.5539/jas.v5n2p134.

Bahattarai, A., Bhattarai, B., & Pandey, S. (2015). Variation of Soil Microbial Population in Different Soil Horizons. Journal of Microbiology & Experimentation, 2(2): 2–5. DOI: 10.15406/jmen.2015.02.00044.

Dorren, L., & Rey, F. (2004). A review of the effect of terracing on erosion. In Briefing Papers of the second SCAPE workshop in Cinque Terre (IT), 13-15 April 2004 (pp. 97–108).

Driessen, P., Deckers, J., & Spaargaren, O. (2001). Lecture Notes on the major Soils of the world. In World Soil Resources Reports (pp. 94–334). FAO, Rome.

Eze, P. N. (2015). Spatial variability and classification of soils on a Legon hill catena in the Accra Plains , Ghana. Journal of Soil Science and Environmental Management, 6(8): 204–214. DOI: 10.5897/JSSEM15.0495.

García-Orenes, F., Morugán-Coronado, A., Zornoza, R., *et al.* (2013). Changes in Soil Microbial Community Structure Influenced by Agricultural Management Practices in a Mediterranean Agro-Ecosystem. PLoS ONE, 8(11): 1–9. DOI: 10.1371/journal.pone.0080522.

Gomez, K. A., & Gomez, A. A. (1984). Statistical Procedures for Agricultural Research (Vol. 6). John Willey & Sons, Inc.

Hazelton, P., & Murphy, B. (2007). Interpreting Soil Test Results: What do all the Numbers mean? (N. D. of N. Resources, Ed.). CSIRO Publishing.

Johnson, T. R., & Case, C. L. (2007). Laboratory Experiments in Microbiology (8th ed.). Pearson.

Landon, J. R. (1991). Booker Tropical Soil Manual. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman Scientific and Technical Publishers.

Lawal, B. A., Tsado, P. A., Eze, P. C., Idefoh, K. K., Zaki, A. A., & Kolawole, S. (2014). Effect of Slope Positions on some Properties of Soils under a Tectona grandis Plantation in Minna , Southern Guinea Savanna of Nigeria. International Journal of Research in Agriculture and Forestry, 1(2): 37–43.

Magdoff, F., & ES, H. V. (2009). Building SoilS Better Crops, Sustainable Soil Management. (F. Magdoff & H. V. ES, Eds.) (3rd ed.). Sustainable Agriculture Research and Education (SARE) program, USA.

Okalebo, J. , Gathua, K. W., & Woomer, P. L. (2002). Laboratory methods of soil and plant analysis: A working manual (2nd ed.). Kenya.

Pal, S. K. (2013). Soil sampling and methods of analysis. Pitam Pura, New Delhi - 110 088: New India Publishing Agency (NIPA).

Paul, E. A. (2007). Soil Microbiology, Ecology, and Biochemistry. (E. A. Paul, Ed.) (3rd ed.). Oxford: Elsevier.

Ramos, M. C., Cots-Folch, R., & Martínez-Casasnovas, J. A. (2007). Effects of land terracing on soil properties in the Priorat region in Northeastern Spain: A multivariate analysis. Geoderma, 142(3–4): 251–261. DOI: 10.1016/j.geoderma.2007.08.005.

SAS. (2008). SAS/STAT® 9.2 User's Guide. SAS Institute Inc.,. Cary, NC., USA.

Swer, H., Dkhar, M. S., & Kayang, H. (2011). Fungal population and diversity in organically amended agricultural soils of Meghalaya, India. Journal of Organic Systems, 6(2): 3–12.

Verdoodt, A., & Van Ranst, E. (2003). Land Evaluation for Agricultural Production in the Tropics. A Large-Scale Land Suitability Classification for Rwanda. (G. U. Laboratory of Soil Science, Ed.). Ghent, Belgium.

Wallenius, K. (2011). Microbiological characterisation of soils: Evaluation of some critical steps in data collection and experimental design. Helsinki.

Widomski, M. K. (2011). Terracing as a Measure of Soil Erosion Control and Its Effect on Improvement of Infiltration in Eroded Environment. (Danilo Godone, Ed.), Soil Erosion Issues in Agriculture. InTech. DOI: 10.5772/24683.