Variation of soil nutrients in maize growing areas along the altitudinal gradient of Taita hills transect in Kenya

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Abstract

Maize is the main staple food crop in Kenya but its yield is being affected by biotic and abiotic factors which reduce maize yield while soil nutrient elements increase the yield. Most plants grow by absorbing nutrients from the soil depending on the nature of the soil. Soil texture affects how well nutrients and water are retained in the soil. Clays and organic soils hold nutrients and water much better than sandy soils. As water drains from sandy soils, it often carries nutrients along with it through leaching. When nutrients leach into the soil, they are not available for plants to use thus affecting the plant health. This study evaluated several physical and chemical properties of soil along the altitudinal gradients of Taita hills which is characterized by graded changes in climatic conditions. Both nitrogen and carbon increased with increase in altitude while Potassium, phosphorus and pH deceased with increase in altitude. Moisture and temperature appear to be important drivers in soil parameter and therefore biological patterning along the transect.

Key words: Altitudinal gradient, Soil nutrient, Transect, Soil texture, Soil pH, Leaching.

1. Introduction

Maize (*Zea mays* L. [Poaceae]) is an extremely important crop for millions of people in Africa. Maize is mainly cultivated by subsistence farmers for human consumption while the surplus is used as animal fodder (Minja, 1990; Kfir *et al*., 2002). Since the 1980s, many countries in sub-Saharan Africa have remained net importers of maize. This has been attributed to the rapidly expanding population and stagnating yields over the years (FAO, 1999). In spite of this, it is forecasted that by the year 2020, the global demand for maize will have grown by 45% of which 72% will be in developing countries while only 28% in the industrialised nations (James, 2003). In the densely populated areas of Kenya that have a high maize yield potential, the crop is grown on the same plot continuously year after year due to population pressure and land constraints. This has led to a steady decline in soil fertility and a net reduction in yields in these areas (FEWS, 2008).

According to (Batiano, 2005), soil fertility degradation and decline in productivity have been described as important constraints to food production and security in Sub-Saharan Africa. Scientific research has contributed immensely to the improvement of agricultural practice. However despite the availability of high yielding and pest resistant varieties of major crops there is still a large yield gap between the potential yield provided by scientific experiment and the yield obtained by the farmers in Africa, leaving sub-Saharan Africa experiencing food insufficiency and insecurity (Boutfirass *et al*., 1999). In order to forestall the surging demand, new methods of production need to be sought while reinforcing the existing ones to better manage the complex of problems facing maize farmers in tropical Africa (FAO, 2002). Restoration of graded land for enhanced ecosystem services and agricultural production requires baseline data on chemical and physical characteristic of soil along the gradient. The objective of this study was to determine the variation of soil texture, total organic carbon (TOC), total nitrogen (TN), phosphorus, potassium and pH along the altitudinal gradient of Taita Hill which is characterized by graded changes in climatic conditions within a short distance to see whether they are contributing to low maize production in the area.

2. Materials and methods

2.1 Study Site

All soil samplings were done in one study transect, Taita hills in Kenya. This transect was characterized by rapid changes in altitudinal gradients with graded changes in temperatures and humidity patterns, and had maize plants grown along the gradients as shown in (table 1 and table 2). Taita transect included six sites, between latitude 03°39.086 to 03°47.936' S and longitude 38°29.575' to 38°38.001' E. This transect occur in an altitudinal gradient starting at Kipusi (818 m) to Vuria (1,814 m) this is clearly shown in (table 1).

Table 1. Taita hills studied characterized by altitudinal gradients.

	Localities	Latitude	Longitude	Altitude (m asl)	Soil characteristics
Taita hills	Kipusi	S 03°47.870' - 03°47.936'	E 38°36.726' – 38°38.001'	818 - 871	rhodic ferralsols
	Dembwa	S 03°44.140' – 03°44.721'	E 38°36.051' - 38°36.446'	1,083 – 1,102	rhodic ferralsols, with ferralic arenosols and ferralo-chromic luvisols

	Josa	S 03°42.988' – 03°43.306'	E 38°35.610' - 38°35.801'	1,340 – 1,358	humic cambisols, with humic nitisols, dystric regosols
	Mbengonyi	S 03°41.736' – 03°42.046'	E 38°36.210' - 38°36.601'	1,467 – 1,490	humic cambisols, with humic nitisols, dystric regosols
	Kighala	S 03°39.086' – 03°39.265'	E 38°33.803'- 38°33.896'	1,678 – 1,709	chromic acrisols, with cambisols and ferralsols
	Vuria	S 03°40.275' – 03°40.475'	E 38°29.575' - 38°29.656'	1,797 – 1,814	rankers and cambisols

Table 2. Monthly temperature (°C) and relative humidity (%) (Means ± standard error) along the Taita hills transect.

	Localities	**Altitude (m asl)**	**Temperature over the day**	**Temperature over the night**	**Relative humidity over the day**	**Relative humidity over the night**
Taita Hills[1]	Kipusi	818 - 871	27.3 ± 0.5	20.5 ± 1.4	56.7 ± 2.2	83.7 ± 1.7
	Dembwa	1,083 – 1,102	25.6 ± 0.7	18.5 ± 0.3	62.8 ± 1.7	92.7 ± 1.5
	Josa	1,340 – 1,358	21.4 ± 0.6	18.1 ± 0.5	71.5 ± 2.5	91.7 ± 0.9
	Mbengonyi	1,467 – 1,490	21.3 ± 0.5	16.6 ± 0.4	74.5 ± 2.4	90.4 ± 2.1
	Kighala	1,678 – 1,709	20.1 ± 0.5	15.8 ± 0.4	81.0 ± 2.1	95.1 ± 1.8
	Vuria	1,797 – 1,814	19.4 ± 0.7	15.1 ± 0.4	76.4 ± 2.0	94.6 ± 1.7

[1]from June 2012 to June 2013

2.2 Soil sampling and analysis

Soil samplings were done in October 2012. For each transect and altitudinal zone, soil samplings were done in 10 cultivated plots. Each of the cultivated plots represented one replicate per altitudinal zone. For each plot, 3-4 sub-samples were randomly selected, sampled and grouped to finally represent the entire farmer's plot. Prior to soil sampling, 1-2 cm upper surface soil layers was first removed from each sampling area to avoid contamination of the samples resulting from foreign material such as crop residues. Soil sample were collected, at a depth of between 0-25 cm by the use of soil augur. All soil samples were passed through a 2.0mm sieve before analysis so as to increase the surface area. Soil pH was measured with a glass electrode (soil to solution =1:2.5 using 1M KCl) total organic carbon (TOC) was measured by the dichromate oxidation method (Kalembasa and Jenkinson 1973). Total nitrogen (TN) was measured by Kjeldhal digestion method (Jackson 1973). Phosphorus level was determined at 880 nm using (Model Milton Roy Spectronic 21D UV-Visible Spectrophotometer). Potassium was determined using a flame photometer (Corning M 410) and analyzed according to the method of (Anderson and Ingram, 1993). Soil texture was determined by use of hydrometer method to determine textural grade, an equilateral triangle was used for the purpose of textural classes. For each altitude, the temperature and relative humidity (Table 1 and table 2) were recorded each hour during the study period using HOBO data loggers placed permanently in one of the farmer's plots.

2.3 Data analyses

All data were log-transformed to fit to normal distribution as well as homogeneity of the variance. Untransformed values are presented in the figures and tables. One-way analyses of variance (ANOVA 1) were used to indicate significant factors and interaction of separate means. All statistics were done using R (http://www.r-project.org/2014).

3. Results and discussion.

3.1 Soil texture

The chemical and physical analysis of the soil samples collected showed changes from one altitudinal zone to another in almost all parameters measured along the transect. (Table 3) shows physical properties of six representative soil sites. Sand was a dominant soil class in all sites. The percentage of sand was highest in Kipusi (lower altitude) with 84.4% and lowest at Mbengonyi (one of the three higher altitude) with 68.2%. The trend of soil texture (silt and clay) in Taita Hills showed that lesser percentage was in Kipusi where silt was 5.6% and clay was 10.0%. Josa had the highest percentage of clay 17.4% while Mbengonyi had the highest percentage silt 17.0%. All these variation were significant in all altitudes as shown in (table 3).

Table.3. Soil texture (%) (Mean ± standard errors) along the altitudinal gradient of Taita hills transect.

Locality	Altitude (m a s l)	Clay %	Sand %	Silt %
Kipusi	818 - 871	15.6 ± 1.56^{ab}	76.4 ± 2.08^{b}	8.6 ± 1.70^{ab}
Dembwa	1,083 – 1,102	16.2 ± 1.5^{ab}	70.8 ± 1.81^{ab}	13.0 ± 1.12^{bd}
Josa	1,340 – 1,358	17.4 ± 1.73^{b}	68.2 ± 1.04^{a}	15.4 ± 1.52^{cd}
Mbengonyi	1,467 – 1,490	13.0 ± 1.86^{ab}	70.0 ± 1.65^{ab}	17.0 ± 1.30^{d}
Kighala	1,678 – 1,709	15.6 ± 1.39^{ab}	74.4 ± 1.90^{ab}	10.0 ± 1.07^{abc}
Vuria	1,797 – 1,814	10.0 ± 1.31^{a}	84.4 ± 1.54^{c}	5.6 ± 0.83^{a}
		$F_{5,54} = 2.79$	$F_{5,54} = 11.92$	$F_{5,54} = 10.8$
		$P < 0.05$	$P < 0.001$	$P <$ 0001

Multiple comparisons of means: Turkey contrasts. Means with different letters are significantly different at 95% confidence interval.

3.2 Carbon and nitrogen

Both total organic carbon and total organic nitrogen increased with increase in altitudinal gradient as shown in (figure 1). They showed a significant variation $F_{5, 54} = 9.68$, $P < 0.001$ for total organic carbon, $F_{5, 54} = 9.44$, $P < 0.001$ for total nitrogen at 95% confidence interval. This corroborated with (Jenny *et al.*, 1949) that decomposition of organic maters is related to climatic parameter. The relationship between TN and TOC with altitude has been investigated and positive correlations were reported (Sims and Nielsen, 1986). Altitude influences TN and TOC by controlling the soil water balance; soil erosion and geologic deposition processes (Tan *et al.*, 2004). Also, there was relationship between TOC and soil texture whereby carbon increase with increase in the amount of clay and silt. These significance relationship of soil texture (clay and silt) and TOC reflect importance of plant residues inputs in the formation of soil. These are in agreement with (Bechtold and Naiman, 2006; Cabezas and Comin, 2010) who observed that TOC storage in the soil was strongly correlated with the concentration of fine particles. This is because soil with high clay content may have high TN and TOC content due to slow decomposition of organic maters.

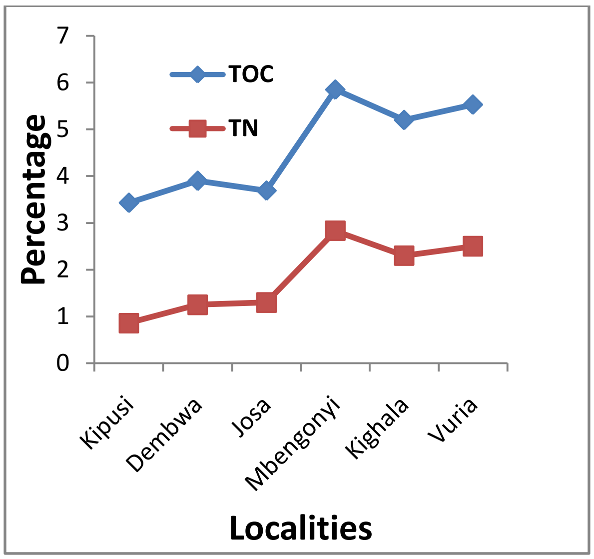

Fig. 1. The percentage Total Organic carbon and Total Nitrogen along the transect.

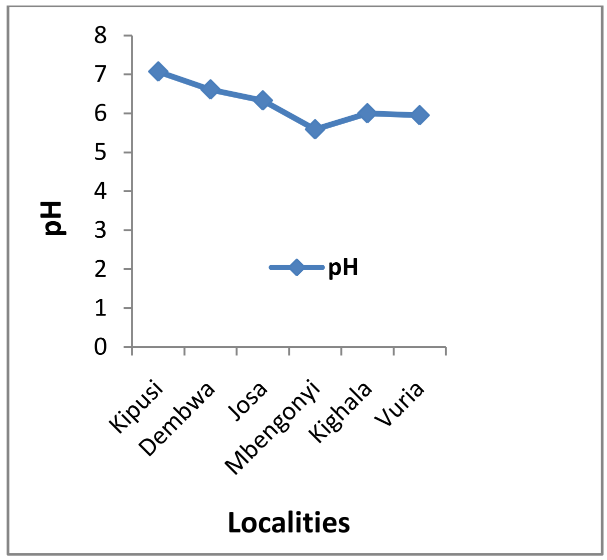

Fig. 2. Change in pH along the transect.

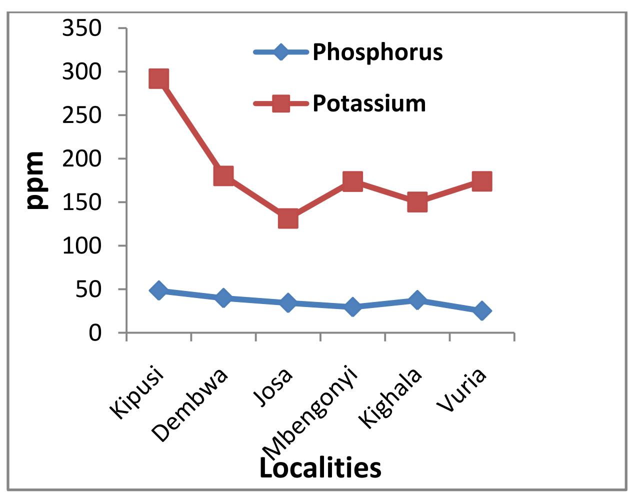

Fig.3. Concentrations of total phosphorus and potassium along the transect.

3.3 Potassium, Phosphorus and pH

Potassium clearly decreased with increase in altitude. It showed a significant difference between the altitudes $F_{5, 54} = 3.86$ $P < 0.01$(Figure 3). Phosphorus weakly decreased in concentration with increasing altitude but this trend was not significant $F_{5, 54} = 0.965$, P=0.447 (figure 3). Changes in soil properties with altitude is influenced strongly by microclimate and topography (Proctor et al., 2007; Bendix *et al.*, 2008; Wilcke *et al.*, 2008; Gerold *et al.*, 2008). Generally cooler, wetter condition at higher altitude reduces biological activity and increase leaching. Steeper profile encourage run off and subsurface movement of water down slope. This manifests in the reduction of nutrients susceptible to weathering such as potassium (K). Associated with the loss of alkaline metal ion like (K^+) from the soil is a decrease in soil pH. This is the reason behind pH significant decrease with increasing altitude $F_{5, 54}=11.32$ $P<0.0001$ (Schawe *et al*., 2007; Proctor *et al.*, 2007; Wilcke *et al.*, 2008) as seen in the current study figure 2. These alkaline metal ions are deposited in the lower altitude causing an increase in pH around these areas as shown in (figure 2.) Low soil pH in the higher altitude is also thought to reflect the acidic nature of organic matter decomposition (Schrumpf *et al.*, 2001). Maintaining the right pH for maize affects the plants' ability to utilize nutrients from the soil. Despite the different levels of soil pH most areas were within the best range of 5.8 to 6.5, as recommended by the University of Rhode Island Extension. Various research efforts have shown that potassium stimulates early growth, increases protein production, improves the efficiency of water use, is vital for stand persistence, longevity, and improves resistance to diseases and insects while Phosphorus (P) is essential for plant growth. It stimulates growth of young plants, giving them a good and vigorous start (Wild, 1988). Therefore low concentration of these nutrients in the soil might be the cause of low maize production in these areas.

4. Conclusions

Soil total organic carbon and total nitrogen content increased concomitantly with increase in altitude due to low temperature and high humidity in the high altitude which reduced the rate of decomposition of organic matter. Potassium and Phosphorus concentration decreased with an increase in altitude due to leaching caused by high precipitation in the higher altitude. The soil pH decreased with increase in altitude due to loss of alkaline metal ion like (K^+) through leaching. Moisture and temperature appear to be important drivers in soil parameter and therefore biological patterning along the transect. Therefore to boost maize production soil need to be amended with potassium and phosphorus based fertilizer especially in the higher altitude while nitrogen needs to be added in the lower altitude.

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References

Anderson, J. M., & Ingram, J. S. I. (1993). Tropical Soil Biology and Fertility: A Handbook of Methods. (2nd ed), CAB. International, Oxfordshire, Wallingford, UK., ISBN: 0-85198-821-0.

Bationo, S.H., Chien, J., Henao,C .E., Christianson & Mokwunye, A.V.(1990).Agronomic evaluation of two un acidulated and partially acidulated phosphate rocks indigenous to Niger. *Soil Science Society Of America Journal* **54**:1772-177.

Bechtold, J. S., & Naiman, R. J. (2006). Soil texture and nitrogen mineralization potential across a riparian topsequence in a semi-arid savanna. *Soil Biol. Biochem*., **38**: 1325–1333.

Bendix, J., Rollenbeck, R., Richter, M., Fabian, P., & Emck, P. (2008). Climate. Pp. 63-73. In, Beck, E., Bendix, J., Kottke, I., Makeschin, F. & Mosandl, R. (eds), *Gradients in a Tropical Mountain Ecosystem of Ecuador.* (SpringerVerlag: Berlin Heidelberg).

Boutfirass, M., Gharous, M. EI., Mourid . M. EI., & Karrou, M. (1999).Optimizing soil water use research in deficient water environments of Morocco. In: N. Van Duivenbooden, M. Pala, C. Studer & C. L. Bielders (Eds.), Efficient soil water use: the key to sustainable Crop production in the dry areas of West Asia ,and Northand SubSaharan Africa. ICARDA ,Aleppo/ICRISAT, Patancheru , pp.125-142.

Cabezas, A., & Comín, F.A.(2010). Carbon and nitrogen accretion in the topsoil of the Middle Ebro River Floodplains (NE Spain): Implications for their ecological restoration. *Ecological engineering.,* **36**: 640–652.

FEWS (2008). FEWS -In Depth Kenya. http://www.fews.net/docs/Publications accessed 19 March 2008.

Food and Agriculture Organization (1999). FAOSTAT Statistical database. Agricultural data. http://www.fao.org accessed 15 September 2008.

Food and Agriculture Organization (2002). FAOSTAT Statistical database. Agricultural data. http://www.fao.org accessed 15 September 2008.

Gerold, G., Schawe, M., & Bach, K. (2008). Hydrometeorologic, pedologic and vegetation patterns along an elevational transect in the montane forest of the Bolivian Yungas. Erde **139**: 141-168.

Jackson, M.L. (1973). Soil Chemical Analysis. *Pentice Hal of India*, Pvt. Ltd., New Delhi.

James, C. (2003). Global Review of commercialised Transgenic Crops: (2002). Feature: Bt-maize *ISAAA Briefs. No. 29 ISAAA Ithaca, NY* http://www.isaaa.org/ Resources/Publications accessed 13 October 2007.

Jenny, H., Gessel, S. P., & Bingham, F.T. (1949). Comparative study of decomposition of organic matter in temperate and tropical regions. *Soil Science*., **68**: 419– 432.

Kalembasa, S. J. and Jenkinson, D.S. (1973). A comparative study of titrametric and gravimetric methods for the determination of organic carbon in soils. *J. Sci. Food Agric* **24**:1085-1090.

Kfir, R., Overholt, W.A., Khan, Z.R., and Polaszek, A. (2002). Biology and management of economically important lepidopteran cereal stemborers in Africa. *Annual Review of Entomology* **47**: 701-731.

Minja, E.M. (1990). Management of *Chilo* spp. infesting cereals in Eastern Africa. *Insect Science and its Application* **11**: 489-499.

Proctor, J., Edwards, I. D., Payton, R.W. & Nagy, L. (2007). Zonation of forest vegetation and soils of mount Cameroon, West Africa. *Plant Ecology* **192**: 251-269

Schawe, M., Glatzel, S., & Gergold, G. (2007). Soil development along an altitudinal transect in a Bolivian tropical montane rainforest: podzolization vs. hydromorphy. *Catena* **69**: 83-90.

Schrumpf, M., Guggenberger, G., & Valarezo, C. (2001). Tropical montane rain forest soils. Die Erde **132**:43-59

Sims, Z.R., & Nielsen, G.A. (1986). Organic carbon in Montana soils as related to clay content and climate. *Soil Science Society of America Journal*., **50**: 1269– 1271.

Tan, Z. X., Lal, R., Smeck, N. E., & Calhoun, F. G., (2004). Relationships between surface soil organic carbon pool and site variables. Geoderma., **121**: 185–187.

Wilcke, W., Yasin, S., Schmitt, A., Valarezo, C., & Zech, W. (2008). Soils along the altitudinal transect and in catchments. Pp. 75-85. In, Beck, E., Bendix, J., Kottke, I., Makeschin, F. & Mosandl, R. (eds), Gradients in a Tropical Mountain Ecosystem of Ecuador. (Springer Verlag, Berlin Heidelberg).

Wild, A. (Ed.) (1988). "Russell's Soil Conditions and plant growth". 11th Edition, Longman group UK LTD, London pp.797

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