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Influence of Cropping System and Residue Management on Selected Soil Chemical Properties

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Authors' contributions

This work was carried out in collaboration between both authors. Author EKR designed the study, performed the laboratory and statistical analysis and wrote the first draft of the manuscript. Author PKO wrote the protocol and managed the analyses of the study. Both authors managed the literature searches, interpreted data, read and approved the final manuscript.

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ABSTRACT

Declining soil fertility in sub-Saharan Africa caused by continuous cropping without nutrient inputs has resulted in declining crop yield. The study was aimed to determine the effects of crop rotation and crop residue management on soil pH, organic carbon, nitrogen and available soil P. A split plot experimental design was set up with crop management system (maize monocropping and maize – bean rotation) as main plots and crop residue (maize stover) as sub plots, in three consecutive cropping seasons. At planting, all plots received 60 kg of P_2O_5/ha and 60 kg of K_2O/ha. Results for the three cropping seasons indicated slight decrease in soil acidity, (5.42±.11), increase in soil organic carbon (2.39±.40) and soil total nitrogen from the initial value of 0.15% to 0.22±.03 due to legume rotation. Available soil P improved from 2.99 to 8.65±1.63 cmol kg^{-1}showing significant differences ($P \le 0.05$) under rotation system plus addition of crop residue. Rotation of maize and legumes with crop residue addition is recommended for farmers, which will benefit them in improving soil fertility.

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Keywords: Cropping system; organic carbon; residue management; soil nutrients; soil fertility.

1. INTRODUCTION

Maize is a main staple crop and a source of income and employment for millions of farming families in the region. It is the staple food crop for 96 percent of Kenya's population with 125 kg per capita consumption and provides 40 percent of the calorie requirements [1]. Continuous cultivation of maize on the same piece of land without adequate farm management practices in Kenya has extensively affect soil quality attributes and possibly maize production in the long run. Soil organic carbon and nitrogen are soil quality indicators [2] and are major determinants of the sustainability of agricultural production systems. Organic matter is of great importance to soils, because it affects the physical, chemical and biological properties of soils [3]. Soil organic carbon is directly linked to soil organic matter [4]. A typical agricultural soil contains about 0.10 to 0.15% total N, or approximately 5,604 kgNha^{-1} in the surface 30cm. Only 1 to 4 percent of this total N becomes plant-available during a growing season, [5,6]. Total nitrogen levels between 0.1 and 0.2% are taken as low, while those below 0.1 % are very low for tropical soils [7]. Nitrogen has a profound effect on soil fertility and therefore crop yield. Furthermore, nitrogen contributes to an increase in yield and contributes to the quality of after-harvest residue [8]. It was noted by [9] that solutions to smallholder farmers' soil fertility problems may be found in the strategic combination of organic resources, in particular from nitrogen-fixing legumes with small amounts of mineral fertilizers. It is well known that legumes have an advantage of adding nitrogen to the soil through biological nitrogen fixation (BNF) by participating in a symbiotic relationship with Rhizobia spp. Beans (*Phaseolus vulgaris*) are legumes widely grown in Kenya traditionally as sole crops or intercropping with cereals especially maize. One way of curbing soil fertility problems is by maximizing the productivity of grain legumes in addition to cereal production. Plant residues provide a valuable source of organic N for subsequent crops [10]. The positive effects of these materials have been attributed to enhanced nutrient inputs to soils, and improved soil physical and biological properties [11]. However, the objective of the study was to determine the influence of continuous cereal cropping, cereal-legume intercropping and maize stover residue in a quest to unveiling sustainable agricultural practices that would improve the livelihoods of poor resource farmers in the study areas.

2. MATERIALS AND METHODS

2.1 Site Description

Researcher-designed, farmer-managed trials were done in Nyabeda, Siaya County, during the 2009SR, 2010LR and 2010SR cropping seasons. Nyabeda lies in a sub-humid agro-climatic zone and falls in a lower midland 2 agro-ecological zone. It is located at a latitude of 0° 07' N and longitude of 34° 24' E. The altitude is 1420 mASL and receives total annual rainfall between 1200-1600 mm with mean annual temperature of 23.2° C. The soil is kaolinitic, isohyperthemic Kandiustalfic Eutrudox with a pH of 5.14 (1:2.5 soil/water suspension), described as Ferralsols [12].The soils contain 57% clay, 24% silt and 19% sand and are known to be deficient in N and P [13].Soil nutrient levels before the experiment were as follows: extractable K (cmol kg^{-1}), 0.10; P (cmol kg^{-1}), 2.99 Ca (cmol kg^{-1}), 4.69; Mg (cmol kg^{-1}), 1.68; Total SOC, 1.35% and total nitrogen, 0.15%.

2.2 Soil Sampling

Soil samples were collected at the beginning of the experiment for initial characterization of the site at 0-20 cm depths using an auger. Ten soil samples were taken with an auger from the upper soil layer (0-20 cm) in each of the plot, mixed, air-dried, finely ground, sieved (<2mm) and stored in labeled plastic bags. Soil sampling in plots was done following the transect method [14]. A composite sample was made from 10 samples collected randomly from different parts of each plot, mixed, sub- sampled, air dried and passed through a 2 mm sieve for pH, particle size, extractable phosphorus, and analysis of exchangeable bases, and through 60 mesh soils for organic carbon and total nitrogen analysis [14]. Soil sampling was done each season immediately after harvesting the crop for 3 consecutive seasons to determine mainly the changes in soil pH, OC, total nitrogen and Olsen P which are sensitive to crop residue and cropping sequences. The collected soil sample was air dried at 40°C, ground and sieved using a 60mm sieve for particle analysis and 2 mm-mesh sieve for analysis of nitrogen, carbon and phosphorus.

2.3 Field Procedures and Data Collection

Crop residues were sampled from the previous season treatments soon after harvesting and analyzed for nitrogen concentration and converted to kg N ha^{-1} by multiplying with their dry weights. Initial land preparation was by hand digging with a hoe at about 15 cm depth in all plots. Seeding was done by drilling a slot in the soil using a sharp stick. For each crop management system, the sub-plot was split and the rate of nutrient P applied was adapted to the soil condition and crop sequence. The treatments were then replicated four times. The main plots measured 6 m x 6 m (36 m^2) and sub-plots measured 6 m x3 m (18 m^2). Conventionally, plots were hand ploughed and weed removal was done using hoe. Large weeds were removed by hand pulling. Maize stover from the previous season was chopped into small pieces to ensure uniform application. Certified maize (*Zea mays*) seeds Hybrid 502 were sown at 0.75m by 0.25 m in both monocropping (MS) and rotation (RS) plots with two seeds per hole then later thinned to one plant per hole after ten days. In rotation plots, soyabean (*Glycine max* (L.) Merr) TGX 1448-2E, locally known as SB20, was planted in the following season drilled on single lines. The effective distance between rows of soyabean was 0.325 m hence a rate of 0.09 kg per plot or 50 kg ha^{-1} was used. Rainfall at the Nyabeda experimental site was measured daily using a simple rain gauge installed in the experimental farm.

2.4 Experimental Design and Field Layout

The study consisted of the following treatment combinations:

1. Crop Management Systems;

    a. Maize monocropping (CMS1)
    b. Maize-bean rotation (maize in first season then legume the following season) (CMS2)

2. Crop residue management systems;

    a. crop residue (maize stover) removed (-CR)
    b. crop residue (maize stover) retained (+CR)

The experiment was arranged in a split plot design with crop management system (CMS) as the main plots and soil surface management (CR) as sub-plots. Treatments were then replicated four times in a factorial combination with replication as blocks.

2.5 Laboratory Analyses

Soil analyses were carried out at University of Eldoret soils laboratory. Soil pH was measured with a glass electrode using a soil: water ratio of 1:2.5 (Okalebo et al., 2002) Organic carbon (OC) was determined by Walkley and Black wet combustion method [14] and converting Walkley and Black method estimates into TOC values as described by Velmurugan et al. [15]. Total N was measured by Kjehldahl method. P was determined using the Olsen P method. All analyses were done following the procedures by [14].

2.6 Data Analysis

Data generated on soil phosphorus, carbon, nitrogen and pH were entered into a Microsoft Excel spreadsheet. Analysis of Variance (ANOVA), using Genstat programme version 12 was performed and means were separated by least significant differences (*LSD*). Statistical differences among treatment means were declared at 5% level of significance.

3. RESULTS AND DISCUSSION

3.1 Soil Changes under Different Crop Management Systems

Cumulative rainfall amounts per season recorded were 402, 690 and 593mm in 2003SR, 2004LR and 2004SR respectively while the number of rainfall days for the three seasons were 40, 53 and 50 rain days (R.D) respectively. However, rainfall intensities varied in the rain days within the season. It was observed that the study area receives low amounts of rainfall and that dry spells are a common phenomenon with drought also being a common occurrence in the area. This observation would have contributed to the seasonal changes in the three cropping seasons.

3.2 Soil pH Changes under Different Crop Management Systems

Table 1 shows soil pH ranged from a value of 5.2 to 5.7. , total organic carbon ranged from 1.72 to 2.85% (Table 2), total N in soil ranged from 0.17 to 0.24%. From these observations, soil organic carbon and N contents in surface soils were very low according to the recommendation of 2.60% as given by Landon [7] and Mungai et al., [16]. The surface (0-15 cm) soil pH was not significantly different as influenced by crop management system in the three cropping seasons. In rotation crop management system, significant ($p \leq 0.05$) difference was observed with pH in no residue addition higher than when residue was added, in 2003SR. The higher soil pH in rotation soil compared with the continuous cereal soils was likely due to the much higher NO^{-3} uptake of the more vigorously growing plants and compensatory exudation of OH^{-}. Imai (17) measured the pH in soybean-based and mungbean-based rotation systems for 10 years and found rotation-induced pH changes of up to 1 pH unit. Powell and Ikpe [18] reported from a similar soil of the region that a near neutral pH resulted in maximum dissolution of P from iron and aluminium complexes.

Residue addition showed an improvement in lowering the soil acidity. This was possibly because of continuous build up of organic matter on the surface soil and the compounded effect of no nitrogen fixation effected by the legume within the cropping layer. Pocknee and Sumner [19] concluded that the major factors of organic amendments that influenced soil pH were basic cations and N contents. Tan [20] explained that organic acids produced by organic matter have the capability to hold cations and anions. The ions so adsorbed are subsequently released slowly to the plants. Similar results based on several studies, deduced that an initial pH increase commonly occurred after addition of organic materials, which lasted for approximately 1-2 months, followed by a pH decline. Crop residue release exctracts in the soil media, which change the chemical composition of the soil, increasing pH, exchangeable calcium and decreasing exchangeable Al [21]. The possible mechanism previously proposed by Michael [22] was that upon addition of organic matter, Al^{3+} ions are adsorbed on the surface of the added organic compounds and Al^{3+} ions are precipitated due to increase in soil pH. These researchers found that the magnitude of the initial pH rise was dependent on the type of residue, application rate and buffer capacity. Michael [22], observed that for amendments of 20 t ha^{-1} maize stover, pH increases of 0.81-0.85 pH units were reported compared with increases of 0.8-1.5 pH units at 40-50 t ha^{-1} maize stover rates earlier reported by Juo et al.[1]. These rates are, however, too heavy to be practiced under normal farming set-up like the one in western Kenya. The resulting effect is an increment of soil organic matter, which is known to act as soil buffer, thus reducing free H^{+} ions and stabilizing pH level of the soil.

However, Juo et al. [1] reported that the extent of acidification can be controlled by choice of cropping systems as well as soil and residue management. A good correlation between buffering capacity (BC) and organic matter content has been documented in several studies [23,24] and the importance of SOM to maintain stable pH values, despite acidifying factors, was documented by Cayely et al., [25].

Table 1. Soil pH under different cropping system in 2003SR, 2004LR and 2004SR cropping seasons

	CR	2003 SR	2004 LR	2004SR
MS	-CR	5.3	5.3	5.5
	+CR	5.5	5.6	5.5
RS	-CR	5.4	5.4	5.5
	+CR	5.2	5.4	5.4
		$l.s.d_{.(.05)}$	$l.s.d_{.(.05)}$	$l.s.d_{.(.05)}$
RM		0.1	0.1	NS
RS+RM		0.1	0.18	NS
CV%		2.6	2.9	2.6

CMS-crop management system; CR-crop residue; MS-monocropping system; RS-rotation system; SR-short rains; LR-long rains

3.3 Effects of Crop Management System on Soil Organic Carbon

Higher means of OC were observed in rotation than monocropping in all the three cropping seasons (Table 3). The differences were highly significant ($P \leq 0.05$) in 2003SR cropping season. Similarly, residue significantly ($P \leq 0.05$) influenced soil OC in 2004SR cropping seasons with mean OC higher under rotation than monocropping systems. The interaction of crop and residue management significantly ($P \leq 0.05$) influenced soil OC in 2003SR and 2004LR cropping seasons where means of OC were higher under rotation than monocropping with l.s.d values of 0.003 and 0.029 respectively. Naab [26] reported that soil organic C was increased by N inputs, from both fertilizer and by retention of residues and by N fixation in case of the legume planted. These results concurred with those reported by Singh et al. [27] and Mirkena et al. [28].

Research findings show there is progressive accumulation of decomposing organic matter on the surface soil layer [1] resulting from high accumulation of legume leave drops and perhaps the dead microbial population responsible for nitrogen fixation. Soil organic matter improves soil structure, increases water holding capacity, increases cation exchange capacity (CEC) and increases capacity of low activity clay soils to buffer changes in pH [29]. Soil OC was higher in 2003SR than the following two seasons. The seasonal variation of soil OC is a function of other factors such as physical (porosity, soil aggregate stability, water holding capacity and structure) and chemical properties (nutrient supply capability and salt content), many of which are a function of SOM content. The content of OC in a soil is determined by losses through decomposition, erosion of particles and dissolution of organic matter as well as the nature and quantities of inputs of organic matter [30]. The ultimate contribution of crop residue to SOC is controlled by the type (quality) and amount (quantity) of plant residue added to the soil [31]. Low SOC amount is also an environmental threat since low fertility results in low biomass yield. Such level can also result in significant fertilizer loss because of low buffer or retention capacity.

3.4 Effects of Crop Management System on Soil Nitrogen

Crop management was highly significant ($P \leq 0.05$) with N higher under rotation than monocropping system. Residue management significantly ($P \leq 0.05$) affected soil N in 2003SR cropping seasons with no significant difference in 2004LR and 2004SR cropping seasons (Table 3). Interaction of crop and residue management significantly ($P \leq 0.05$) influenced soil N in 2003SR cropping season. No influence was observed in 2004LR and 2004SR cropping seasons. Measurements of initial soil N before the experiment showed lower values before treatment application of between 0.15 compared to measurements taken during the cropping periods. There was a distinct difference in soil N in the long rain than the short rain season, with short rains accumulating more N than in the long rain season. This could have been due to increased biological activity during the short rains than in the long rains, which is associated to high environmental temperatures during these short rains seasons, and possibly because of some N being leached and washed away by surface run-off during high rainfall intensities during 2004 LR than in the other two seasons.

Table 2. Soil OC (%) under different cropping system in 2003SR, 2004LR and 2004SR cropping seasons

	CR	2003 SR	2004 LR	2004SR
MS	-CR	2.53	2.03	2.56
	+CR	2.82	1.85	2.52
RS	-CR	2.75	1.72	2.7
	+CR	2.75	1.77	2.7
		l.s.d$_{(.05)}$	**l.s.d$_{(.05)}$**	**l.s.d$_{(.05)}$**
CMS		0.003	NS	NS
TS		0.002	NS	NS
CR		NS	NS	0.003
CMS x CR		0.003	0.029	NS
CV%		1.2	9.5	1.5

CMS-crop management system; CR-crop residue; MS-monocropping system; RS-rotation system; SR-short rains; LR-long rains

3.5 Effect of Crop Management System on Soil Phosphorus

Soil phosphorus (P) ranged from 6.03 to 11.07 ppm. Available P (bicarbonate extractable P) as low as 6.03 cmol Pkg^{-1} of soil is below the critical

Table 3. Soil total N (%) under different cropping system in 2003SR, 2004LR and 2004SR cropping seasons

CMS	CR	N(%) 2003SR	N(%) 2004LR	N(%) 2004SR
MS	- CR	0.24	0.18	0.24
	+ CR	0.24	0.17	0.24
RS	- CR	0.24	0.17	0.24
	+ CR	0.24	0.2	0.23
		l.s.d.(.05)	**l.s.d.(.05)**	**l.s.d.(.05)**
CMS		0.003	NS	NS
CR		0.002	NS	NS
CMS x CR		NS	NS	0.003
CV%		1.2	9.5	1.5

CMS-crop management system; CR-crop residue; MS-monocropping system; RS-rotation system; SR-short rains; LR-long rains level of 10 cmol Pkg^{-1} of soil according to ratings given in Okalebo et al.,(14). P levels in soils were measured at the end of every harvest season in order to monitor the trend of P changes during cropping. Under crop management system P levels were significant (P≤0.05) in 2003SR and 2004SR with P levels higher in rotation than in monocropping. Under residue management P levels showed no significant difference in any of the cropping season.

Table 4. Soil available P (mg kg^{-1}) under different cropping system in 2003SR, 2004LR and 2004SR cropping seasons

CMS	CR	2003SR	2004LR	2004SR
MS	-CR	10.32	9.34	11.07
	+CR	8.67	10.09	7.25
RS	-CR	6.03	8.76	8.3
	+CR	7.07	10.59	6.34
		l.s.d.$_{0.05}$	l.s.d.$_{0.05}$	l.s.d.$_{0.05}$
CR		5.52	0.12	6.01
CV%		13.5	2.9	18.6

CMS-crop management system; CR-crop residue; MS-monocropping system; RS-rotation system; SR-short rains; LR-long rains

There was no influence on soil available P under the interaction of crop and residue management in all the three cropping seasons. Legume rotated with maize is envisaged to increase soil N level by fixation and from leave biomass being incorporated into the soil during and after plant growth period. This is expected to increase SOC, in turn enhance solubilisation and mineralization of soil P, and subsequently increase available soil P for plant uptake. However, the degree of solubilisation and mineralization is dependent on the amount of biomass added in relation to the level of soil acidity. Researchers have reported increased soil P availability due to organic matter ability to reduce P sorption on acid soils [32,33]. This process of enhancing P absorption by plants appears to be particularly important in highly weathered, fine textured, and acid tropical soils, where great proportions of applied P fertilizer are not available to plants due to strong fixation of P on iron and aluminium oxides [34,35]. In the acid Ferralitic soils of this study the measured rise in pH could have made a major contribution to the observed rotation-induced increases in P availability by influencing P solubility and equilibrium concentrations. It is concluded that increased P availability is attributed to indirect effects, such as pH-dependent stimulation of P mineralizing bacteria [36]. This indicates the likely interaction between chemical and biological factors involved in rotation effects on poorly buffered Western Kenya soils.

4. CONCLUSIONS AND RECOMMENDATIONS

From the results of this study, retention of crop maize stover from the previous season has a potential in improvement of soil organic carbon in the low humus soils of Nyabeda characterized by relatively low SOM levels. Practicing residue application under rotation system even without addition of fertilizer N has a potential in increasing soil total N, soil organic carbon and enhancing availability of P. In this study it can be deduced that crop residue management in combination with maize-legume rotation have a potential in soil fertility restoration for poorly degraded soils like those in western Kenya. Instead, farmers mostly use stover as firewood and feed to livestock. They also practice maize monocropping. From the study, it can be concluded that rotation of soyabeans and maize can to an extent improve soil N and P. Further studies should consider combined maize-legume rotation, improved technology to reduce soil acidity and addition of higher value organic matter source with the aim of determining the best combination that will enhance soil available P. It is important to note that consistent practice of rotation over several seasons and with enhanced mode of incorporation of leave biomass is required to significantly change soil chemical parameters.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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