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Full Length Research Paper

Effect of long-term integrated soil fertility management by local farmers on nutrient status of a Typic Dystrandept under potato-based cropping system

***Tabi[1] FO, Bitondo[1] D, Yinda[2] GS, Kengmegne[1] SSA and Ngoucheme[1] M**

[1]Department of Soil Science, Faculty of Agronomy and Agricultural Sciences, University of Dschang
[2]Department of Environmental Science, University of Buea
*Corresponding Author E-mail: obenft@yahoo.com

Abstract

Farmers in the western highlands of Cameroon use poultry and other animal manures with mineral fertilizers to increase crop yield. However, the effect of their practices on soil quality is not known. This study was designed to: identify the main cropping system; evaluate soil nutrient status; investigate relationships between nutrients and assess the suitability of farmers' practices on soil quality. Cropping system survey was carried out using structured questionnaires and interviews. Baseline soil information was obtained from a representative Typic Dystrandept profile. An intensively cropped area (3 ha), was sampled at 0-25 cm soil depth and analyzed for soil chemical properties. Nutrient contents were compared with critical levels to declare sufficiency or deficiency. Suitability of farmers' practices was assessed by comparing soil properties with those of the reference profile using Student's T-test. Correlation analysis was performed among soil properties. The dominant cropping system was potato-based. pHw varied from 5.03 to 6.28 with a mean of 5.8; while organic carbon (OC), total nitrogen (N) and C/N ratio ranged from 5.0 to 8.13 %, 0.24 to 0.83 % and 7.29 to 31.92, with means of 6.73 %, 0.6 % and 12.55 respectively. Available P varied from 7.5 to 37.3 mg/kg; while Ca, Mg, K and CEC varied from 4.24 to7.84, 0.4 to 5.5, 0.3 to 0.7 and 26.7 to 36.0 cmol/kg; with means of 6.4, 2.2, 0.4 and 33.0 cmol+/kg respectively. All the nutrients were in medium concentrations and the soils were acidifying. $\triangle$pH was less negative under current farmers' practices. Apart from exchangeable Ca and CEC which decreased ($p<0.05$) and pH_{KCl} and total N which increased ($p<0.01$ and $p<0.05$ respectively) significantly, no significant changes relative to the baseline were observed with other soil properties. Mg^{2+} was the most dominant cation. For an ideal cationic balance, 2.76 cmol+/kg Ca and 0.29 cmol/kg K are required under farmers' practices. Available P and Ca were positively and significantly correlated (r=0.72), while K was significantly and negatively correlated (r=0.50*) with Ca. Although poultry manure is a major source of Ca, the required quantity to combine with mineral fertilizers on a Typic Dystrandept is not known. We recommend that for high yields to be obtained and production sustained, farmers' practice of ISFM should be encouraged and supported with recommendations of mineral fertilizers and animal manures from on-farm experiments and the use of ammonium sulphate, prohibited.**

Keywords: Nutrient status, integrated soil fertility management, Agro-technology transfer, Potato cropping system, Bambouto highlands.

INTRODUCTION

Cropping systems in the tropics are generally characterized by high nutrient losses and negative nutrient balance especially in N, P and K (Smaling, 1993). Long-term processes that adversely affect sustainability, such as decrease and eventual depletion of soil nutrient stocks, are less visible and receive a lower priority (Ehabe et al., 2010). Most often, tropical soils under peasant farming systems are progressively being mined of their nutrients (Kanmegne, 2004) whereas there is need to secure present productivity and ensure the sustainability of these farming systems.

Various technologies have been developed to reverse this negative trend, with particular emphasis on integrated soil fertility management. The sole use of mineral fertilizers was not as successful in the tropics as in the temperate zone during the green revolution era. Similarly, sole use of organic materials was plagued with problems of bulkiness, unavailability, low quality and slow release of nutrients. In view of the aforementioned, combining organic and mineral inputs has been advocated as a sound management principle for smallholder farming systems in the tropics because neither of the two inputs is usually available in sufficient quantities and because both inputs are needed in the long-term to sustain soil fertility and crop production (Vanlauwe and Zingore 2011). Vanlauwe and Zingore (2011) define ISFM as 'a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic principles.

Results from long-term planned experiments from experimental stations and researcher assisted on-farm trials on the benefits of ISFM abound (Bationo, 2004) but however, there is limited information on how farmers' indigenous practices of ISFM have affected nutrient status and sustainability of cropping systems. Famers in Femok, Cameroon practice market gardening on typic Dystrandept soils and over the years have been using combined application of poultry, pig manure and mineral fertilizers on their fields in variable amounts, with limited guidance from agricultural extension workers. These farmers are not aware of any fertilizer recommendations or their crops, but have over the years from try-and-error established local measures considered suitable for their cropping systems. Transfer of information on ISFM has been from farmer- to-farmer interaction through field visits and on-the-spot assessment of growth and yield characteristics on farmers' fields.

Soil fertility is today regarded as a major survival issue, thus upscaling ISFM is a major approach to increase food security and promote adaptation to climate change which is a challenge to agricultural sustainability. Since fertilizer is very expensive for most smallholder farmers in SSA, the Alliance for a Green Revolution in Africa (AGRA) has adopted ISFM as a framework for boosting crop productivity through combining fertilizer use with other soil fertility management technologies, adapted to local conditions (Vanlauwe and Wommer, 2011). We believe that if farmers' practices of ISFM are evaluated and the results communicated to them with improvements, if necessary, the rate of adoption of ISFM would be high through farmer's existing networks or groups. Working with existing farmer associations and their umbrella networks to promote ISFM also offers several advantages (Sanginga and Woomer, 2009).

This study was designed to: identify the main cropping system; evaluate nutrient status of soils; investigate relationships between nutrients and to assess the suitability of farmers' practices on soil quality of an Inceptisol.

MATERIALS AND METHODS

Description of the site

Mount Bambouto is located between latitude 5°25' to 5₀45' N and longitude 10°00' to 10°15' E. it is one of the major volcanic mountains of the west Cameroon highlands (Leumbe Leumbe et al., 2005). Specifically, the study was carried out in Femok (Bafou), a mid-altitude zone located between 1600 and 2000 m on the southern slope of Mount Bambouto (Figure 1). The soils were classified as Typic Dystrandept (Doube 1989). The mid-altitude zone has a sub-equatorial climate modified by altitude (Ngoufo, 1988), wet and humid with a long rainy season (March - November) and a short dry season (December - February). Mean annual rainfall is 1690 mm and mean monthly temperature fluctuates around 18°C.

A survey was carried out to identify cropping systems in the area. Seventy four questionnaires were administered, designed to capture major cropping systems, use of mineral fertilizers and manure (animal, compost and others), number of years of integrated soil fertility management (ISFM) practice, quantities of mineral fertilizers and manure used and contact with extension agents. Based on the results of the survey, the main cropping system was selected for soil characterization. Only fields of farmers with more than 10 years of farming experience were used in the study.

Baseline soil information was obtained from a representative Typic Dystrandept profile (Table 1) described and analyzed in 1989 (Doube 1989). This is a soil that has developed on volcanic material overlaying basaltic lava. Feldpars (limited quantities), augite, kaolinite, gibbsite, quartz and vermiculite (small quantities) were the identified minerals (Doube, 1989). From an intensively cropped area (3 ha), 19 samples were randomly sampled at 0-25 cm and analyzed for soil chemical properties. The samples were air-dried at room temperature and crushed to pass through a 2 mm sieve. The soils were analyzed for the following properties: pH, organic carbon, cation exchange capacity (CEC), Total N (totN), available P, exchangeable K, Ca, Na and Mg, following procedures outlined by Pauwels *et al.* (1992). Soil pH was determined by a pH meter with a soil/water ratio of 1:2.5. Organic carbon was determined by Walkley and Black method (Walkley and Black, 1934) and total organic matter (OM) was calculated by multiplying the organic carbon by a factor of 1.724 (Walkley and Black, 1934). Available P was extracted following the Bray 1 procedure (Bray and Kurtz, 1945). The cation exchange

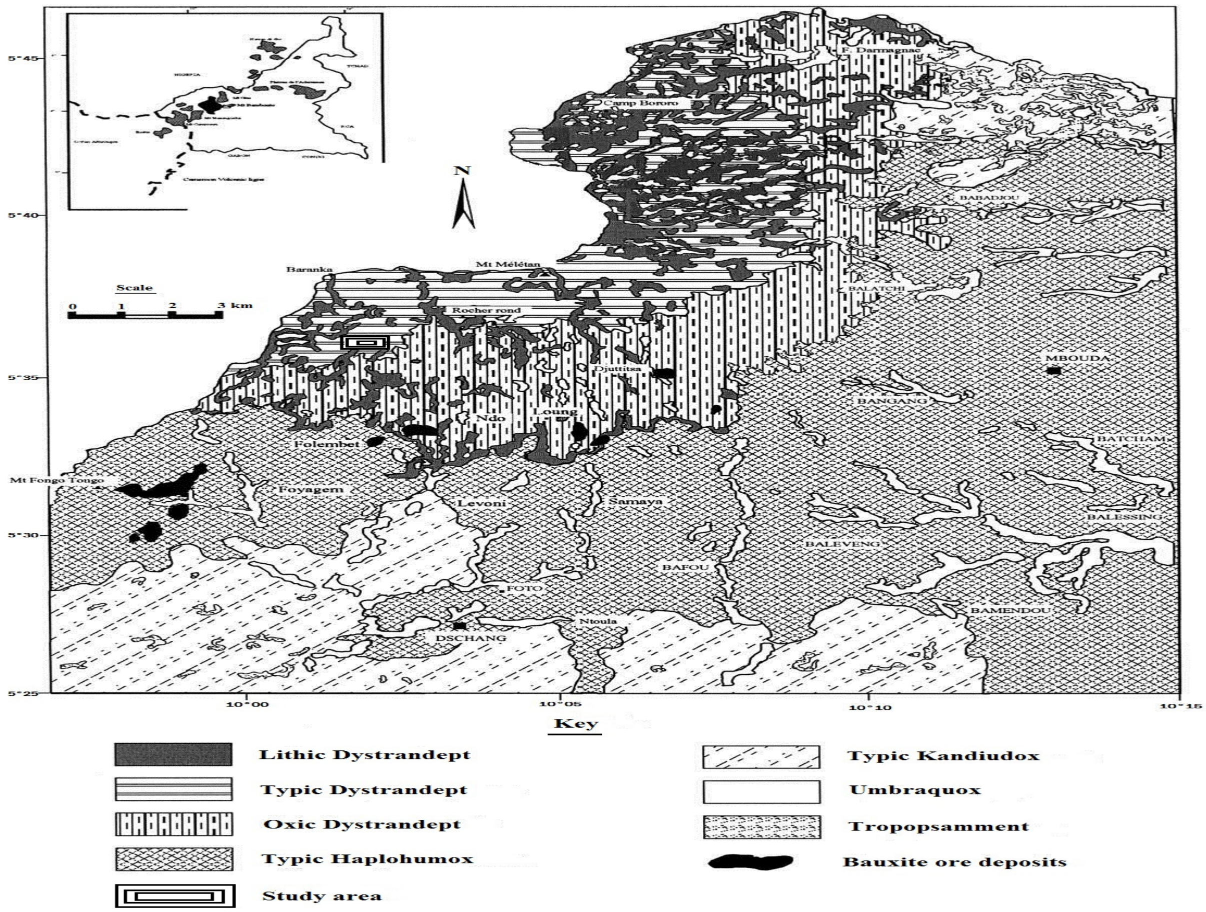

Figure 1: Map of Cameroon showing study area (adapted from Tematio *et al*., 2004)

Table 1: Soil properties of a Typic Dystrandept in the bambouto highland of Cameroon

	Soil depth (cm)				
Soil properties	**0-28**	**28-52**	**52-72**	**72-84**	**84-190+**
Sand (%)	6	5	4	3	25
Silt (%)	28	30	21	10	3
Clay (%)	66	65	75	88	73
Bulk density (g/cm3)	0.62	0.64	0.72	0.87	0.86
Organic carbon (%)	6.3	5.3	4.4	5.1	4.2
Total nitrogen (%)	0.5	0.4	0.3	0.3	0.1
C/N	12.6	13.2	14.6	17.0	42.0
pH (water)	5.8	6.1	6.1	6.1	6.0
pH (KCl)	4.7	5.0	5.2	5.2	5.3
Available P (Olsen) (mg/kg)	20.5	11.1	30.7	5.5	2.8
Exchangeable bases (cmol+/kg)					
Ca	8.4	10.7	10.4	2.4	8.2
Mg	2.4	2.8	2.3	2.4	1.6
K	0.4	0.2	0.3	0.3	0.4
Na	0.1	0.1	trace	trace	trace
CEC (NH_4OAc_7) cmol/kg	45.4	42.4	38	33.9	24.7
Base saturation (%)	24.9	32.5	34.2	44.8	41.3

Table 2: Classification of natural fertility levels in soils based on total N, available P, CEC and individual exchangeable cations

Natural fertility level	OM	N	P	Ca^{2+}	Mg^{2+}	K_+	CEC
		%	mg/kg	-------------cmol+/100g-------------			
Very high	>6.0	>0.30		>20	>8	>1.2	>40
High	4.2-6.0	0.23-0.30	>46	10-20	3-8	0.6-1.2	25-40
Medium	2-4.2	0.13-0.23	16-46	5-10	1.5-3	0.3-0.6	15-25
Low	1-2	0.05-0.13	7-16	2-5	0.5-1.5	0.12-0.3	5-15
Very low	<1	<0.05	<7	<2	<0.5	<0.12	<5

Adapted from Verheye (2008) and EUROCONSULT (1989); available P is by Bray 2 method

Table 3: Use of mineral fertilizers and organic manure by farmers

Inputs	Percentage of respondents	Remarks	Rate of application[1]	
			Mineral kg/ha	Organic t/ha
Mineral fertilizers and manure	93	NPK 20-10-10, urea, poultry manure, pig manure, cow dung and farm yard manure (FYM)	500 - 2000 (NPK 20-10-10); 50 - 300 (urea)	5.3 - 30 (poultry manure),
	43	NPK 20-10-10, Urea, poultry manure		
	56	NPK 20-10-10, FYM		
	34	Ammonium sulphate and other fertilizers		

1 Application of manure is done 2 - 3 times per year depending on the number of times the farmer crops the same piece of land.

capacity was (CEC) was determined by the ammonium saturation method. Exchangeable bases (Ca, Mg, K and Na) were extracted with 1N ammonium acetate at pH 7 and were determined by flame photometry.

Results obtained were compared with those of the reference profile using one sample t-test in order to evaluate changes in properties. Similarly, soil analytical data was compared with critical levels of nutrients in order to identify sufficiency or deficiencies (Table 2). Pearson's correlation analysis was done to investigate relationships between soil properties.

RESULTS AND DISCUSSION

Cropping system survey

The dominant cropping system is mixed cropping, principally potato-based. Associated crops include cabbage, carrot, onion, leaks, beet root and spices. Because of the high population density, long rainy season and increasing demand for food, the soil is cultivated continuously. Two or three crops are harvested sequentially a year on most farmers' (93%) fields.

Farmers apply poultry manure, cow dung, FYM and mineral fertilizers (Table 3) at variable rates of 50 - 300 kg/ha (Urea), 500 - 2000 kg/ha (NPK 20-10-10). Animal manure (predominantly poultry manure) is applied during land preparation and mineral fertilizer in two to three splits during the growing cycle, with the amounts depending on the experience of the farmer. Integrated soil fertility management is reflected in all stages of the crop production cycle (land preparation, planting, weeding, and management of manure and crop residue). Crop residues with high lignin content are usually burnt in cases where their presence complicates tillage operations and makes seedbed preparation more difficult. Succulent residues which decompose very fast are ploughed into the land. The losses in nutrients that may result from burning of crop residue are compensated with high application rates of poultry, FYM, pig manure and cow dung, which may make the system sustainable. Poultry and pig manure are preferred because of their high nutrient contents (Dikinya and Mufwanzala, 2010), low C/N ratio (Folorunso and Ojeniyi, 2003), which subsequently increases crop yield (John et al., 2013). They decompose faster and release nutrients to the crop on demand. The C/N ration of poultry and pig manures

Table 4: Soil (0-25 cm) properties under farmers' current practice of integrated soil fertility management (ISFM) compared to baseline characteristics (0-28 cm) of a reference profile of 1989

		Farmers' fields			
Soil property	**Baseline**	**Range**	**Mean±S.E**	**t**	**prob**
Organic carbon (%)	6.3	5.0 - 8.13	6.7±0.23	1.890	0.075ns
Total N (%)	0.5	0.24 - 0.83	0.6±0.03	2.586	0.019*
C/N	12.6	7.29 - 31.92	12.6±1.19	-0.041	0.968ns
pH_w (1:2.5)	5.8	5.0 - 6.3	5.6±0.08	-0.354	0.727ns
pH_{KCl} (1:2.5)	4.7	4.4 - 5.3	5.0±0.06	5.599	<0.01**
Available P (Bray 2 P) mg/kg	20.5	7.5 - 37.3	26.0±2.12		
Excangeable bases ($cmol_+$/kg)					
Ca	8.4	4.24 - 7.84	6.4±0.29	-6.861	<0.01**
Mg	2.4	0.36 - 5.52	2.2±0.31	-0.588	0.564ns
K	0.40	0.33 - 0.66	0.44±0.03	1.51	0.150ns
CEC7 ($cmol_+$/kg)	45.4	26.7 - 36.0	33.0±0.60	-20.622	<0.01**

could be as low as 6.7 and 6.9 respectively (Foluronso and Ojeniyi, 2003).

The soils were slightly acidic, high in organic carbon and nitrogen contents (Table 4). Soil organic matter is an important indicator of soil quality and sustainable agriculture and agricultural practices can strongly affect its content and chemistry. Long term organic manure combined with chemical fertilizer application improved soil organic matter content, and increased soil total N. Han et al. (2006, 2010) observed similar increases in soil organic carbon after combined application of mineral fertilizers with recycled organic manure. Published result suggest that continuous manure compost application at a rate of more than 30 t/ha is necessary to build up the organic C content of the soil to the ideal level to maintain good soil structure, high soil biodiversity, and high crop productivity (Lee et al. 2006). In Nigeria, application of poultry and pig manure together with plant residue was reported to significantly increase soil organic matter (Folorunso and Ojeniyi, 2003; Ojobor et al., 2011).

The status of Ca, Mg, K and available P was medium, while CEC was high even though a highly significant decrease ($p<0.01$) was recorded under current farmers' practices. Apart from exchangeable Ca and CEC which decreased significantly ($p<0.01$) and pH_{KCl} and total N which increased significantly ($p<0.01$ and $p<0.05$ respectively), no significant changes in soil properties relative to baseline were observed with other soil properties. The net negative charge (ΔpH) was very high in the baseline (-1.1) and high under current practice (-0.6). The decrease may be attributed to movement of clay particles from the topsoil to the subsoil, which is associated with constant soil disturbance. Although decrease in pHw was not significant, minor changes in pH have significant implications on nutrient status and availability. The soils are acidifying under potato-based cropping system. Acidification may be attributed to increasing use of acidifying N mineral fertilizers, leaching losses of bases and continuous mining of bases through export of potato harvest. Both urea and ammonium sulphate are known to be acidifying but ammonium suphate acidifies about two times more than what urea does (Fageria et al., 2010). About 34 % of farmers (it could even be more) use ammonium sulphate. Increasing acidity will significantly reduce Ca content as reflected by the strong correlation (r = 0.72**) between Ca and pHw (Table 5). Leaching of NO_{3-} after fertilizer application is accompanied by positively charged basic cations such as Ca^{2+}, Mg^{2+} and K^+ to maintain the electric charge on the soil particles (Fageria et al., 2010). The decrease in the Ca^{2+}/Mg^{2+} ratio from 3.5 in 1989 to 2.9 (2012) indicates that the leaching of bases with nitrate ion was more with Ca^{2+} than with Mg^{2+}. The decrease in Mg^{2+} between 1989 and 2012 under farmers' practices was not significant ($p>0.05$). Ca and Mg uptakes are enhanced when Ca^{2+}/Mg^{2+} ratio is between 3 and 5 (Verheye, 1998).

In relation to cation balance, Mg^{2+} was the most dominant cation. With the baseline soil data, 1.56 cmol/kg Ca and 0.39 cmol/kg K were needed to establish an ideal cation balance (Ca/Mg/K 76/18/6). With current farmers' practices, 2.76 cmol/kg Ca and 0.29 cmol/kg K are required. This implies that although ISFM is employed, the practice is not sufficient to correct for Ca imbalance. However, it has been able to correct 25% of initially (in 1989) identified K requirement. Doube (1989) reported that the quantities of calcium or magnesium present in profiles of dystrandepts indicated less than 10 % of minerals rich in Ca or Mg. The relative importance of K on the exchange complex (K saturation) was 1.33 %, which was lower than what is generally recommended (Verheye, 1998) for normal cropping (2 %) and intensive cropping (4 %). The ranges in Ca and Mg saturation were from 12.18 to 25.37 % and 1.05 to 17.69 %, with means of 19.61 % and 6.84 % respectively. The lower levels of Ca and Mg saturation could be related to excessive use of mineral N fertilizers and subsequent acidification.

Table 5: Correlation coefficients between soil chemical properties

Soil properties	pHw	pHKCl	CEC	OC	N	C/N	P	Ca	Mg
pH_w									
pH_{KCl}	-0.21ns								
CEC	0.24ns	-0.14ns							
OC	0.30 ns	-0.04ns	0.08ns						
N	-0.03ns	-0.25ns	0.36ns	0.21ns					
C/N	-0.22ns	0.19ns	-0.24ns	0.37ns	**-0.77****				
P	**0.73****	-0.39ns	0.00ns	-0.26ns	0.31ns	**-0.53***			
Ca	**0.72****	-0.16ns	0.19ns	-0.27ns	0.22ns	-0.33ns	**0.72****		
Mg	0.04ns	-0.24ns	-0.21ns	0.11ns	-0.19ns	0.12ns	0.23ns	-0.01ns	
K	-0.44 ns	0.22ns	0.20ns	0.06ns	-0.37ns	**0.47***	**-0.63****	**-0.50***	-0.29ns

** Significant at 1 %; * Significant at 5 %; ns Not significant; OC is organic carbon, N is total nitrogen; C/N is carbon/nitrogen ratio; P, Ca, Mg and K are available P, extractable Ca, Mg and K

Fageria et al. (2010) observed decreasing levels of Ca and Mg saturation with increasing rate of N fertilizer in form of urea or ammonium sulphate. Application of compost and animal manure increases soil quality (Lee et al., 2006) and this could be responsible for the average-to- high status of soil nutrients under continuous cropping of the typic dystrandept in the Bambouto highlands. However, excessively high application rates of poultry manure have been reported to increase significantly the electrical conductivity (EC) of the soil, which is detrimental to the crop and thus a potential threat to productivity (Dikinya and Mufwanzala, 2010). Although poultry manure has been used extensively to increase crop yield, appropriate amounts to apply remain unclear to many farmers. As pointed out by Rumi et al. (2012), there still exists a need to assess the potential impacts of chicken manure on soil chemical properties and crop yield and in particular, evaluating the critical application levels.

Available P and Ca were positively and significantly correlated (r = 0.72**), while K was significantly and negatively correlated with Ca (r = 0.50*) and P (r = -0.63**). With a low Ca^{2+}/Mg^{2+} ratio, P availability and subsequent uptake is hampered.

CONCLUSION AND RECOMMENDATIONS

The dominant cropping system on Typic Dystrandept is potato-based (with cabbage, carrot, onion, leeks, beet root and other spices as associated crops), characterized by integrated use of manure (predominantly poultry and to a lesser extent cow dung and pig manure) and mineral fertilizers.

Although soil nutrient status under integrated soil fertility management practiced by farmers was moderate to high, soil acidification and cation imbalance were increasing. Ca was the most deficient cation in the exchange complex. The Ca/Mg ratio was less than normal, which could affect P availability and subsequent uptake. About 2.76 cmol/kg Ca and 0.29 cmol/kg K are required to correct for cation imbalance in the potato-based cropping system. Apart from exchangeable Ca and CEC which decreased significantly (p<0.05) and pH_{KCl} and total N which increased significantly (p<0.01 and p<0.05 respectively), no significant changes in soil properties relative to baseline were observed for other soil properties. Correlation between organic carbon and Ca (r=-0.27ns) and P (r=-0.26ns) was weak and negative. Available P and Ca were positively and significantly correlated (r = 0.72**), while K was significantly and negatively correlated (r = 0.50*) with Ca. The sources of manure currently used by farmers are major sources of Ca but the appropriate amount to apply in order to adequately correct for the cationic balance is presently not known.

We recommend that for high yields to be obtained and production sustained, farmers' practice of ISFM should be encouraged and supported with recommendations (adequate manure and mineral fertilizers) from on-farm experiments. In addition to this, use of ammonium sulphate should be prohibited.

REFERENCES

Bationo A (2004). Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa. Academy Science Publishers (Kenya) in association with Tropical Soil Biology and Fertility Institute of CIAT. 608p.

Bray RH, Kurtz LT (1945). Determination of total organic and available forms of phosphorus in soils. Soil Sci. 59:22-229.

Dikinya O, Namasiku Mufwanzala N (2010). Chicken manure-enhanced soil fertility and productivity: Effects of application rates. 2010. Journal of Soil Science and Environmental Management Vol. 1(3):46-54.

Doube M (1985). Pedogenesis, classification and charge properties of the bambouto soil sequence (West Cameroon), Ph.D. Thesis, Faculty of Sciences, State University of Ghent, Belgium, 184p + appendices.

Ehabe EE, Bidzanga NL, Mba C, Njukeng JN, Inacio de Barros, Enjalric F (2010) Nutrient Flows in Perennial Crop-Based Farming Systems in

the Humid Forests of Cameroon American Journal of Plant Sciences, 1:38-46.
EUROCONSULT (1989). Agricultural compendium for rural development in the tropics and the subtropics, Elsevier Amsterdam. 740p.
Fageria NK, Dos Santos AB, Moraes MF(2010). Influence of urea and ammonium sulfate on soil acidity indices in lowland rice production. Communications in soil science and Plant analysis, 41:1565-1575.
Folorunso OO, Ojeniyi SO (2003). Effect of sole and amended plant residues on soil nutrient content and yield of okra. Asset Series A (2003) 3(4):45-53.
Han XZ, Song C, Wang FX, Wang FJ, Zou WX (2010). Effect of long term fertilization on soil fertility and crop yield in a Udic Mollisol. 19th World Congress of Soil Science, Soil Solutions for a Changing World 1 - 6 August 2010, Brisbane, Australia. Published on DVD.
Han XZ, Wang SY, Veneman PLM, Xing BS (2006). Change of organic carbon content and its fractions in black soil under long-term application of chemiacal fertilizers and recycled organic manure. Communications in Soil Science and Plant Analysis 37:1127-1137.
John NM, Uwah DF., Iren OB, Akpan JF (2013). Changes in Maize (*Zea mays L.*) Performance and Nutrients Content with the Application of Poultry Manure, Municipal Solid Waste and Ash Composts. J. Agric. Sci. 5(3):270-277.
Kanmegne J (2004). “Slash and Burn Agriculture in the Humid Forest Zone of Southern Cameroon: Soil Quality Dynamics, Improved Fallow Management and Farmers’ Perceptions,” PhD Thesis, Wageningen University and Research Centre.
Lee C, Wu M, Asio VB, Chen Z (2006). Using a soil quality index to assess the effects of applying swine manure compost on soil quality under a crop rotation system in Taiwan. Soil Science Vol. 171, No. 3 171:210-222.
Leumbe Leumbe O, Bitom D, Tematio P, Temgoua E, Lucas Y (2005). Etude de sols ferralitiques a caratères andiques sur trachytes en zone de montagne humid tropicale (Mont Bambouto - Ouest cameroun). Etude et Gestion des Sols 12(4):313-326.
Ngoufo R (1988). Les monts bamboutos, environnement et utilisation de l’espace. Thèse Doctorat 3eme cycle de geographie physique. Universite de Yaounde, 374p.
Ojobor SA, Egbuchua CN, Okonmah IU (2011). Effects of four levels of pig manure on yield of upland rice and soil chemical properties in Asaba, Delta north agroecological zone, Delta state, Nigeria. Natural and Applied Sciences Journal 12(2):1-8.
Okalebo JR, Gathua KW, Woomer PL (1993). Laboratory methods of soil and plant analysis. A working manual. Soil Science Society of East Africa (SSSEA). Technical Publication 1.
Olsen SR, Cole CV, Watanabe FS, Dean LA (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Cire, vol. 939. U. S. Gov. Print. Office, Washington D.C, pp. 1-19.
Pauwels JM, Van Ranst E, Verloo M, Mvondo Ze A (1992). *Méthodes d’analyses de sols et de plantes, équipement, gestion de stocks de verrerie et de produits chimiques*. A. G. Building. Bruxelles.
Rumi F, Kashem MA, Osman KT (2012). Recovery of soil test phosphorus from an acidic soil amended with organic and inorganic phosphorus. Open Journal of Soil Science 2:382-388.
Smaling EMA (1993). The soil nutrient balance: an indicator of sustainable agriculture in sub-Saharan Africa. The Fertilizer Society Proceedings no. 340:1-18.
Tematio P, kengni L, Bitom D, Hodson ME, Fopoussi JC, Leumbe HG, Mpakam HG, Tsozue D (2004). Soils and their distribution on Bambouto volcanic mountain, West Cameroon Highland, Central Africa. Journal of African Earth Sciences, 39:447-457.
Vanlauwe B, Zingore S (2011). Integrated soil fertility management: an operational definition and consequences for implementation and dissemination. Better Crops 95(3):4-7.
Verheye W (1998). Land use, Land cover and soil Sciences. Vol. IV. Management of agricultural land: Chemical and Fertility aspects. Encyclopedia of Life Support Systems (EOLSS).
Walkey A, Black IA (1934). Determination of organic matter in soil. Soil Sci. 37:549-556.