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Cropping systems and soil quality and fertility in south-central Uganda

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Abstract

Little is known about how cropping systems influence soil quality and fertility in Uganda. Some cropping systems are more valued and as a result are given more nutrients and planted in certain soils, all of which leads to varying soil quality and fertility. This study compared soil quality (soil pH, cation exchange capacity (CEC), electric conductivity (EC), total N, and depth to restrictive layer (DRL)) and fertility (extractable P, K, Ca, Mg, and Na, and base saturation (BS) from five cropping systems (banana (Musa × paradisiaca L.)-dominant (B), coffee [Coffea robusta (L.) Linden]-dominant (C), banana-coffee (BC), annual with no crop rotation (ANR), and annual with crop rotation (AR); fertilized and unfertilized soils; and three soil types (black (Phaeozem), red (Ferralsol), and black-stony) in south-central Uganda. The analysis included farm assessments to establish management history of studied fields and soil sampling from 52 fields in Masaka District, Uganda. Main-effects ANOVA was employed to determine differences in means in soil under different cropping systems, soil types, and fertilizer use. Soil quality (pH at depths of 0 to 10 and 20 to 30 cm, CEC, and EC) and fertility (extractable Ca and Mg) varied by cropping system. The AR and B systems had higher soil quality and fertility compared to other cropping systems. Soil quality (pH at depths of 0 to 10 and 0 to 15 cm and DRL) and soil fertility (extractable P and K) varied by soil type. Black and black-stony soils had higher soil quality and fertility than red soils. Soil quality and fertility did not vary by fertilizer use. The results of this study indicate that both cropping system and soil type are associated with soil quality and fertility in south-central Uganda.

Keywords

Annual cropping, perennial cropping, soil management, soil type

Disciplines

Agriculture | Agronomy and Crop Sciences | Soil Science

Comments

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Cropping systems and soil quality and fertility in south-central Uganda

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Little is known about how cropping systems influence soil quality and fertility in Uganda. Some cropping systems are more valued and as a result are given more nutrients and planted in certain soils, all of which leads to varying soil quality and fertility. This study compared soil quality (soil pH, cation exchange capacity (CEC), electric conductivity (EC), total N, and depth to restrictive layer (DRL)) and fertility (extractable P, K, Ca, Mg, and Na, and base saturation (BS) from five cropping systems (banana (*Musa × paradisiaca* L.)-dominant (B), coffee [*Coffea robusta* (L.) Linden]-dominant (C), banana-coffee (BC), annual with no crop rotation (ANR), and annual with crop rotation (AR); fertilized and unfertilized soils; and three soil types (black (Phaeozem), red (Ferralsol), and black-stony) in south-central Uganda. The analysis included farm assessments to establish management history of studied fields and soil sampling from 52 fields in Masaka District, Uganda. Main-effects ANOVA was employed to determine differences in means in soil under different cropping systems, soil types, and fertilizer use. Soil quality (pH at depths of 0 to 10 and 20 to 30 cm, CEC, and EC) and fertility (extractable Ca and Mg) varied by cropping system. The AR and B systems had higher soil quality and fertility compared to other cropping systems. Soil quality (pH at depths of 0 to 10 and 0 to 15 cm and DRL) and soil fertility (extractable P and K) varied by soil type. Black and black-stony soils had higher soil quality and fertility than red soils. Soil quality and fertility did not vary by fertilizer use. The results of this study indicate that both cropping system and soil type are associated with soil quality and fertility in south-central Uganda.

Key words: Annual cropping, perennial cropping, soil management, soil types.

INTRODUCTION

East African soils exhibit poor quality characteristics that are attributable to their geological age, climate, and land use. In Uganda, the most common soil type is Ferralsol (FAO, 2009), which is depleted in nutrients, highly weathered and comparatively infertile soil. The fertility of East African soils is further degraded by anthropogenic

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activities, primarily through agriculture. As the majority of Ugandan population depends on agriculture, looking at agricultural activities and their impact on soil is important.

Agricultural use changes soil properties through cropping and soil management. In Uganda, cropping systems are characterized by intercropping annual and perennial crops. The two most common crops in south-central Uganda are Robusta coffee [*Coffea robusta* (L.) Linden] and banana (*Musa* × *paradisiaca* L.), both of which are perennial and often intercropped (Okonya et al., 2013). Soil management practices are insufficient to maintain or improve soil quality and can include application of organic and inorganic fertilizers; practicing rotations, or fallowing; and installing trenches for soil and water conservation (Nkonya, 2002). The dynamics between cropping systems, soil management, and soil types need to be studied to better understand their influence on soil quality and fertility.

Several studies have found that cropping systems have an effect on soil quality. Intensive monocropping of banana disturbed soil's biotic structure, negatively impacted microbial respiration and water content at field capacity of Andosols and Nitisols in French West Indies (Clermont-Dauphin et al., 2004).) Annual crops were predicted to have the greatest erosion rates (93 tons of soil ha^{-1} $year^{-1}$) followed by rangelands (52 tons of soil ha^{-1} $year^{-1}$), banana-coffee (47 tons of soil ha^{-1} $year^{-1}$), and banana alone (32 tons of soil ha^{-1} $year^{-1}$) in central Uganda (Lufafa et al., 2003). Cropping system influenced culturable rhizosphere bacterial community structure irrespective of plant species in West African soils (Alvey et al., 2003).

Agricultural inputs can positively impact soil properties, moreover, coffee agroforestry systems had greater soil organic carbon than coffee monocrops in Ferrallitic soils in Uganda (Tumwebaze and Byakagaba, 2016). Low-input subsistence farming caused serious N depletion in Kenya (De Jager et al., 2001). Agricultural inputs can positively impact soil properties, especially organic and synthetic fertilizers. Frequent fertilizer use increased concentrations of exchangeable K and P in fruit and rubber tree plantation compared to the plantations with no fertilizer use in China (Zhang and Zhang, 2005). Straw application in Niger led to an increase in base saturation and pH and a decrease in extractable Al (Kretzschmar et al., 1991). Green manuring improved organic matter and soil microbial activity in the tropics (Chander et al., 1997). Application of banana stalks, field crop residues, and cattle manure increased banana yields in central Uganda (Bekunda and Woomer, 1996).

More research is needed on the effects of cropping systems on soil quality and fertility in south-central Uganda. Additionally, farmer practices need to be included in the analysis. This study looked at soil quality and fertility parameters and their variation by cropping system, fertilizer use, and soil type in south-central Uganda.

MATERIALS AND METHODS

Site description

The study site was located in Masaka District, near Lake Victoria in south-central Uganda. The district covers an area of 1,603 km^2, half of which is wetlands, with an average altitude of 1,150 m above sea level. The area is under a banana-coffee agroecological zone. Banana production has been on-going for 1000 to 1500 years (Lejju et al., 2006) while native Robusta coffee was developed as a plantation crop around 1900s (Thomas, 1947).

A favorable equatorial climate with two rainy seasons per year has allowed intensified banana production without crop rotation for millennia (Lejju et al., 2006). However, due to population increase (152 to 248 people per km^2 from 1999 to 2012) and consequent pressure on land resources, soil fertility has been deteriorating (Sebukyu and Mosango, 2012). The banana-coffee cropping history of Masaka District and its declining soil fertility make it a good area to study why and how soils are declining.

Field sampling

Farmer interviews, farm assessments, and soil sampling were conducted from June to September 2016 in Masaka District covering six sub-counties (Bukakata, Mukungwe, Buwunga, Kabonera, Kyanamukaka, Kyesiga) and one division (Katwe-Butego). In total, 52 smallholder farms were assessed representing 42 villages. Figure 1 shows the location of the sampled villages in Masaka District.

The study was designed to examine field-level soil quality and fertility under annual and perennial cropping systems in Masaka District, Uganda. Multi-stage, purposive sampling method was used to identify farms. First, one to two villages was randomly chosen from each of 26 parishes, making 42 villages in total. Then, one to two farms in each village were identified from either farmer training records kept by local extension services or by village leaders. One field was chosen per farm for assessment based on a cropping system.

Farm assessments included taking soil samples; interviewing farmers on soil management practices and history of the assessed field; and researcher observations of the soil, location, and crops grown. All farm assessments were performed by the same two people to ensure comparability of the results across fields. According to farmer recalls, field age ranged from one to 100 years of cropping with a mean of 28 years. The majority of fields (n=30) has been in agricultural production between one and twenty years following removal of bush or native forest. The number of crops per field ranged from one to five with a mean of 2.6 crops per field. Major crops included coffee, banana, common bean (*Phaseolus vulgaris* L.), and maize (*Zea mays* L.). The majority of fields were intercropped while 13 fields were monocropped. All fields fell into one of the three major local soil types with black (Liddugavu, Phaeozems), red (Limyufumyufu, Ferralsols), and black-stony types (Luyinjayinja), representing 19, 25, and 8 fields, respectively.

Cropping and soil management

The study investigated five cropping systems: banana-dominant (B), coffee-dominant (C), banana-coffee (BC), annual with no crop rotation (ANR), and annual with crop rotation (AR). The B system had banana as the main crop, which was either mono-cropped or

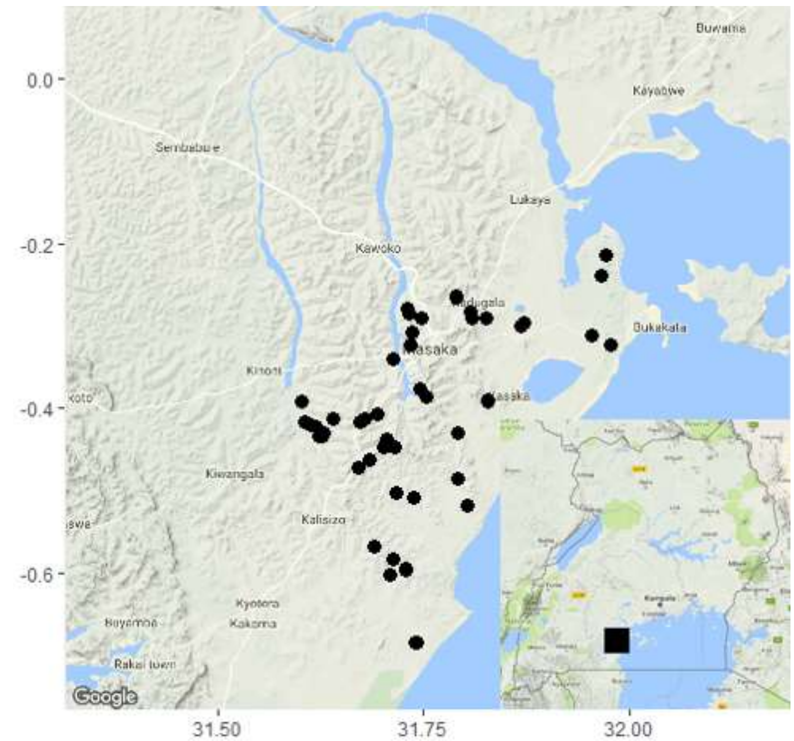

Figure 1. Map of Masaka District and sampled villages.

intercropped with one or more annual crops such as beans, maize, and cassava (*Manihot esculenta* Crantz). The C system had coffee as the main crop, which was either monocropped or intercropped with one or more annual crops such as beans, maize, and cassava. BC system had banana and coffee as two main crops, which could be intercropped with one or more annual crops such as beans, maize, and cassava. The ANR system had only annual crops such as maize, beans, and cassava, which could be mono-cropped or intercropped. The AR system also consisted of annual crops such as maize, beans, and cassava, which could be monocropped or intercropped. Farmers in this system, however, rotated crops from season to season.

All farmers were interviewed on crops they grew during the time of the interview and in previous season, and crop rotation. Based on the responses to these questions and field observations, the researcher determined categorization of the cropping system. The analysis included a binary fertilizer use variable (no vs. yes). All farmers were interviewed on any nutrient application to the fields including organic (animal manure, mulch, agricultural residues, green manure, compost) and inorganic fertilizers (diammonium phosphate (DAP), calcium ammonium nitrate (CAN), urea). The fertilizer use variable, therefore, did not differentiate between organic and inorganic fertilizers. Inorganic fertilizer application rates are too small (gross average rate of 1 kg ha^{-1}) in Uganda to cause any significant changes in soil properties (Nkonya, 2002; Ronner and Giller, 2013). As a result, the fertilizer use variable combined organic (n=26) and inorganic (n=9) nutrient applications.

The soil type variable included three levels: black, red, and black-stony. Farmers were asked to classify their soil and based on their responses; which were supplemented with field observations; each field was characterized as either under black, red, or black-stony soil. According to FAO-UNESCO soil legend, black soil corresponds to Phaeozems and is generally more fertile than other soil types (Goettsch et al., 2016). Red soil corresponds to Ferralsols (Goettsch et al., 2017) and is strongly weathered. Red soil forms more than 70% of the soil on which most of the farming is practiced in Uganda (Wortmann and Kaizzi, 1998). Black-stony soil is shallow, characterized by plinthitic and quartzitic stones, and is located on hilltops or outcrops (Mulumba, 2004).

Soil sampling and analysis

Fifteen soil properties were examined, including pH at different depths (0 to 10, 0 to 15, 10 to 20, 20 to 30, 30 to 50 cm), cation exchange capacity (CEC), electrical conductivity (EC), total N, extractable P, K, Na, Ca, Mg, base saturation (BS), and depth to restrictive layer (DRL).The CEC, EC, total N and extractable P, K, Na, Ca, and Mg were determined at depth of 0 to15 cm. Soil pH and EC were measured using the potentiometric method with soil to water ratio of 1:2. Soil CEC was estimated based on the quantities of Ca^{2+}, Mg^{2+}, and K^{+} extracted by the Mehlich-3 test (Ross and Kettering, 2011). Total N was measured by Kjeldahl digestion with sulphuric acid and selenium as a catalyst. Extractable P, K, Na, Ca, and Mg were measured by Mehlich-3 test (Mehlich, 1984). The BS was calculated based on the concentrations of Mg, K, Ca and Na. DRL was measured in the center of each field by digging vertically with a shovel until it was physically impossible to continue. Most often, the restrictive layer was characterized by parent material.

All soil parameters were separated into two categories: soil quality and soil fertility. Soil quality included soil pH, CEC, EC, total N, and DRL. These parameters represent intrinsic soil properties that are generally slow to change. Soil fertility included extractable

P, K, Ca, Mg, Na, and BS; Na is not a nutrient but it can indicate soil quality problems if high levels are found. These soil properties represent a dynamic state or health of a soil that reflects its condition under a specific management systems (Karlen et al., 1997).

Statistical analysis

Analysis of variance (ANOVA) was performed in R to examine the main effects of cropping system, fertilizer use, soil type on soil quality and fertility (RStudio Team, 2015). Following significant F-test, means were compared using Tukey's Studentized Range Test at $P \leq 0.1$. Analyses was performed on natural log-transformed EC, P, K, Ca, and Mg concentrations, which were back transformed for presentation to readers. Pearson correlations and simple linear regressions (RStudio Team, 2015) were included for better understanding of the relationships among soil parameters.

RESULTS

Cropping systems and soil quality and fertility

Soil quality and fertility varied by cropping system. Soil pH at depths 0 to 10 cm cm, CEC and 20 to 30 EC are varied by cropping system (Table 1). Soil pH at depths of 0 to 10 cm and 20 to 30 cm, CEC, and EC varied by cropping system. The AR had significantly greater soil pH at depth 0 to 10 cm compared to ANR and C systems. Soil pH at depth 20 to 30 cm was the greatest in B systems followed by AR, BC, ANR, and C systems. The AR, B, and BC had significantly greater soil pH at 20 to 30 cm depth compared to the C.

The CEC level was the greatest in AR systems followed by B, ANR, BC, and C systems. The AR had significantly higher CEC concentration compared to the rest of the systems. The B had significantly higher CEC concentration compared to C systems. EC level was the greatest in AR systems followed by B, BC, ANR, and C systems. The AR, B, and BC systems had significantly higher EC concentration compared to the C.

The C system had the lowest pH at depths 0 to 15, 10 to 20, and 30 to 50 cm. All systems had similar total N concentrations, ranging from 0.14 and 0.15 mg kg^{-1}. The C system had the greatest depth to restrictive layer followed by BC, B, ANR, and AR systems. Soil fertility varied by cropping systems. Such soil fertility parameters as extractable Ca and Mg were significant (Table 2). The extractable Ca concentration was the greatest in AR systems followed by B, BC, ANR, and C systems. The Mehlich-3 Mg concentration was the greatest in AR systems followed by B, BC, ANR, and C systems.

The AR systems had the greatest extractable P concentrations followed by B, BC, C and ANR systems. BC systems had the greatest extractable K followed by B, ANR, AR, and C while ANR and AR systems had higher Na concentration compared to B, C, and BC systems. The AR system had highest BS followed by B, BC, ANR, and C systems.

Soil types, quality and fertility

Soil quality and fertility varied by soil type. Such soil quality parameters as pH at depths 0 to 10 and 0 to 15 cm, and DRL were significant (Table 1). Black-stony soil had significantly greater pH at depth of 0 to 10 cm compared to red. Black soil also had significantly higher pH at depth 0 to 15 cm compared to red soil. Black-story and black soils had similar and higher pH at all depths compared to the red soil type. Black-stony soils had the shortest depth to restrictive layer (57 cm) followed by red (65 cm) and black soil types (70 cm). Black-stony and black soils also had higher and similar CEC concentrations compared to the red soil type. Black-stony soil had higher total N concentration compared to red and black soil types.

Soil fertility varied by soil type. Such soil fertility parameters such as extractable P and K were significant. Black soil had the greatest concentration of P followed by black-stony and red. Black-stony soil had the greatest concentration of K followed by black and red soils with red soil having significantly lower K concentration compared to black-stony. Black and black-stony soil types had the greatest and similar concentration of Ca, Mg, and BS compared to red soil type. Black and red soils had similar and lower Na concentration compared to black-stony soil.

The red soil type was the most frequent and it was primarily under BC and C cropping systems, the black soil type was the second most frequent and it was primarily under BC, B, and AR systems while the black-stony soil type was the least frequent and was under BC and ANR systems.

Fertilizer use and soil quality and fertility

Soil quality and fertility did not vary by fertilizer use. Out of a total of 52 fields, 17 received no fertilizer of any type. Fertilized soil, however, had higher soil pH, CEC, EC, and total N compared to the unfertilized soils (Table 1). Fertilized soils also had highest BS and nutrient concentrations while Na was not different between fertilized and unfertilized soils (Table 2).

Correlations among soil chemical properties

Almost all soil parameters were either highly ($r > 0.8$) or moderately (r of 0.5 to 0.8) positively correlated with each other at the significance level of $P \leq 0.01$ (Table 3).

Soil pH was correlated with almost all of the measured soil properties except for P, Na, and soil DRL. This indicates that soil pH is dependent on Ca, Mg, and K. Soil DRL was not correlated with any soil parameter, which could mean that it is influenced by either soil forming processes, landscape position, or erosional-depositional

Table 1. Soil quality properties from three soil types (black, black-stony, and red), fertilized and unfertilized soils, and five cropping systems (AR is annual with crop rotation, ANR is annual with no crop rotation, B is banana-dominant, BC is banana-coffee , and C is coffee-dominant). Soil collected from Masaka District, Uganda with collection period from June to September 2016.

Variables	Property	pH 0-10 cm	pH 0-15 cm	pH 10-20 cm	pH 20-30 cm	pH 30-50 cm	CEC 0-15 cm (meq 100g^{-1})	EC 0-15 cm (µS cm^{-1})	Total N 0-15 cm (mg kg^{-1})	DR[c] (cm)
Soil type										
Black	n=19	5.9[ab]	5.9[a]	6.1	6.2	6.1	10.1	60	0.14	70[a]
Black-stony	n=8	6.0[a]	5.9[ab]	6.1	6.1	6.0	10.9	56	0.16	57[b]
Red	n=25	5.7[b]	5.5[b]	5.9	6.0	5.9	8.7	49	0.14	65[ab]
Fertilizer use										
Yes	n=35	5.8	5.7	6.04	6.07	6.03	8.86	67	0.14	5.8
No	n=17	5.7	5.6	5.98	6.09	6.01	7.74	63	0.13	5.7
Cropping system										
AR	n=5	6.1[a]	6.1	6.3	6.2[ab]	6.0	14.9[a]	67[a]	0.14	58
ANR	n=6	5.6[b]	5.5	5.9	5.9[bc]	5.9	9.3[bc]	43[bc]	0.15	62
B	n=9	5.9[a]	6.0	6.2	6.3[a]	6.3	10.7[b]	65[a]	0.14	65
BC	n=26	5.8[ab]	5.6	6.1	6.1[ab]	6.0	8.9[bc]	56[ab]	0.15	66
C	n=6	5.6[b]	5.3	5.6	5.7[c]	5.7	6.4[c]	34[c]	0.14	74
Significance	***P*-value**									
Soil type		*	*	NS	NS	NS	NS	NS	NS	**
Fertilizer use		NS	NS	NS	NS	NS	NS	NS	NS	NS
Cropping system		*	NS	NS	*	NS	**	**	NS	NS

**, *, and NS indicate statistical significance at $P \leq 0.05$, 0.10, and not significant, respectively. [ab] Means followed by a different letter within a column set are significantly different at $P \leq 0.10$ by LSD test. [c]DRL = depth to restrictive layer.

processes (Figure 2).

DISCUSSION

Cropping systems and soil quality and fertility

Coffee and ANR systems had the lowest soil quality and fertility while B and AR systems had the highest. The BC system exhibited moderate soil quality and fertility compared to the other systems. Low soil quality and fertility in coffee systems can be attributed to several factors. First, Mulumba (2004) found that 99% of the farmers in the Lake Victoria Basin of Uganda grow coffee because it is the main source of income. The study also reported that only 58 and 26% of the farmers mulched and controlled erosion under coffee compared to 70 and 72% of the farmers who mulched and controlled erosion under banana.

This was attributed to greater returns per hectare from the coffee compared to banana and the importance of banana as a major staple crop.

Table 2. Mehlich-3 extractable P, K, Ca, Mg, and Na concentrations from three soil types (black, black-stony, and red), fertilized and unfertilized soils, and five cropping systems (AR is annual with crop rotation, ANR is annual with no crop rotation, B is banana-dominant, BC is banana-coffee, and C is coffee-dominant). Soil collected from Masaka District, Uganda with collection period from June to September 2016.

Variables	Property	P (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	Na (mg kg^{-1})	BS[b] (%)
Soil type							
Black	n=19	43[a]	134[ab]	856	159	32	71
Black-stony	n=8	21[b]	187[a]	841	160	36	72
Red	n=25	20[b]	94[b]	625	123	32	62
Fertilizer use							
Yes	n=35	28	121	772	149	31	67
No	n=17	25	116	660	125	31	66
Cropping system							
AR	n=5	45	114	1562[a]	262[a]	37	78
ANR	n=6	18	117	613[bc]	118[bc]	37	63
B	n=9	29	126	1080[ab]	196[ab]	32	75
BC	n=26	28	134	656[bc]	130[bc]	31	65
C	n=6	19	70	424[c]	84[c]	30	57
Significance		*P* value					
Soil type		*	**	ns	ns	ns	ns
Fertilizer use		ns	ns	ns	ns	ns	ns
Cropping system		ns	ns	*	*	ns	ns

**, *, and NS indicate statistical significance at $P \leq 0.05$, 0.1, and not significant, respectively. [b]BS: base saturation [ab]Means followed by a different letter within a column set are significantly different at $P \leq$ 0.1 by LSD test.

Table 3. Pearson correlation coefficients (r) among selected soil properties.

Variables	pH	CEC	EC	N	P	K	Na	Ca	Mg
pH									
CEC	0.77[b]								
EC	0.52[b]	0.49[b]							
N	0.44[b]	0.64[b]	0.23						
P	0.18	0.34[a]	0.52[b]	0.16					
K	0.62[b]	0.59[b]	0.82[b]	0.47[b]	0.36[b]				
Na	0.16	0.23	0.17	0.29[a]	0.05	0.21			
Ca	0.87[b]	0.97[b]	0.53[b]	0.59[b]	0.34[a]	0.62[b]	0.21		
Mg	0.86[b]	0.96[b]	0.49[b]	0.61[b]	0.26	0.60[b]	0.20	0.97[b]	
DRL	-0.21	-0.23	-0.18	0.11	0.24	-0.18	-0.09	-0.24	
BS	0.98[b]	0.77[b]	0.43[b]	0.42[b]	0.14	0.52[b]	0.15	0.87[b]	-0.22[b]

[a]Correlation is significant at $P \leq 0.05$. [b]Correlation is significant at $P \leq 0.01$.

Therefore, soil quality management is motivated by food security rather than income. Second, coffee production diminishes soil quality through the removal of nutrients by harvest (Shively and Hao, 2012). In Uganda, coffee is harvested twice per year and is sold as unprocessed beans meaning that the husks from the coffee are unlikely to be returned to distant coffee fields. This slow removal of nutrients over time can lead to significant nutrient deficiencies in soil. Indeed, low P and K concentrations in the coffee system are explained by the

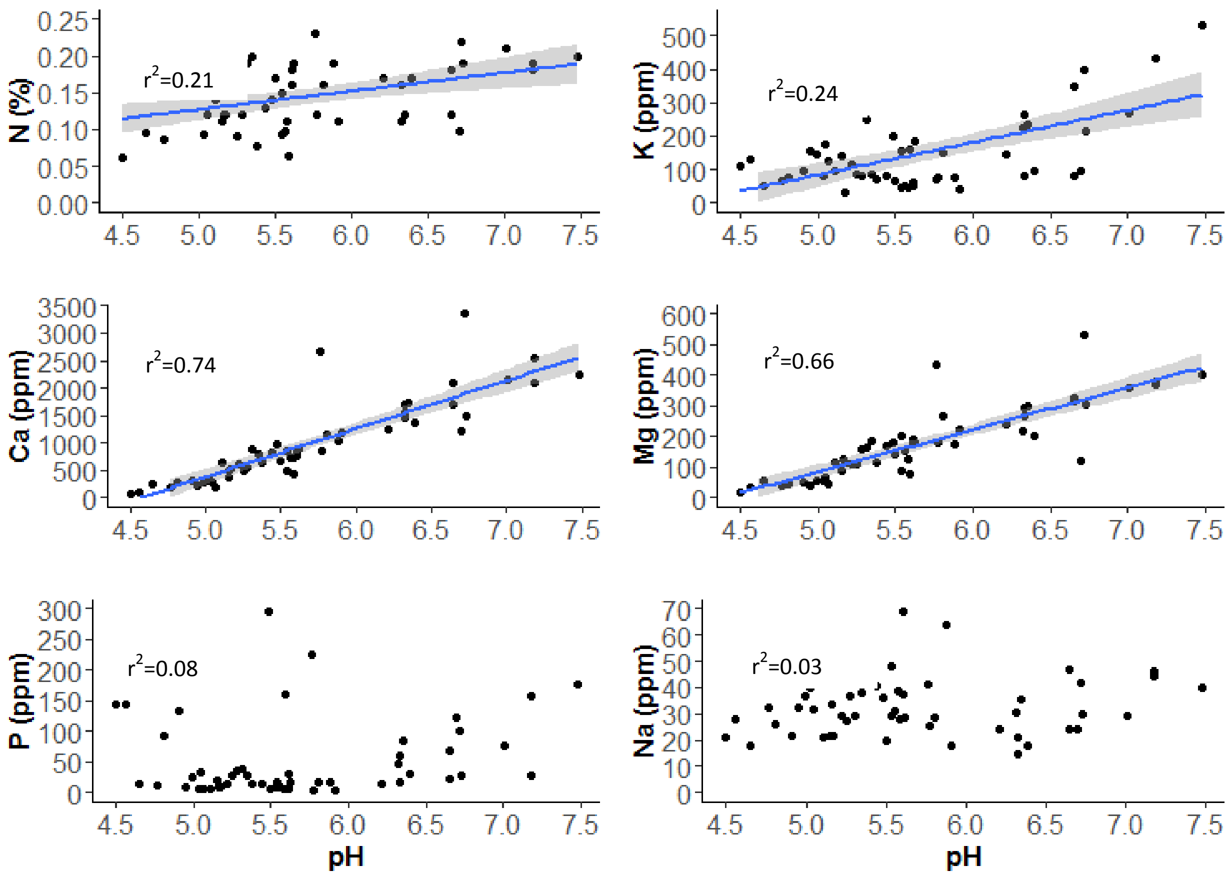

Figure 2. Linear relationships for soil pH predicting total N, extractable K, Ca, Mg, P, and Na from 53 farms in Masaka District, Uganda 2016.

removal of residues by harvest (Yamoah et al., 1990). Low Ca and Mg concentrations were also found by Nzeyimana et al. (2013) in Tanzanian coffee soil which caused Al toxicity. The sampled soils had low BS which leads to high extractable Al and limitations to crop production.

Thirdly, coffee plantations do not produce enough residues that could be used for mulch or soil cover as, for example, banana or maize do, thus further depleting the soil through erosion and leaching. Finally, coffee, as a non-staple crop, is typically grown away from home and soil fertility decreases within the farm at an increasing distances from the homestead due to limited labor (Nzeyimana et al.,, 2013). These characteristics of coffee production help explain low soil quality and fertility in coffee systems. Additionally, coffee is evenly spread across all three soil types indicating that there is either no soil preference to grow coffee or no choice in what soil to grow coffee since not every farmer has multiple soil types.

Low soil quality and fertility under ANR systems was confirmed by Mulumba (2004). He found that annual cropping systems had lower soil pH, soil organic N, and exchangeable Mg and P compared to banana and banana-coffee systems. This could be attributed to minimal soil management and the fact that annuals can be both cash and food crops. Indeed, Mulumba (2004) found that only 5% of the farmers in the Lake Victoria Basin of Uganda practiced mulching on annual cropping systems.

Banana and AR systems showed higher soil quality and fertility compared to other systems. Bananas are most often intercropped with such annual crops as beans and maize, both of which provide residues for mulching (Bekunda and Woomer, 1996). Higher nutrient content in banana soils can also be attributed to banana residue use in banana plantations and typically more organic residue use in banana systems as they tend to be closer to the homestead. Bekunda and Woomer (1996) and Wortmann et al. (1998) found that most farmers transferred annual crop residues to banana fields. Farmers also tend to allocate their best land to banana cropping because banana is essential to food security. All of these can explain greater levels and concentrations of soil pH, CEC, EC, and macronutrients in banana soils compared to coffee soils.

Additionally, the results indicate that farmers prefer to grow banana on black and red soils only. Black-stony soils are too shallow, drought-prone, and have poor water infiltration rate to be dedicated to a major food security crop like banana (Wortmann et al., 1998). Both land choice and soil management explain why fields cropped with banana contain more nutrients, especially K, than fields under coffee and annual crops. The AR systems had the highest soil quality and fertility compared to the rest of the systems. Specifically, these cropping systems had the highest levels and concentrations of CEC, EC, P, Ca, and Mg. This can be attributed to several factors. First, the rotation of crops has many benefits, some of which include pest and disease suppression and prevention. Second, crop rotations can contribute to improved nutrient and water uptake. Finally, because soil is affected by the previous crop, the type, and quantity of crop residues produced, practicing crop rotations can provide organic matter and nutrients to soil.

The rotations studied in this paper consisted of maize, beans, and cassava with different farmers rotating different combinations of these crops. Cereal/legume rotation was found to improve soil P availability and increase P uptake (Alvey et al., 2001). Additionally, it was demonstrated that soils under cereal/legume rotation had higher Mg than the soils under continuous maize (Okpara and Igwe, 2014). These findings help explain why AR systems in this study had the highest concentrations of P and Mg compared to other systems. The AR systems were found primarily in black and black-stony soils and since black soils are the most fertile, it can help explain why these systems are associated with high soil quality and fertility compared to other systems.

Soil types and soil quality and fertility

Black and black-stony soils had similar and higher soil quality and fertility compared to red soils. This indicates that there are similarities between black and black-stony soils. The fact that several cropping systems were found in black-stony soils indicates that this type of soil is common.

Fertilizer use and soil quality and fertility

Soil quality and fertility did not vary by fertilizer use which can be explained by minimal application of organic and inorganic nutrients by Ugandan farmers. Murage et al. (2000) found that 100% of the studied farmers in Kenya attributed low soil fertility to inadequate use of organic and inorganic fertilizers. Synthetic fertilizer is estimated to be used by only 10% of smallholder farmers in Uganda with the average application rate of 1 kg ha^{-1} (Benin et al., 2002).

High cost of fertilizer limits its use and it is not profitable on nutrient depleted soils (Ronner and Giller, 2013). Organic inputs such as manure, compost, and mulch are practiced by a small number of farmers due to labor requirements and lack of availability (Nkonya et al., 2004).

Conclusion

Soil quality and fertility varied by cropping system and soil type. The AR and B systems were associated with the highest soil fertility and quality while ANR and C systems were associated with the lowest soil fertility and soil quality. Black and black-stony soils were found to have similar and higher soil quality and fertility than red soils. Fertilizer use was not found to be associated with soil quality or fertility. Soil in C and ANR systems should be studied more to establish whether its quality is impacted by farmer decision to grow specific crops in certain soil types or by crop management practices.

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CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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Field Assessment

1. Date
2. Farmer ID
3. Sub-county
4. Parish
5. Village
6. Geographic coordinates:
7. Slope

Crops

8. Crops grown on the plot this season
9. Crops grown on the plot last season
10. Does the plot have a rotation? If yes, what is it?
11. Provide a brief history of the plot as far back as you remember

Field Management

12. Do you use purchased fertilizers on this plot? Specify.
13. Do you return or add crop residue to this plot? If so, what are they?
14. Do you practice fallowing on this plot?
15. Do you do any other soil management practices?

Soil Description

16. How would you describe soil quality on this plot?
a) Poor b) Fair c) Good d) Excellent
17. What is soil type on this plot?
a) Red (Limyufumyufu) b) Black (Liddugavu) c) Stony (Luyijayinga) d) Sandy (Lusenyusenyu)
18. Past or present soil erosion
19. Restrictions on rooting
a) Stone layer b) hard setting E horizon c) Dense massive clay rich Bt horizon d) other (specify)

20. Description of soil horizons

Soil horizon	Depth	Soil texture	Soil Structure	Soil color (Munsell)	Soil consistence	Root abundance	Root architecture	Microbial life	pH

Soil texture: a) sandy loam b) loam c) silt loam d) sandy clay loam e) clay loam f) silty clay loam g) sandy clay f) clay g) silty clay
Soil structure: a) platy b) single grain c) blocky d)columnar/ prismatic e) granular f) massive
Soil consistence: a) loose b) very friable c) friable d) firm e) very firm f) extremely firm
Microbial life: a) none b) some c) vivid
Root architecture: a) vertical b) horizontal
Root abundance: a) none b) few c) common d) abundant

21. Visible nutrient deficiencies:

Crop	Growth stage	Discoloration	Other crop damage	Observations

22. Visible pest damage:

Crop	Type of damage	% of damaged crop	Any visible pests?	Observations