Influence of Crop Rotation, Tillage System and Residue on Soil Chemical Changes for Ferralitic Soils in Western Kenya

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ABSTRACT

The bottom line of traditional farming systems in sub-Saharan Africa is primarily mining of soil nutrients. Declining soil fertility is caused by continuous cropping without nutrient inputs; depletion of soil nutrients and loss of organic matter, which has resulted in declining crop yield. To mitigate some of the practices causing reduced soil fertility, an on-farm experiment was conducted at Nyabeda in Siaya District, Nyanza Province, Western Kenya region to determine the effects of crop rotation, tillage system and crop residue management on the changes in soil pH, organic carbon, N levels and available soil P. A split-split plot experimental design was set up with crop rotation (maize with soy-beans) as main plots, tillage system (minimum tillage and conventional tillage) as sub-plots and crop residue management (with and without crop residue) as sub-sub plots for three consecutive seasons. At each planting, all plots received 60 kg of P_2O_5*/ha and 60 kg of* K_2O*/ha. Results for the three seasons indicated slight decrease in soil acidity, increase in soil organic carbon, soil total nitrogen and available soil P* ($p \leq 0.001$) *with rotation system where crop residue was returned, against control experiment of mono-cropping system without addition of crop residue. In 2004LR, tillage + residue significantly* ($p=0.014$) *contributed to soil pH variation. Slight increase in soil N suggests higher capacity for N fixation and mineralization in soils under rotation than monoculture in maize cropping. Rotation of maize and legumes under conventional tillage with crop residue addition may be envisaged as option for farmers to adopt in order to benefit from reduced input costs, improved soil fertility and enhanced food security.*

Key words: Soil nutrients, Residue management, Crop rotation, Tillage, Organic carbon

INTRODUCTION

The continuous cultivation of maize on the same piece of land without adequate farm management practices in Kenya is likely to affect soil quality attributes and possibly maize production in the long term. Soil organic carbon and nitrogen are soil quality indicators (Ngome et al., 2011) and major determinants of the sustainability of agricultural production systems (Blair et al., 1995). Organic matter is of great importance in soil, because it affects the physical, chemical and biological properties of soils (Baldock and Skjemstad, 1999). Soil organic carbon is directly linked to soil organic matter (Olson et al., 2005). Soil organic carbon (SOC) threshold for sustaining soil quality is widely suggested to be about 2% below which deterioration may occur. In some soils, SOC levels as low as 0.5% results in fertilizer responses and soils as high as 2% SOC also respond to small N doses (Muzinguzi et al. 2013). The soil levels of nitrogen forms available to plants are generally low, and they range from 1 to 5% (Bednarek and Tkaczyk 2002). Nitrogen has a profound effect on soil fertility and crop yield. This nutrient contributes to an increase in yield and after-harvest residue, thus preventing the loss of soil organic matter (Wiater and Chwil 2005).

It was noted by Palm et al., (1997) 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 obtaining nitrogen through biological nitrogen fixation (BNF) by participating in a symbiotic relationship with Rhizobia spp. Beans (*Phaseolus vulgaris*) are legumes widely grown in Kenya traditionally, either as mono-crops/sole crops or in association with cereals especially maize. One way of curbing soil fertility problems is by maximizing productivity of grain legumes in addition to cereal production. Plant residues provide a valuable source of organic N for subsequent crops (Hayat et al., 2008). Studies by Rotich (2012) reported positive effects by maize crop residues on yields of subsequent maize. The positive effects of these materials have been attributed to enhanced nutrient inputs to soils, and improved soil physical and biological properties (Okalebo et al., 2004)

MATERIALS AND METHODS

Researcher designed farmer managed trials were done in Nyabeda, Siaya County (Figure 1).

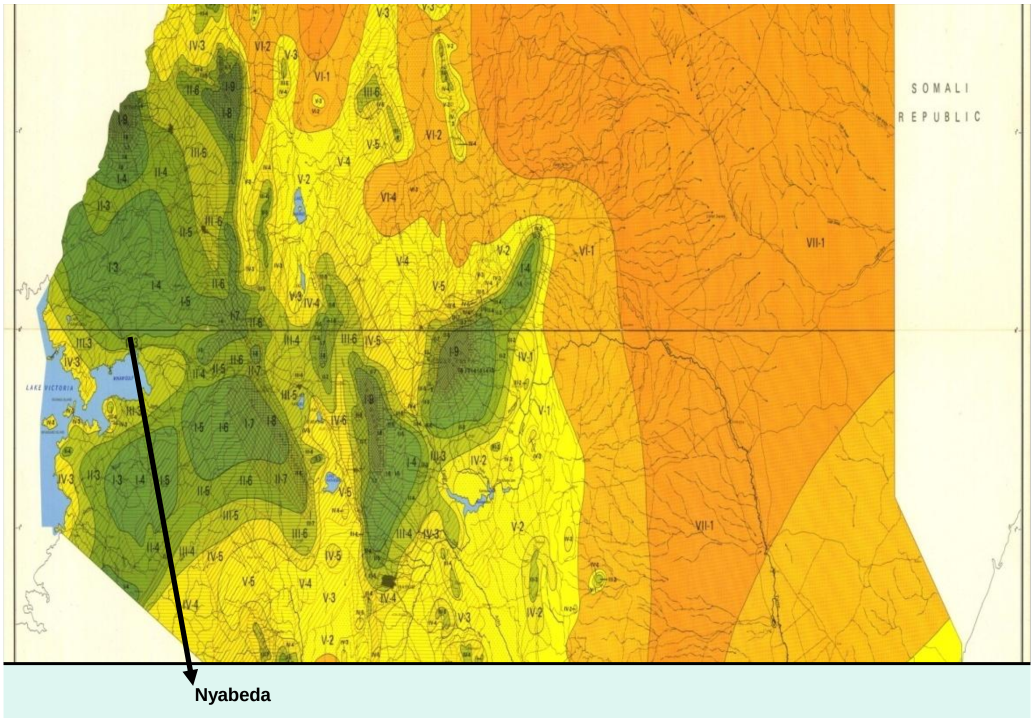

Figure 1: Location of experimental trials in Western Kenya.
Source: United States Department of Agriculture (2004)

The soil is kaolinitic, isohyperthemic Kandiustalfic Eutrudox with a pH of 5.14 (1:2.5 soil/water suspension), described as Nitisol (FAO, 1990) with 57% clay, 24% silt and 19% sand and is known to be deficient in N and P (Sombroek et al., 1980).The study consisted of two Crop Management Systems(CMS); monocropping (MS) and rotation (RS) and two soil surface crop residue (CR) management systems; crop residue removed (-CR) crop residue retained (+CR). 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 (Okalebo et al., 2002). 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. Organic carbon (OC) was determined by Walkley and Black wet combustion method. Total N was measured by Kjehldahl method. All analyses were done following the procedures by Okalebo et al. (2002). The experiment was arranged in a split plot design with crop management system (CMS) as the main plots and soil surface crop residue management (CR) as sub-plots. Treatments were then replicated four times in a factorial combination with replication as blocks. Data generated on soil phosphorus, carbon, nitrogen and pH were entered into a Microsoft Excel spreadsheet and then Analysis of Variance (ANOVA), using Genstat Software Programme, Version 12 was performed and means were separated by least significant differences (*LSD*), when the *F*-test indicated factorial effects on the significance level of $P < 0.05$.

Statistical differences among treatment means were declared at 5% level of significance. Means were separated using LSD at $p = 0.05$. The statistical model was: -

$$Yij = \mu + Ci + Rj + CRij + \Sigma ij$$

where Yij = plot observations, μ = mean of plot observation, Ci = effects of crop management ($i = 1, 2$), Rj = effect of residue ($j = 1, 2$), CRij = interaction between C and R, and Σ_{ij} = experimental error due to plots ij.

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 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 6m by 6m ($36m^2$) and sub-plots measured 6m by 3m ($18m^2$). 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 0.25m in both mono-cropping (MC) and rotation (RC) plots with two seeds per hole; then after ten days, thinned out to one plant per hole. In rotation plots, soy-bean (*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 soy-bean was 0.325m hence a rate of 0.09kg per plot or 50 kg ha^{-1} was used.

RESULTS AND DISCUSSION

A summary of initial soil characteristics at the study site is given in Table 1. Soil pH ranged from a value of 5.29 to 5.93. Total organic carbon ranged from 1.72 to 2.82% while P ranged from 1.7 to 6.0 ppm. The total N in soil ranged from 0.17 to 0.24%. Available P (bicarbonate extractable P) was as low as 2.99 me $100g^{-1}$ of soil, below the critical level of 10 mg Pkg^{-1} of soil according to ratings given in Okalebo *et al.*, (2002). P levels in soils were also measured at the end of every harvest season in order to monitor the trend of P changes during cropping. Soil organic carbon and N contents in surface soils were very low according to recommendation of 2.60% as given by Landon (1991) and Mungai *et al.*, (2009).

Table 1: Mean initial soil characteristics of the study sites (Nyabeda) for 0-15 cm depth

		Ranges	Comment
Soil type	Ferralsol		
Sand:silt:clay ratio	19:24:57		
pH (water)	5.6		low
Extractable K (me $100g^{-1}$)	0.1		
P (mg P kg^{-1})	2.99	< 10, low	Low
Ca (cmol kg^{-1})	4.69		
Mg (cmol kg^{-1})	1.68		
Total SOC (%)	1.35	>3, high; 1.5-3, moderate; 0.5-1.5, low; <0.5,very low	Moderate
Total Nitrogen (%)	0.15	>0.25-High; 0.12-0.25, moderate; 0.05-0.12, low; <0.05, very low	Moderate

Source; Okalebo et al., 2002

Rainfall at Nyabeda experimental site was measured daily using a simple rain gauge installed in the experimental farm. 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 (Figure 2). However, rainfall intensities varied in the rain days within the season. It was observed that the study area received low amounts of rainfall and that dry spells are a common phenomenon with drought also being a common occurrence in the area.

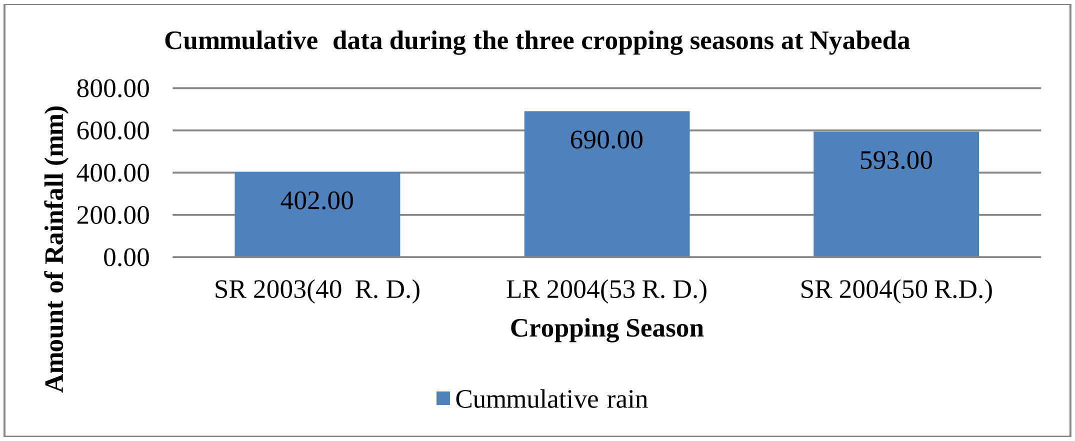

Figure 2: Cumulative rainfall per season at the Nyabeda experimental site for three cropping seasons (planting to harvesting date**).**

The surface (0-15cm) soil pH was not significantly different as influenced by crop management system in the three cropping seasons. Under residue management, rotation system showed significant (*p*= **0.006) and (p< **0.001) difference over no residue in 2003SR and 2004LR cropping seasons, respectively. Under tillage system and residue management interaction, significant difference was observed in 2003SR and 2004LR growing seasons. The higher soil pH in rotation soil compared with continuous cereal soils was likely due to much higher NO^{-3} uptake of the more vigorously growing plants and compensatory exudation of OH^{-}. Imai (1991) measured 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 (1992) reported from a similar soil of the region that a near neutral pH resulted in maximum dissolution of P from iron and aluminium complexes.

Table 2: Soil pH under different cropping system in 2003SR, 2004LR and 2004SR cropping seasons

CMS	RM	pH 2003SR		pH 2004LR		pH 2004SR	
MS	-CR	5.3	5.3	5.5	5.4	5.6	5.5
	+CR	5.3		5.3		5.5	
	Means		5.4		5.4		5.5
RS	-CR	5.3	5.5	5.4	5.4	5.5	5.7
	+CR	5.4		5.4		5.7	
	Means		5.4		5.3		5.7
	Overall Means		5.3		5.4		5.6
		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	

Residue addition showed an improvement in lowering 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 legume within the cropping layer. Pocknee and Sumner (1997) concluded that major factors of organic amendments that influenced soil pH were basic cations and N contents. Similar results based on several studies, for example Juo et al. (1995) 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 (citation). These researchers found that the magnitude of initial pH rise was dependent on the type of residue, application rate and BC. For example, for amendments of 20 t ha^{-1} maize stover, pH increases of 0.81-0.85 pH units (Table 2) 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.(1995). 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.*(1995) 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 (Starr et al., 1996; Curtin et al., 1996) and the importance of SOM to maintain stable pH values, despite acidifying factors, was documented by Cayely et al., (2002).

Table 3: Soil %OC under different cropping system in 2003SR, 2004LR and 2004SR cropping seasons

CMS	CR	2003 SR		2004 LR		2004SR	
MS	-CR	2.53	2.68	2.03	1.94	2.56	2.54
	+CR	2.82		1.85		2.52	
	Means		2.29		1.96		2.48
RS	-CR	2.75	2.75	1.72	1.75	2.7	2.7
	+CR	2.75		1.77		2.7	
	Means		2.6		1.85		2.55
		l.s.d$_{(.05)}$		l.s.d$_{(.05)}$		l.s.d$_{(.05)}$	
CMS		0.003		NS		NS	
RM		NS		NS		0.003	
CMS x RM		0.003		0.029		NS	
CV%		1.2		9.5		1.5	

Higher means of % OC were observed in rotation than mono-cropping in all the three cropping seasons (Table 3). The differences were highly significant ($p=0.003$) in 2003SR cropping season. Similarly, residue significantly ($p<0.05$) influenced soil % OC in 2004SR cropping seasons with mean %OC higher under rotation than mono-cropping systems. The interaction of crop and residue management significantly ($p<0.05$) influenced soil % OC in 2003SR and 2004LR cropping seasons where means of % OC were higher under rotation than mono-cropping with l.s.d values of 0.003 and 0.029 respectively. Shah et al. (2003) 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 Surekha et al., (2003) and Shah et al., (2007). Research findings show there is progressive accumulation of decomposing organic matter on the surface soil layer (Juo et al. 1995) resulting from high accumulation of legume leave drops and perhaps the dead microbial population responsible for nitrogen fixation. Organic matter in soils improves soil structure, increases water holding capacity of soils, increases cation exchange capacity (CEC) of soils and increases capacity of low activity clay soils to buffer changes in pH (Omotayo and Chukwuka , 2009). 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 as observed by Doran and Safley, (1997). The content of % OC in a soil is determined by losses of organic carbon through decomposition, erosion of particles and losses through dissolved organic matter and the nature and quantities of inputs of organic matter (Karlen et al., 2003; Norfleet et al., 2003). The ultimate contribution of crop residue to SOC is controlled by the type (quality) and amount (quantity) of plant residue added to the soil (Palm *et al*., 1997, 2001; Vanlauwe, 2003). 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.

Crop management was highly significant ($p<0.05$) with %N higher under rotation than mono-cropping system. Residue management significantly ($p<0.05$) affected soil % N in 2003SR cropping seasons with no significant difference in 2004LR and 2004SR cropping seasons (Table 4). Interaction of crop and residue management significantly ($p<0.05$) 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 N in the order of 2003SR (0.24%) > 2004SR (0.18-0.19%) > 2004LR (0.24%). 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 2004LR than in the other two seasons.

Table 4: Soil total N under different cropping system in 2003SR, 2004LR and 2004SR cropping seasons

CMS	RM	%N 2003SR		%N 2004LR		%N 2004SR	
MS	- CR	0.24	0.24	0.18	0.17	0.24	0.24
	+C R	0.24		0.17		0.24	
RC	- CR	0.24	0.24	0.17	0.19	0.24	0.23
	+C R	0.24		0.2		0.23	
			l.s.d.$_{(.05)}$	l.s.d.$_{(.05)}$		l.s.d.$_{(.05)}$	
CMS		0.003		NS		NS	
RM		NS		NS		0.003	
CMS x RM		0.003		0.029		NS	
CV%		1.2		9.5		1.5	

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

CMS	RM	2003SR Means		2004LR Means		2004SR Means	
MS	-CR	30.96	28.5	28.02	29.15	33.2	27.48
	+CR	26.03		30.27		21.77	
RS	-CR	36.09	28.65	26.27	29.02	24.9	17.45
	+CR	21.21		31.78		10.01	
		l.s.d.$_{0.05}$		l.s.d.$_{0.05}$		l.s.d.$_{0.05}$	
CMS		NS		NS		NS	
CV%		13.5		2.9		18.6	

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. 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 (Harrison, 1997; Jama et al., 1997). 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 mineralising bacteria (Bagayoko et al., 2000). This indicates the likely interaction between chemical and biological factors involved in rotation effects on poorly buffered Western Kenya soils.

CONCLUSIONS AND RECOMMENDATIONS

The combined treatment of crop residue coverage at a recyclable amount of at least 2 t ha^{-1} (about aield) third of stover yield and rotation of leguminous species can be considered an effective technology, due to its improvement of soil nutrient status, particularly N and P, for carrying out sustainable agriculture in western Kenya. From the results of this study, addition of crop residue 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. This is due to the decomposition of the residues releasing nutrients, especially N to the soil and the maintenance of these nutrients in the upper soil layer. Three cropping seasons in this research study were used and the results show effectiveness of use of maize stover and rotation system as demonstrated in this short-term experiment. In this study it was deduced that crop residue management under rotation system have a potential in soil fertility restoration strategy for poorly degraded soils like those in western Kenya. Farmers should be encouraged to retain maize stover, at least 2 t ha^{-1}, on their fields. Instead, farmers mostly use stover and core residue as firewood and feed to livestock. Further studies should consider the rotation with addition of higher value organic matter source with the aim of determining the best combination that will enhance soil available P. A longer term trial should also be considered that would evaluate residual effects of continued soy-beans rotation and application of indigenous P sources like RP since the level of available soil P due to rotation and residue addition accompanying mineral P source may take longer with benefits that show up later. 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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