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ENHANCING NUTRIENT AVAILABILITY AND COFFEE YIELD ON ACID SOILS OF THE CENTRAL PLATEAU OF SOUTHERN RWANDA

Cyamweshi R. A.[1]*, Nabahungu N.L[1]., Mukashema A.[2], Ruganzu V.[1], Gatarayiha M.C.[3], Nduwumuremyi A.[1] and Mbonigaba J.J.[1]
1 Rwanda Agriculture Board, Kigali, P.O BOX 5016, Rwanda
2National University of Rwanda, Huye, P.O BOX 56, Rwanda
3National Agricultural Export Development Board, Kigali, P.OBOX 104, Rwanda

ABSTRACT: *Soil acidity is among the major constraints to coffee productivity in Southern Rwanda. An experiment was conducted in 2010 to evaluate lime effect on nutrient availability and cherry yield of Coffee Arabica L. grown on acid soils of Nyamagabe District. The experiment was set in a randomized completely bloc design with two lime treatments (0 and 1.25 t ha^{-1} $Ca(OH_2)$) applied under eragrostis mulched and non mulched conditions. Results showed that lime increased soil pH and decreased aluminium saturation and enhanced nutrient availability with values varying from 2-35.9 ppm, 3.1-5.5 Cmol (+) kg^{-1} and 0.57-1.56 Cmol(+) kg^{-1} for available phosphorus, exchangeable Ca^{2+} and Mg^{2+}, respectively. Moreover, interaction lime-mulch led to higher N content in the soil (0.19%) and higher cherry yield (8.5t ha^{-1}) compared to the control (3.8 t ha^{-1}). Cherry yield positively correlated with soil pH (r^2=0.71), soil calcium (r^2=0.56), soil magnesium (r^2= 0.53), total N (r^2=0.30), available P (r^2=0.62) and negatively with aluminium saturation (r^2=0.3). Application of lime in mulched coffee is recommended to improve nutrient availability and coffee yield on acid soils of Southern Rwanda.*

KEYWORDS: *Acid soils, Arabica coffee, cherry yield, lime*

INTRODUCTION

Coffee is among the major source of export revenue for a large number of countries with around 125 million people worldwide depending on the commodity for their livelihoods (Giovannucci et al., 2002). In the world, Coffee is the second most traded commodity next to petroleum and the most widely consumed beverage worldwide. About 151 million 60 kg bags are produced annually worldwide of which 55.9 million 60 kg bags are from Brazil and 25 million 60 kg bags in Vietnam 2013 (Vega, 2008).

In Africa, coffee producers accounted for about 12% of global supply and about 11% of global exports of the product for the 2009/10 season, Ethiopia being the biggest producer of the commodity (Mafusire et al., 2010). Rwanda is the ninth-largest producer of Arabica coffee in Africa, with 500,000 small farms averaging less than 1 hectare (USTIC, 2009). While a relatively small contributor to the world coffee market, the country produces some excellent coffees with qualities commonly found in other east African nations such Kenya. The commodity makes a big business and accounts for 68% of Rwanda's total foreign currency earnings (Birgit et al., 2011).

However, coffee production volatility threatens Rwanda's potential of becoming a key supplier of high-quality coffee. This has contributed to insufficient levels of production to attract global demand and thus, made Rwanda coffee invisible to the bulk market. For example, a drop in production of about 25% was observed in 2003 (14500 tons) followed by an increase in 2004 (29 000 tons), and again a decrease in 2005 (18500 tons). In this regards, the country contributed less than one percent to the worldwide exported coffee. Therefore, Rwanda's coffee production needs to be optimized by minimizing the oscillation of the production cycle (UNECA, 2013). Among several factors that affect coffee productivity in the area are acid soil infertility and low use of organic mulch (Bucagu et al., 2013). In fact, the soils under coffee plantations in Nyamagabe district are dominantly acidic (pH <5.0) (Cordingly, 2009). According to Shiang (2010), such soils constitute an important growth and yield limiting factor for crops. Acidic conditions enhance the presence of trivalent cation (Al^{3+}) (Lidon and Barreiro, 2002), which is the most toxic of all Al species available to plants (Hoshino et al., 2000). This results in alterations of the physiological and biochemical processes of plants and consequently loss of productivity (Mora et al., 2006). Under acidic conditions some of the vital nutrients such as P, Ca and Mg are made unavailable in the soil solution for plant uptake due to the abundance of elements such as Al and Mn. At low pH, Al-toxicity is reportedly the main stress factor for plants (Poschenrieder et al., 2008). The principal effect on plant growth from soluble aluminium in the soil solution is increased acidity via Al hydrolysis and reduced root proliferation and function. This reduces the ability of plants to extract water and other nutrients in the soil with negative effect on crop productivity (Obiri-Nyarko, 2011).

In order to counteract the effect of soil acidity on crop growth, liming is a traditional practice often applied to soils to restore Ca and Mg availability for plants and adjust soil acidity (Carvalho and Van Raij, 1997; Cyamweshi et al., 2013). Naidu et al. (1990) observed the beneficial effect of liming in reduced micronutrient toxicity while increasing the availability of Ca, P, Mo and Mg in the soil. In the same line, application of lime increased soil pH, enhanced nutrient availability (Ca, Mg and P) and recorded mammoth yield increase of maize compared to treatments without lime in acid soils of Ghana (Buri et al., 2005).

However, conflicting reports show that the prior liming of highly weathered acid soils can result in an increase, a decrease or no change in the availability of nutrients (Amarasiri and Olsen, 1973). For example, in acid soils, Ca and Mg contents increase and adsorption of phosphate by amphoteric soil surfaces generally decreases slowly as the pH is raised from 4 to 7; but in soils initially high in exchangeable Al^{3+}, liming resulted in the formation of new, highly active, phosphate adsorbing surfaces as the Al^{3+} ions precipitate as insoluble polymeric hydroxy-Al cation species (Haynes, 1984).

Another constraint that hinders coffee productivity is low or no use of organic mulch in the area which suggests poor maintenance of coffee plantations (Bucagu et al., 2013). According to Bai and Blumfield (2013), mulch is an important agricultural technique that helps to control weeds and prevents loss from soil moisture. Murungu et al. (2011) reported that mulch helps to regulate soil temperature thereby increasing the survival seedlings under extreme conditions. In steep slope areas such in high lands of Nyamagabe district, mulch would play an important role in controlling water-driven soil erosion and therefore improving vegetation establishment for the control of soil erosion (Ogban et al., 2001). Benefits of mulching has been also emphasized by various workers, who reported that mulch contributes to reduce soil particle detachment and transport (Opara-Nadi, 1993), improves organic matter content and soil fertility, soil water storage capacity, and infiltration rate and increases crop growth and yield (Mbagwu, 1991; Owaiye, 1993; Ogban et al., 2001).

The vegetation is mostly dominated by Eragrostis blepharoglumis K. Schum on acid soils of Nyamagabe district, which constitutes the mulching material used by most coffee farmers (Loveridge et al., 2002). Although lime and mulch effects on soil properties are generally well documented, limited information is available about their effectiveness in improving nutrient availability and coffee productivity in the Central Plateau of Southern Rwanda. Therefore, the objectives of this study were (i) to evaluate the effect of liming and mulching materials on soil chemical properties and yield of Arabica coffee and (ii) determine coffee fertiliser application rate that take account of nutrient removal from cherry harvest for improved Arabica coffee productivity on acid soils of Southern Rwanda.

MATERIAL AND METHODS

Site description

This study was conducted in Nyamagabe district, in Southern Rwanda Province. The area belongs to the agro-climatic region of the central Plateau of Rwanda, characterized by hilly topography with average altitude of 1500 m above sea level. Nyamagabe is located between 2° 27' 33" S and 29° 33' 52" E. The area is hilly with altitude varying between 1800 to 2700 m above sea level and receives 1597 mm rainfall per year distributed over two cropping seasons. The long rainy season starts in September and ends in December (Season A), followed by a short dry season from January to February and the short rainy season starts in March and ends in June (Season B). The mean annual temperature is 18 ^{o}C with little fluctuation. Soils in the study area are classified as a deep Typic Hapludox developed from acid granite and gneiss parental materials. They are generally acidic (pH 3.6-5), deficient Ca, Mg and P, highly weathered, and with moderate sesquioxide contents.

Field Experiment

Soil and leaf sampling and experimental layout

The farmers' coffee fields used for this study were soil sampled (0-20 cm depth) for site characterisation prior to the start of the experiments. The samples were analysed for $pH_{(H2O)}$, organic matter, total N, and available phosphorus following the procedure outlines by Okalebo et al. (2002). Other soil parameters evaluated included exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) and acidity (Al^{3+} + H^{+}). The same soil parameters were reanalyzed after at the harvest of coffee in order to ascertain treatment effects on nutrient availability. Concurrently, laboratory coffee leaf test of macronutrients N, P, K, Ca and Mg was performed to evaluate coffee nutritional status. In this regards, two pairs of leaves were collected at the four cardinal points (eight leaves per plant) from eight plants per plot. The leaf pair collected was the third leaf pair from the apex of fruit branches located at the coffee plant medium third position, showing at least five well-developed leaf pairs. Leaves from each plot were put together (64 leaves) in labeled paper bags and sent to the laboratory, where leaf samples were submitted for chemical analysis according to Bataglia *et al*. (1983).

The experiment was laid out in a randomized complete block design with three replications. Treatments included two levels of lime (0 and 1.25 t $Ca(OH)_2$ ha^{-1}) and two conditions of coffee fields (mulch and non mulched coffee trees). A locally known Coffee Arabica L., variety Bourbon Mayagez 139 was used in this study. Each experimental coffee field contained 250 coffee trees.

Coffee yield and mineral fertiliser rate for sustained coffee production

At harvesting campaign, 10 plants were randomly selected in each treatment, harvested and extrapolated to yield in t ha^{-1}. In order to obtain the amount of macronutrients (N, P, K, Ca and Mg) removed through coffee harvest; the coffee cherries in each treatment were dried, grinded and submitted to chemical analysis according to the procedure outlined by Bataglia *et al*. (1983). In order to cater for nutrient loss from the harvest, coffee yield and nutrient removed were then computed to determine coffee fertiliser rate of N, P, K, Ca and Mg that farmers could apply for sustainable coffee production in the Central Plateau of Southern Rwanda.

Data processing and analysis

Data obtained in the field were pooled in the process of analysis using analysis of variance (ANOVA) with GenStat version 13.1. Significant treatment means were separated using Tukey's test. Moreover, linear correlations between soil nutrient availability and coffee yield were also performed using the same GenStat 13.1.

RESULTS

Effect of lime and mulch on soil acidity under coffee fields

Results of soil chemical analysis present the values of soil reaction as well as the exchange acidity (Table1). The average soil pH in the control plots was 4.67. Lime decreased soil acidity, thereby increasing significantly (P=0.001) soil pH under limed coffee plantations. However, interaction lime-mulch produced more effect (pH=5.6) than when lime was solely applied (pH=5.48). Moreover, lime application reduced significantly exchangeable acidity. Al^{3+} which was the most dominant ion on the soil colloid decreased significantly (P=0.001) from 1.9 cmol (+) kg^{-1} in the control to 0.47cmol (+) kg^{-1} under limed coffee trees. Besides, analysis of variance revealed significant ($P<0.05$) decrease of aluminium saturation from 22.5 cmol (+) kg^{-1} in the control to 6.45 cmol (+) kg^{-1}. There was no significant effect of mulch, neither applied alone or in combination with lime.

Table 1. Lime and mulch effects on soil acidity under coffee plantations

Parameter	pH_W	H^+	$Al3^+$	Sat Al (%)
Control	4.7[a]	0.98[a]	1.9[a]	22.5[a]
Mulch	4.6[a]	1.04[a]	1.74[a]	20.59[a]
Lime	5.48[b]	0.48[a]	0.47[b]	6.45[b]
Mulch+lime	5.6[b]	0.84[a]	0.91[b]	9.82[b]
CV (%)	2.1	6.4	7	6.6
F pr	0.001	Ns	0.009	0.011

Mean values followed by the same letter are not significant. Mean separation was performed by Tukey's test

Nutrient availability under coffee Arabica fields

Results showed that the soil of Nyamagabe district is deficient in main nutrients particularly N, P, K, Ca and Mg based on critical nutrient levels required for adequate growth of coffee Arabica (Table 2). Lime application improved the level of exchangeable bases in the soil. Compared to the control, there was significant ($P<0.05$) improvement in soil bases with 5.45, 1.86 and 3.69 Cmol (+) kg^{-1} for Ca^{2+}, Mg^{2+} and K^+, respectively. Besides, interaction lime-mulch induced the highest available phosphorus content of 35.9 ppm compared to other treatments with highly significant ($P<0.001$) difference at lime level. There was no effect of sole application of lime on total N. In fact, Mulch enhanced significantly ($P=0.005$) total N with 0.19% against 0.09% in the control. Moreover, interaction lime-mulch induced significant difference ($P<0.042$) though with a low percentage of total N compared to the mulched treatments.

Table 2. Lime and mulch effects on soil nutrient availability under coffee trees

Parameter	Tot N (%)	Org C (%)	Av P (ppm)	CEC_{pH7} (Cmol(+)Kg^{-1})	Ca^{2+} (Cmol(+)Kg^{-1})	Mg^{2+} (Cmol(+)Kg^{-1})	K^+ (Cmol(+)Kg^{-1})
Control	0.09[a]	1.42[a]	2.1[a]	9.05 [a]	3.12 [a]	0.57[a]	0.51[a]
Mulch	0.19[b]	0.87a	2.12[a]	8.02 [a]	3.38 [a]	0.72[a]	3.69[a]
Lime	0.15[b]	2.12a	35.63[b]	10.89[b]	4.45[b]	1.08[a]	0.56[a]
Mulch+Lime	0.18[b]	5.84[b]	35.88[b]	10.62[b]	5.45[c]	1.9[b]	3.55[a]
CV%	3.7	5.6	3.5	3.0	3.2	3.5	11.2
F pr.	0.005	0.031	<.001	0.037	0.002	0.01	ns

Mean values followed by the same letter are not significant. Mean separation was performed by Tukey's test

Lime and mulch effect on coffee nutrient uptake

Table 3 presents results of coffee leaf analysis before and at coffee cherry harvest. Lime and mulch treatments improved nutrient uptake compared to the control. Lime significantly ($P<0.05$) increased Ca and Mg contents in coffee leaves with the highest amounts induced by lime-mulch interaction.

Table 3. Lime and mulch effects on nutrient uptake by Arabica coffee tree

Trt	% N	% tot P	% K^+	% Ca^{2+}	% Mg^{2+}
Control	2.6[a]	0.12[a]	2.3[a]	3.9[a]	0.6[a]
Mulch	2.2[a]	0.25[a]	2.5[a]	4.8[a]	0.5[a]
Lime	2.8[a]	0.14[a]	2.9[a]	6.9[ab]	0.9[a]
Mulch+Lime	2.8[a]	0.16[a]	4.0[b]	6.4[b]	1.06[ab]
CV(%)	2.6	5.1	2.8	3.1	3.5
F pr.	ns	ns	0.03	0.046	0.024

Mean values followed by the same letter are not significant. Mean separation was performed by Tukey's test

Coffee cherry yield and fertiliser rate for sustainable coffee production

Table 4 presents coffee cherry yield in each treatment and the corresponding nutrient removed through cherries. The yield of coffee Arabica was highly significantly ($P<0.001$) affected by lime treatments and significantly ($P<0.05$) influenced by mulch. The interaction lime x mulch produced the highest yield of 8.5 t ha^{-1} of coffee cherries against 6.1 t ha^{-1} and 3.8 t ha^{-1} under lime treatments and the control, respectively. Although there was no significant difference between treatments concerning nutrient concentration in harvested coffee cherries, the highest amount of nutrients appeared to be in treatments that received lime. When considering coffee fields that received lime, the average amount of nutrients removed through the harvest of cherries was therefore equivalent to 2.0, 0.2, 3.1, 3.8 and 0.5 % for N, P, K, Ca and Mg, respectively.

Considering the above figures of nutrient removed through harvested cherries and the highest coffee yield as induced by lime amendment (8.5 t ha^{-1}), the calculated nutrient amounts of N, P and K required to replenish the soil for sustainable coffee production in the Central Plateau of Southern Rwanda corresponded to 170 kg N ha^{-1}, 39 kg P_2O_5 ha^{-1} and 38 kg K_2O ha^{-1}. Concerning the amount of Ca and Mg needed to return in the soil based on nutrient removal, the same amount of 1.25 t ha^{-1} $Ca(OH)_2$ could be used as usual once in three seasons.

Table 4. Coffee cherry yield and harvest based nutrient removal

Trt	Cherry Yield (t ha^{-1})	% N	% P	% K^+	% Ca^{2+}	% Mg^{2+}
Control	3.8 [a]	1.8[a]	0.2 [a]	2.4 [a]	3.7[a]	0.5[a]
Mulch	4.7 [a]	1.8 [a]	0.1 [a]	2.5[a]	2.9[a]	0.5[a]
Lime	6.1[b]	2.1[b]	0.2 [a]	3.2[a]	3.3[a]	0.6[a]
Mulch+Lime	8.5 [b]	1.9[b]	0.2 [a]	3.0[a]	4.3[a]	0.5[a]
CV(%)	3.9	2.3	3.4	4.1	3.4	4.18
F pr.	<.001	<.001	ns	ns	ns	ns

Mean values followed by the same letter are not significant. Mean separation was performed by Tukey's test

Correlation between coffee cherry yield and soil chemical parameters

There was a direct influence of soil chemical properties on coffee cherry yield. A strong positive correlation was found between coffee yield and soil pH (r^2=0.71), Ca (r^2=0.56), Mg (r^2= 0.53), a moderate positive correlation with soil total N (r^2=0.30) and a negative correlation with aluminium saturation (r^2=0.3). Although there is a positive relationship between coffee cherry yield and soil available P (r^2=0.62), one needs to double the amount of P in order to increase coffee yield, for example from 4 t ha^{-1} of cherries to 5 t ha^{-1} (Fig.1).

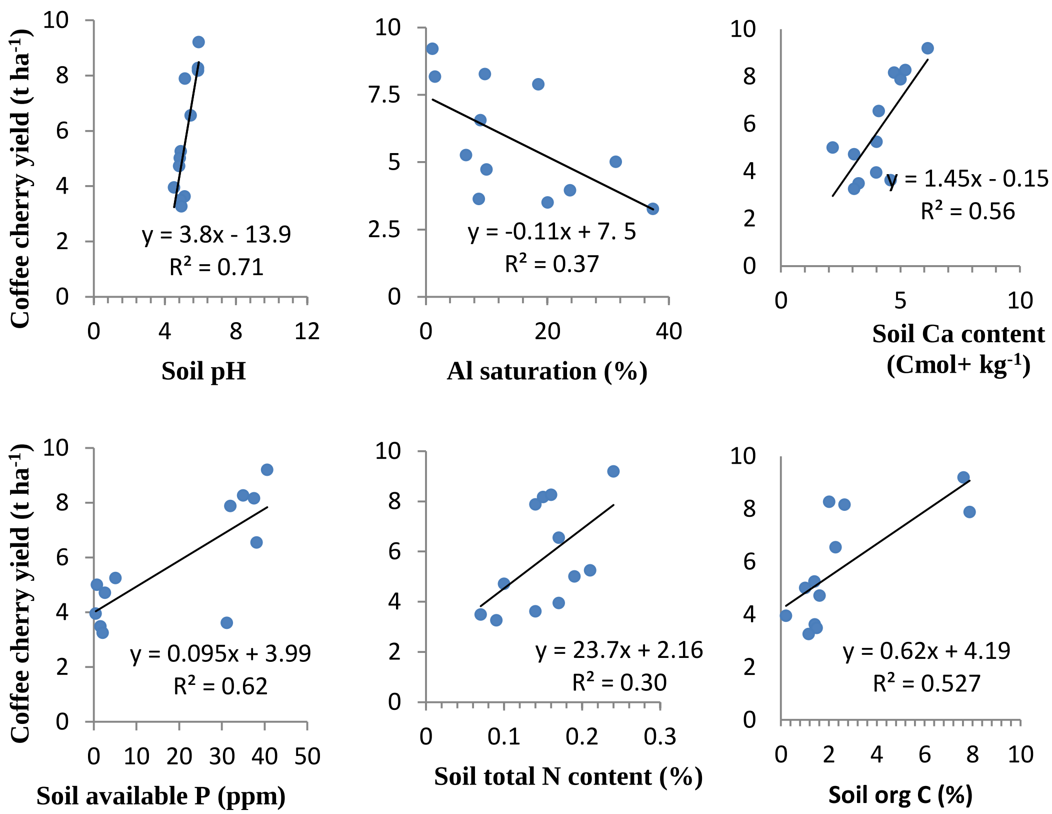

Figure 1. Correlation between coffee cherry yield and soil chemical properties

DISCUSSION

Lime and mulch effect on soil acidity and nutrient availability under coffee plantations

The increase in soil pH and decrease in the rate of exchangeable acidity and aluminium saturation of the soils under coffee plantations could be attributed to the better neutralization of the saturated Al by applied lime. According to Fageria et al., (2002), liming materials contain basic cations and basic anions (CO_3^{-2}) that are able to pull H^+ from exchange sites to form H_2O + CO_2. Cations occupy the space left behind by H^+ on the exchange. Moreover, liming effect on soil pH under coffee trees might have been enhanced by favorable soil texture that was recorded in Nyamagabe coffee fields as sandy clay with low organic matter content. This is in line with Rutunga et al. (1998) who observed that lime use efficiency is higher in sandy clay than in heavy textured soils in his study on acid soils of Central Plateau of Southern Rwanda.

The increase in the contents of exchangeable bases (Ca, Mg, N and P) under acid coffee soils of Nyamagabe in the Central Plateau of Rwanda emphasized the importance of liming practice in improving nutrient availability for coffee nutrition in the area. According to Fageria et al. (2002), not only lime reduces soil acidity but also, there are several other benefits including, its ability to reduce the toxicity effects of some micro elements by lowering their concentrations while increasing the availability of plant nutrients such as Ca, P and Mg in the soil. This is also confirmed by various workers who reported that application of lime alleviated Al toxicity and improved soil P desorption capacity from soil fixed-P fraction of acid soils beside increased availability in soil Ca, Mg and N nutrients (Cyamweshi et al.,2013; Kisinyo et al.,2013; Rutunga and Neel, 2006). However, the higher amounts of P required for increasing coffee cherry yield denote the strong P sorption capacity of the acid soils of the Central Plateau of Rwanda. This is in line with the finding of Cyamweshi et al. (2013) in their study on acid soils of the highlands of Rwanda and Uganda. The increase in soil organic carbon under limed treatments was probably due to induced breakdown of organic matter in the soil with subsequent release of various nutrient elements.

Nutrient uptake and coffee yield as affected by lime and mulch applications

The improved nutrient uptake by coffee and substantial increase in coffee cherry yields resulted from lime induced nutrient availability. This is clearly manifested by the linear correlation between coffee cherry yield and soil nutrient (Fig.1) and suggests, therefore, proper nutrient management strategies that enhance nutrient availability for improved coffee productivity on acid soil of the Central Plateau of Southern Rwanda.

Beneficial effect of liming of acid soil was also observed by Buri et al. (2005) who recorded 72% increases in maize yield against 48% in non limed treatments. The apparent reason was the increase in soil pH and the availability of other essential nutrient elements. The improved nutrient uptake following liming of the acidic soil of Nyamagabe district might in most cases due to improved coffee root growth and stimulatory effect of lime on the activities of microorganisms which release nutrients from organic matter.

The highest figures of coffee cherry yield and of some measured chemical parameters following lime and Eragrostis mulch treatments underpin the synergistic effect of the lime and mulch on biological productivity of Arabica coffee under acid soil condition in Nyamagabe district. Although there was no significant influence of mulch on most of the measured parameters, mulch application on coffee trees improved lime use efficiency. This was observed when comparing the contributions of lime solely applied and combined lime-mulch with regard to improved measured parameters. In fact, the observation that nutrient availability, uptake and the highest coffee bean yield were found in lime treatments under mulched coffee trees underlines the non negligible role of applied mulch on coffee productivity in the area. This finding is consistent with the reports of various workers, who evidenced the effect of mulch on crop productivity. According to *Vaast et al*. (2006) and Wintgens (2004), application of mulch on coffee soils helps in regulating soil temperature and increases soil moisture by decreasing evapo transpiration from the surface soil, thus contributing to generation of greater number of fruits per node and nodes per lateral branch. This is also in line with the findings of Yunianto (1986), who reported that, the use of mulch helped in reducing over bearing and dieback in Arabica coffee and enhanced its sustainable biological productivity for longer period of time. In his study on mulching effect on soil physical properties, Youkhana & Idol (2009) found that soil bulk density did not decline in mulched plots as opposed to significant changes in bulk density for un-mulched plots. Although significant yield responses to N, P and K fertilisers are reportedly common without much or any other organic materials, Bekeko (2013) observed that coffee production systems may not be sustainable in the long term because of a gradual decline in soil quality.

Application of Eragrostis mulch on coffee trees improved nitrogen uptake by coffee in the study area. This might be due to lime stimulatory effect on soil microorganism activity which decayed mulch and released nitrogen from organic matter. This finding is in line with Youkhana and Idol (2009) who found that addition of mulch from shade tree pruning significantly offset net nitrogen and carbon losses from coffee cultivation in Hawaii. The present finding puts again more accents on the importance of soil mulch in sustaining coffee production and productivity in the central plateau of Southern Rwanda.

The amounts of nutrients concentrated in harvested cherries denote the extent at which Arabica coffee tree might mine the soil of the area. In a study on coffee plant nutrition, Hanisch et al., (2011) found that coffee harvest increases the rate of soil nutrient mining and negatively affects current and future coffee yields. Moreover, the same author observed that after cherry harvesting, most coffee plants die-back as a result of excessive nutrient and sugar movement from the leaves and roots to fill the cherries. This is also in line with the findings of Kuit et al. (2004) who reported that after coffee harvesting, coffee plants get generally weak and exhausted due to low capacity of the soil to supply required nutrients for its proper nutrition. In response to this issue, the calculated nutrient removal and sustenance fertilisation dose will help farmers to maintain soil health for enhanced coffee productivity.

In Rwanda where the two-thirds of the soils are acid with about 3 % of farmers using lime in their coffee farms (Kelly et al., 2001, Nzeyimana et al., 2013), this on-farm research proved the beneficial effects of lime on coffee productivity in acid soils of the Southern Rwanda. It constitutes an important didactic tool for sensitizing and mobilizing coffee farmers so as to raise their awareness on the value of applying lime for improved coffee productivity and income on acid soils of the Central Plateau of Southern Rwanda.

CONCLUSION

The soil under coffee plantations in the Central plateau of Southern Rwanda is strongly acidic and deficient in essential nutrients which affect Arabica coffee productivity in the area. Lime ($Ca(OH)_2$) proved efficient in reducing soil acidity and enhancing nutrient availability. The highest coffee cherry yield resulted from joint application of lime and mulch, thus suggesting a synergistic effect of lime and mulch on the productivity of Arabica coffee in the region. Therefore, Application of lime under mulched condition reduced soil acidity and improved Arabica coffee productivity in the area. In order to replenish nutrients lost through coffee cherry harvest, the study recommends annual application of 170 kg N ha^{-1}, 39 kg P_2O_5 ha^{-1} and 38 kg K_2O ha^{-1} for a sustained coffee production in the Central Plateau of Southern Rwanda.

REFERENCES

Amarasiri, S. and Olsen, S.R. (1973) Liming as related to solubility of P and plant growth in an acid tropical soil. Soil Science Society of America. Proceedings 37:716-721.

Bataglia, O.C., Furlani, A.M.C., Teixeira, J.P.F., Furlani, P.R. and Gallo, J.R. (1983) Methods of Chemical Analysis of Plants. Instituto Agronômico, Campinas, SP, Brazil.

Bekeko Z.(2013) Effect of Maize Stover Application as Soil Mulch on Yield of Arabica coffee (Coffee arabica L., Rubiaceae) at Western Hararghe Zone, Eastern Ethiopia. Sustainable Agriculture Research 2 (3): 15-21 DOI: 10.5539

Birgit H., Niyibizi P. A., Loraine R., Mwumvaneza, V. (2011) Rwanda economic update: seeds for higher growth. Spring Edition. Washington, DC: World Bank.

Bucagu, C., Vanlauwe, B. and Ken Giller, E. (2013) Managing Tephrosia mulch and fertilizer to enhance coffee productivity on smallholder farms in the Eastern African Highlands. European Journal of Agronomy 48:19–29.

Buri, M.M., Wakatsuki, T., Issaka, R.N. (2005) Extent and Management of Low pH Soils in Ghana. Soil Sci. Plant Nutrition 51 (5):755-759

Carvalho, M. C. S., van Raij, B. (1997) Calcium sulphate, phosphogypsum and calcium carbonate in the amelioration of acid subsoils for root growth. Plant Soil 192: 37 – 48.

Cyamweshi R. A., Tenywa J.S., Ebanyat P., Tenywa M. M., Mukuralinda A. and Nduwumuremyi A. (2013) Phosphate Sorption Characteristics of Andosols of the Volcanic Highlands of Central African Great Lakes Region. Journal of Environmental Science and Engineering A 2: 89-96.

Cordingley, J. (2009) Soil Fertility Survey of Rwandan Coffee Sector, Crop Nutrition Laboratory Services, Nairobi.

Fageria, N.K., Baligar, V.C. and Clark, R.B. (2002) Micronutrient in crop production. Advances in Agronomy 77: 185–268

Giovannucci, D., Varangis P., Lewin B. (2002) “Who Shall We Blame: The international politics of coffee.” Tea and Coffee Trade Journal 174(1).

Kelly V.A., Mpyisi, E., Murekezi A., Neven, D., Shingiro, E. (2001) Fertilizer Consumption in Rwanda: Past Trends, Future Potential and Determinants; Policy Workshop on Fertilizer Use and Marketing, organized by MINAGRI and USAID, Rwanda, 22-23 February 2001.

Kisinyo, P. O. Othieno, C. O., Gudu, S. O. Okalebo, J. R., Opala, P. A. Maghanga, J. K., Ng’etich, W. K., Agalo, J. J., Opile, R. W., Kisinyo, J. A. and Ogola, B. O.(2013) Phosphorus Sorption and Lime Requirements of Maize Growing Acid Soils of Kenya. Sustainable Agriculture Research 2 (2), 116.

Kuit M., Don M. Jansen and Nguyen Van Thiet (2004) Coffee handbook: Manual for Arabica cultivation. Tan LamAgriculturalProduct Joint Stock Company, Vietnam.

Lidon, F., Barreiro, M. (2002) An overview into aluminum toxicity in maize. Bulg. J. Plant Physiol. 28, 96 – 112.

Loveridge S., Mpyisi E. and Shingiro E. (2002) Rwandan Smallholder Coffee Tree Maintenance and Cherry Processing Techniques: Results of a National Farm-level Survey, Food Security Research Project. Ministry of Agriculture, Livestock, and Forestry. Division of Agricultural Statistics.

Mafusire, A., Salami, A., Kamara, A. B. Lawson, F.E. (2010) Coffee Production in Africa and the Global Market Situation. Commodity Market Brief 1(2),1-9.

Mbagwu, J. S. C. (1991) Mulching an ultisol in Southern Nigeria: Effects on physical properties and maize and cowpea yields. J. Sci Food Agric. 57,517-526.

Mora, M. L., Alfaro, M. A., Jarvis, S. C., Demanet, R., Cartes, P. (2006) Soil aluminum availability in Andisols of Southern Chile and its effect on forage production and animal metabolism. Soil Use Manage. 22: 95 – 101.

Murungu, F.S., Chiduza , C., Muchaonyerwa, P., Mnkeni, P.N.S.(2011) Mulch effects on soil moisture and nitrogen, weed growth and irrigated maize productivity in a warm-temperate climate of South Africa. Soil and Tillage Research 112 (1): 58–65.

Naidu, R. Syers, J.K.. Tillman R.W and Kirkman, J.H. (1990) Effect of liming and added phosphate on charge characteristics of acid soils. J. Soil Sci. 41:157–164.

Nzeyimana, I., Hartemink Alfred E. and Jan de Graaff (2013) Coffee farming and soil management in Rwanda. Outlook on AGRICULTURE 42 (1), 47–52.

Obiri-Nyarko, F. (2011) Ameliorating soil acidity in Ghana: a concise review of approaches. ARPN Journal of Science and Technology 2:142-154.

Okalebo, J. R., Gathua, K. W. and Woomer, P. L. (2002) Laboratory Methods of Soil and Plant Analysis: A Working Manual. TSBF-KARI, SSEA, SACRED Africa, Nairobi, Kenya, pp. 128.

Ogban, P. I. and Ekerette, I. (2001) Managing the Coastal Plain Soils for Erosion Control and Crop Production in Southeastern Nigeria. J. Sustainable Trop. Agric Res. 2:131 – 138.

Opara-Nadi, A. O. (1993) Effect of Elephant Grass and Plastic Mulches on Soil Properties and Cowpea yield on an Ultisol in South eastern Nigeria. Pp.351 – 260. In: K. Mulongoy and R. Merckx (eds) Soil organic Matter Dynamics and Sustainability of Tropical Agriculture. Johm Wiley and Sons.

Owaiye, A. R. (1993) Effect of Residue Mulch on Characteristics and Productivity of two Soil Classes under Coffee in Nigeria. Pp. 339 – 344. In: Mulongoy and R. Merckx (eds) Soil Organic Matter Dynamics and Sustainability of Tropical Agriculture. John Wiley and Sons.

Poschenrieder, C., Gunsé, B., Corrales, I., Barceló, J. (2008) A glance into aluminum toxicity and resistance in plants. Sci. Total Environ. 400: 356 – 368.

Rutunga V. and Neel H. (2006) Yield trend in the long term crop rotation with organic and inorganic fertilisers on Alisols in Mata. Biotechnol. Agron. Soc. Environ.10 (3): 217 – 228

Rutunga, V., Steiner, K. G. Karanja, N. K., Gachene, C.K.K. and Nzabonihankuye , G. (1998) Continuous fertilization on non-humiferous acid Oxisols in Rwanda "Plateau Central": Soil chemical changes and plant production. Biotechnol. Agron. Soc. Environ. 2 (2):135–142.

UNECA (2013) Making the Most of Africa's Commodities: Industrializing for Growth, Jobs and Economic Transformation; Economic Commission for Africa, Addis Ababa, Ethiopia

USTIC (2009) Sub-Saharan Africa: Effects of Infrastructure Conditions on Export Competitiveness, Third Annual Report. Investigation No. 332-477; USITC Publication 4071.

Vaast, P., Bertrand, B., Guyot, B., and Genard, M. (2006) Fruit thinning and shade improve bean characteristics and beverage quality of coffee (Coffee Arabica L.) under optimal conditions. Journal of the Science of Food and Agriculture 86 (2): 197-204.

Vega, F. E. (2008) The rise of coffee. AM. Sci. 96, 138-145. DOI: 10.1511/2008.70.3640.

Wintgens, J. N. (2004) Coffee: Growing, Processing, Sustainable Production. WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, p. 976.

Youkhana, A. and Idol, T. (2009) Tree pruning mulch increases soil C and N in a shaded coffee agroecosystem in Hawaii. Soil Biology and Biochemistry 41(12), 2527-2534.

Yunianto, Y. D. (1986) Overbearing dieback on Arabica coffee. J. Pel. Parkebu 2 (2), 60-65.

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