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Influence of Amendments Added to Acid Soils on Biochemical Properties, Nitrogen Uptake and Hybrid Maize Yields in Nakuru County, Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Authors JJL, RNO and JKM jointly designed the study and wrote the protocol. Authors JJL and RNO performed the statistical analysis and wrote the first draft of the manuscript. Authors JJL and JKM managed analyses of the study. Authors JJL and RNO managed the literature searches and addressed subsequent reviewer comments and suggestions for improvement. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aim: The current study investigated effect of soil amendments; lime (L), manure (FYM) and minjingu phosphate rock (PR) added to soils on soil microbial biomass carbon and nitrogen (SMB-C and SMB-N), available soil nitrogen (N), crop N uptake and grain yields of two maize hybrids (H513 and H614).
Study Design: Two experiments, one for each maize hybrid as test crop, were laid out in a randomized complete block design with a 2^3 factorial arrangement. The factors each at two levels were L (0 and 3 t ha^{-1}), PR (0 and 60 kg P ha^{-1}) and FYM (0 and 5 t ha^{-1}) giving a total of eight treatments; L, RP, FYM, L+RP, L+FYM, RP+FYM, L+RP+FYM and control (nothing applied).
Methods: Soil and plant samples for the determination of SMB-C and SMB-N, available soil N, and crop N uptake were collected at maize seedling, tasseling and physiological

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maturity.
Place and Duration of the Study: The experiment was conducted in Molo district of Nakuru County, Kenya during the long rain seasons of 2009 and 2010.
Results: SMB-C and N levels were higher in 2010 than 2009, with lower levels obtained at maize tasseling for both maize hybrids. Available soil N and crop N uptake were higher at maize seedling and declined towards maturity. Statistically significant (P<.05) increases in SMB-C and SMB-N and available soil N and uptake were obtained with the application of soil amendments over the control. In all treatments, H513 had lower N uptake than H614 at tasseling and maturity stages of maize growth and correspondingly higher available N in soil. Maize yields (t ha^{-1}) were higher in 2010 than 2009 and in H614 than H513. The H614 yields were significantly higher (P<.05) in L+PR+FYM (3.9) and, L+PR+FYM (4.1) and L+PR (3.9) treatments in 2009 and 2010, respectively. For H513, yields were significantly higher in L+PR+FYM (2.1 and 2.4) and L+PR (1.9 and 2.1) treatments in 2009 and 2010, respectively.
Conclusion: The L+PR+FYM treatment is a feasible acid soil amendment for its superiority in the measured soil and crop parameters. The H513 matured faster than H614 and because of this attribute, is a viable option in response to the diminishing rainfall amounts and unpredictable weather patterns experienced in the County.

Keywords: Maize hybrids H614 and H513; soil acidity; soil amendments; soil microbial carbon and nitrogen; weather patterns.

1. INTRODUCTION

Soils of Molo district in Nakuru County situated in the Kenyan Rift Valley highlands, are primarily acidic with pH (H_2O) below 5.5 [1]. Additionally, the soils are characterized by toxicities of aluminium, iron and manganese, deficiencies of essential elements such as N, P, Ca [2] and low microbial population [3,4]. Besides, the weather patterns have become altered and unpredictable. These conditions are unfavourable for crop growth and have particularly, resulted in poor maize yields - a paramount staple crop of the area [1].

To boost maize production in the region, particularly the long maturing maize hybrid (H614) which is most prominent in this zone, Onwonga et al. [1] recommended application of soil amendments; lime (L), minjingu phosphate rock (PR) and manure (FYM). The effects of combined application of these amendments on soil microbial biomass carbon (SMB –C) and nitrogen (SMB-N), availability and uptake of nitrogen (N) and yield of maize were however not investigated. The possible effect of altered and unpredictable weather patterns on continued reliance on H614 was also not taken into account. These factors thus necessitated the current study.

Garcia et al. [5] indicated that as soil degradation takes place, soil properties change; particularly the microbial activity. Microbial biomass of soil (SMB) defines the functional components of micro biota primarily responsible for decomposition, soil organic matter turnover and nutrients transformation in soil [6]. The SMB immobilizes mineral nutrients and organic substrates on the one hand; thus acting as a sink or mineralizes them on the other hand, thus acting as an immediate source [7]. It also acts as a catalyst for conversion of plant nutrients from stable organic forms to available forms after a period of time [8]. The high turnover rate of SMB is responsible for nutrient release and therefore promotes plant uptake [9]. Crop productivity and nutrient availability in agro-ecosystems is therefore dependent mainly on the activity of SMB. Nitrogen (N) is a key component of enzymes and other proteins essential to all growth functions [10] and influences maize grain yields [11,12]

Climate change has led to changing weather patterns; notably shortened growing season in Kenya, including the Rift Valley province [13]. Kiiya et al. [13,14] indicated that unevenly distributed rainfall in parts of the Rift Valley tended to affect the long maturing maize varieties. Hybrid H513 is an early maturing maize variety that is suited to shortened growing season in the Kenyan Rift Valley Highlands, caused by climate change [13,14]

Objectives of the present study were therefore to (i) determine the effect of soil amendments; L, PR and FYM on SMB-C and N, and available soil N and uptake by maize and (ii) compare performance of maize hybrids H513 and H614 in response to application of the amendments.

2. MATERIALS AND METHODS

2.1 Site Description

The study was carried out at the Kenya Agricultural Research Institute located in Molo district (0°1'S, 35°41'E, 2500m asl) of Nakuru County. The County falls in the medium to high potential agroecological zone of Kenya [15]. Mean annual rainfall of the county is 1171 mm and is bimodal in distribution with the long rainy season (LRS) occurring from March to August and the short rainy season (SRS) from September/October to December [15]. The mean annual rainfall amounts received in 2009 and 2010; when the experiments were conducted, was correspondingly 917 and 1120 mm. The mean maximum and minimum air temperatures were 20.6°C and 6.9°C, respectively. Analyzed soil (0-60 cm) properties (Table 1) were; acid [pH (H_2O) 4.7], with 0.18% total N, medium exchangeable bases ($cmol_ckg^{-1}$); K (0.7), Mg (0.8) and Ca (9.6) and cation exchange capacity of 20.3 $cmol_ckg^{-1}$ [15].

The soils are well drained, deep, dark reddish brown with a mollic A horizon and classified by Jaeztold et al. [15] as mollic Andosol [17].

Table 1. Selected physicochemical properties of soils (0-60 cm depth)

Soil property	Soil Depth (cm)			Soil property	Soil Depth (cm)		
	0-15	15-30	30-60		0-15	15-30	30-60
Exc. Al ($cmol_ckg^{-1}$)	19.8	19.3	18.9	pH KCl	4.1	4.2	4.2
% N_{tot}	0.18	0.15	0.15	Organic C (gkg^{-1})	14	9	8
P (mg kg^{-1})	2.7	2.8	5.8	Ca ($cmol_ckg^{-1}$)	9.6	7.6	8.9
K $cmol_ckg^{-1}$)	0.7	0.6	0.5	Mg ($cmol_ckg^{-1}$)	0.8	0.7	0.8
%C	2.0	1.8	1.8	%sand	35.8	34.2	35.0
CEC ($cmol_ckg^{-1}$)	20.3	19.3	18.7	% silt	28.3	30.0	28.3
Mineral N (mg kg^{-1})	21.1	33.4	27.9	% clay	35.8	36.2	36.7
pH water	4.7	4.9	4.8	Textural class	clay loam (across depths)		

2.2 Treatment Application and Experimental Design

Two experiments, with maize hybrids H513 and H614 as test crops, were laid out in a randomized complete block design with a 2^3 factorial arrangement in plots measuring 3.75 m x 4.8 m during the long rain seasons of 2009 and 2010. The factors each at two levels were

L (0 and 3 t ha^{-1}), PR (0 and 60 kg P ha^{-1}) and FYM (0 and 5 t ha^{-1}) giving a total of eight treatments; L, PR, FYM, L+PR, L+FYM, PR+FYM, L+PR+FYM and control (nothing applied). The treatments were similarly applied to both maize hybrids.

2.3 Agronomic Practices

Land was prepared manually using hand hoes before application of amendments; L (3 t ha^{-1}) as $CaCO_3$ (40% Ca) and Minjingu PR (438 kg PR ha^{-1} equivalent to 60 kg P ha^{-1};) were broadcast and incorporated in the moist soil within 0-15 cm depth using hand hoes, two weeks prior to planting. FYM (5 t ha^{-1}) was placed in planting holes and mixed well with soil, a week prior to planting. The FYM was analysed for determination of nutrient concentration prior to application (Table 2).

Table 2. Nutrient concentration and quantity (kg) in 5 t/ha of the FYM

Nutrients	Total N	Org. C	P	K	Ca	Mg	S
	%		mg kg^{-1}				
Nutrient concentration	1.4	0.8	64	2450	570	5870	700
Nutrient quantity (kg)	70	40	0.32	12.3	2.9	29	3.5

Calcium Ammonium Nitrate (CAN) fertilizer (26%N; 6% Ca) was applied in all plots as a top dress one month after planting, at the rate of 60 kg N ha^{-1} (230.8 kg CAN ha^{-1}).The two maize hybrids; H614 and H513, were sown in the long rainy season of 2009 and 2010 at the rate of two seeds per hill and a spacing of 30 x 75 cm, resulting in five maize rows per plot. Thinning to one plant per hill was done a month after planting to give a total plant population of 44 444 plants ha^{-1}. Recommended cultural practices for maize such as weeding, pest and disease control were carried out in all plots [18]. Weeding was done using hand hoes twice during plant growth. Bestox was used to control cut worms and stalk borers, respectively.

2.4 Sampling of Soil and Plant for Laboratory Analysis

2.4.1 Soil sampling

To determine the initial chemical and physical properties of the soil (Table 1), samples were collected from six profile pits at three soil depths (0-15, 15-30 and 30-60 cm) before application of treatments. Samples from each depth were combined to get one composite sample per soil depth before analysis. For the determination of SMB-C and N and available soil N, top soil (0-15 cm) samples were collected at seedling, tasseling and maturity stages of maize growth from four locations in all plots. The four samples from each plot were composited, passed through a 2-mm sieve, stored at 4°C and analysed within 3 days.

2.4.2 Plant sampling

Plant sampling was done in all plots. At seedling four whole plants were randomly sampled, while at tasseling, leaf opposite the ear was sampled from ten randomly selected plants. At physiological maturity of maize, the above ground portion of plant was harvested from three centre rows and divided into stover (stalk and leaves), cob and grains. The plant samples collected at seedling, tasseling and harvest (stover) were chopped into small pieces and sub-samples oven dried at 65^{o} C for 72 hours. Weights of the oven dried sub-samples were recorded and used to calculate total above-ground dry matter yields.

2.5 Laboratory Analysis of Soil, Plant and Farmyard Manure samples

Standard laboratory procedures were followed in analyzing nutrient contents of soil, plant and FYM samples. Air - dried soils sieved through 2 mm mesh were analyzed for pH (Soil: H_20 and KCl: 1:2.5), texture (hydrometer method), total N (Kjedahl method), total carbon [19], exchangeable Al [20], CEC [21], mineral N and available P according to Okalebo et al. [22]. Exchangeable bases (K, Ca and Mg) were extracted with 1.0 M-ammonium acetate at pH 7 and measured by atomic adsorption spectrophotometry (© Analyticjena). Plant samples were ground and passed through 2 mm sieve and analysed for their N content [22] and subsequent estimation of N uptake. Approximately 1 kg FYM was collected from source (Tatton demonstration Unit of Egerton University) at approximately 45 cm from the surface of the heaps and stored in plastic bags. It was air dried and ground to pass through a 2 mm sieve and analyzed for Total N, organic C, available P, K, Ca, Mg and S (Table 2) according to methods described by Okalebo et al. [22].

2.5.1 SMB-C and N

In the second day of soil sample collection, soils were processed for SMB-C and N by the chloroform fumigation–extraction method [23]. Field-moist soils were fumigated with ethanol-free chloroform for 24 hours. Both fumigated and non-fumigated soils were extracted with 0.5 M K_2SO_4 (for SMB-C and N) by shaking for 30 minutes. SMB- C was determined by a heated sulfuric acid dichromate digestion, and SMB-N was analyzed in a persulfate digestion of the extracts and measured total N using a modification of the micro-Kjeldahl method [24].

2.6 Calculation Procedures and Statistical Analysis

2.5.1 Calculation procedures

2.5.1.1 Nutrient uptake

The total nutrient uptake was calculated at three maize growth stages using the following formulae [25];

Total nutrient uptake = nutrient concentration x dry matter yield ……...........…… (1)

2.5.1.2 Maize yield

Maize from three middle rows of each plot was harvested, dehusked, dried, threshed and weighed. Grain yield (adjusted to 13% moisture content) was recorded and converted to kg ha^{-1} using the following formula;

Grain yield (kg ha^{-1}) = kg grain yield m^{-2} × 10,000m^2 ………………................… (2)

2.5.1.3 SMB- C and SMB-N

The SMB-C and SMB-N were calculated as follows;

SMB-C = E_C/K_{EC}.. (3)

Where E_C = organic C extracted from fumigated soils – organic C extracted from non-fumigated soils; K_{EC} = 0.38 [23]

$$\text{SMB-N} = E_N/K_{EN} \quad (4)$$

where E_N = Total N extracted from fumigated soils – Total N extracted from non- fumigated soils; K_{EN} = 0.45 [26]

2.5.2 Statistical analysis

Analysis of variance (ANOVA) using a general linear model [27] was used to detect statistical variation in treatment effects on SMB-C and N, available soil N and uptake and maize grain yield, at P<.05 level of significance, while Tukey's Honestly Significant Difference was used for mean separation.

3. RESULTS AND DISCUSSION

3.1 Soil Microbial Biomass Carbon and Nitrogen

There were significantly higher levels of SMB-C and N in 2010 than 2009 (Tables 3 and 4). Comparing growth stages, lower levels of SMB-C and N were found at tasseling. Statistically significant (P<.05) increases in SMB - C and N were obtained with the application of soil amendments either singly or in combination compared to the control in both years. The pattern of variation of SMB - C and N in response to the treatments was however similar for both maize hybrids and years (Tables 3 and 4).

There were significantly (P<.05) higher levels of SMB-N in the L+PR+FYM and FYM treatments than PR+FYM, L+FYM and L+PR. Conversely, the PR+FYM, L+FYM and L+PR, had significantly higher levels of SMB-N than PR, L and control treatments at seedling stage of maize (H614) growth in 2009 (Table 3). The level of SMB-N was significantly higher in treatments L+PR+FYM, PR+FYM, L+FYM and FYM at seedling stage of maize (H513) growth in 2009 (Table 3). At maize tasseling and physiological maturity, the FYM, PR+FYM and L+PR+FYM, and the L+PR+FYM treatments had significantly higher level of SMB-N, respectively for both maize hybrids (Table 3). Significantly higher levels of SMB-N were found in the L+PR+FYM and the FYM treatments at all stages of maize (H614 and H513) growth in 2010.

For both maize hybrids, significantly higher amounts of SMB–C were registered in the L+PR+FYM treatment in 2009 during seedling and maturity stages of maize growth (Table 4). At tasseling significantly higher levels of SMB-C were registered in the L+PR+FYM treatment for H614 and L+PR+FYM and PR+FYM treatments for H513. The treatments L+PR+FYM and PR+FYM had significantly higher SMB-C In 2010 at seedling stage of maize (H614) growth (Table 4). SMB-C was significantly higher in the L+PR+FYM treatments followed by PR+FYM, L+FYM and FYM treatments at seedling stage of maize (H513) growth in 2010 (Table 4). In 2010, at tasseling stage of both maize hybrids, SMB-C was significantly higher in the L+PR+FYM treatment. This was followed by the PR+FYM and FYM treatments. Significantly higher amounts of SMB-C were found in the L+PR+FYM treatment for H513 and in the FYM treatment in H614 in 2010 at maturity stage of maize growth

Table 3. Soil microbial biomass nitrogen (µg N g^{-1} dry soil) during plant growth after application of soil amendments

	H614						H513					
	2009			2010			2009			2010		
	Seed	Tass	Mat	Seed	Tass	Mat	Seed	Tass	Mat	Seed	Tass	Mat
control	15.6^{f}	7.7^{e}	11.9^{f}	12.4^{f}	7.2f	11.2^{e}	14.9^{e}	6.9^{e}	9.5^{g}	13.1^{e}	5.6^{d}	7.2^{f}
L	21.2^{e}	17.5^{d}	24.7^{ef}	26.3^{e}	15.9^{e}	21.4^{d}	22.6^{d}	18.1^{d}	24.9^{f}	27.4^{d}	15.2^{c}	20.6^{e}
PR	32.2^{d}	21.9^{cd}	29.2^{de}	33.4^{d}	21.5^{d}	30.6^{c}	31.7^{cd}	20.6^{d}	32.4^{e}	33.2^{cd}	21.6^{c}	29.4^{d}
FYM	50.2^{a}	37.8^{a}	42.5^{b}	61.3^{ab}	39.2^{a}	44.6^{a}	48.7^{ab}	35.3^{a}	44.6^{bc}	68.1^{a}	46.4^{a}	48.5^{a}
L+PR	37.9^{c}	25.1^{bc}	32.7^{cd}	39.6^{c}	28.9^{c}	35.2^{bc}	38.5^{bc}	26.1^{c}	35.6^{de}	39.7^{c}	26.4^{bc}	32.1^{cd}
L+FYM	41.7^{bc}	28.4^{b}	35.2^{c}	57.1^{b}	31.2^{bc}	40.1^{ab}	44.2^{ab}	31.2^{bc}	40.1^{cd}	54.6^{b}	29.1^{b}	38.4^{b}
PR+FYM	45.3^{b}	36.3^{a}	40.3^{bc}	58.2^{b}	34.3^{ab}	39.1^{b}	42.5^{ab}	32.5^{ab}	38.6^{d}	56.1^{b}	30.2^{b}	33.2^{bc}
L+PR+FYM	56.7^{a}	38.2^{a}	49.7^{a}	65.7^{a}	36.2^{ab}	45.4^{a}	51.3^{a}	37.3^{a}	48.2^{a}	70.4^{a}	47.1^{a}	50.1^{a}

Key: Seed= seedling; Tass= tasseling; Mat= maturity; L=Lime; PR=minjingu phosphate rock; FYM=Farm Yard Manure. Means in a column followed by the same letter are not significantly different (P<.05)

Table 4. Soil microbial biomass carbon (µg C g^{-1} dry soil) during plant growth after application of soil amendments

	H614						H513					
	2009			2010			2009			2010		
	Seed	Tass	Mat	Seed	Tass	Mat	Seed	Tass	Mat	Seed	Tass	Mat
control	158.7^{f}	116.8^{f}	161.7^{d}	193.4^{e}	137.2^{e}	208.6^{g}	159.3^{g}	115.3^{f}	157.2^{f}	177.3^{f}	105.6^{f}	152.7^{f}
L	189.3^{e}	132.4^{e}	202.4^{c}	235.2^{d}	151.7^{d}	220.4^{f}	171.7^{f}	133.5^{e}	186.4^{e}	209.4^{e}	127.4^{e}	173.5^{e}
PR	190.2^{e}	161.7^{d}	217.4^{c}	241.3^{d}	189.2^{c}	241.7^{d}	180.8^{f}	154.7^{de}	198.3^{e}	220.4^{d}	142.5^{de}	185.7^{de}
FYM	350.6^{b}	244.5^{b}	379.6^{b}	395.4^{b}	220.5^{b}	392.5^{a}	346.5^{bc}	241.6^{bc}	361.9^{b}	379.5^{b}	231.7^{bc}	332.5^{b}
L+PR	220.3^{d}	171.5^{d}	252.7^{d}	267.5^{c}	158.3^{d}	270.4^{c}	225.3^{e}	169.7^{d}	243.4^{d}	277.6^{c}	152.7^{d}	228.6^{c}
L+FYM	282.7^{c}	215.5^{c}	292.4^{c}	402.4^{b}	187.2^{c}	248.7^{e}	291.3^{d}	221.3^{c}	202.7^{e}	382.3^{b}	210.3^{c}	194.7^{d}
PR+FYM	338.3^{b}	264.8^{ab}	351.6^{b}	411.6^{a}	232.4^{b}	304.2^{b}	334.7^{c}	266.5^{ab}	339.4^{c}	388.4^{b}	251.5^{b}	342.5^{b}
L+PR+FYM	372.6^{a}	281.6^{a}	398.2^{a}	418.3^{a}	260.1^{a}	337.2^{b}	380.2^{a}	284.2^{a}	391.7^{a}	404.3^{a}	276.4^{a}	410.4^{a}

Key: Seed= seedling; Tass= tasseling; Mat= maturity; L=Lime; PR=minjingu phosphate rock; FYM=Farm Yard Manure. Means in a column followed by the same letter are not significantly different (P<.05)

The pronounced levels of SMB-N at seedling stage can be attributed to re-immobilization of N that was mineralized due to low crop N demand at this stage of crop growth. Immobilized microbial biomass N is less susceptible to volatilization or leaching losses and thus serves as a protected source of N that can become available to plants during microbial biomass turnover [28]. N immobilization is transient and inorganic N is mineralized from the microbial community in advance of maximum plant N needs later in the growing season [29]. Nitrogen uptake by maize peaks at tasseling [30] explaining the declined levels of SMB-N at seedling stage. The observed increase in SMB-C at harvest was due to provision of substrates to soil microbes in form of sloughed root cells, root exudates and leaf fall. Tejada et al. [31] observed maximum levels of microbial biomass later in the growing season and attributed this to C addition from plant roots. Adeboye and Iwuafor [32] studying soil microbial biomass in crop rotation systems in a moist tropical savanna Alfisol also found that soil microbial biomass carbon was significantly ($P<.01$) correlated with soil organic carbon.

The elevated levels of SMB-C and N observed with the combined application of amendments may have been due to their positive interaction effects. FYM, a source of soil organic matter, provided C and N that promoted microbial activities while lime and PR ameliorated low soil pH, making it suitable for microorganism to thrive. This is in addition to the supply of phosphorus by PR.

Yang *et al*. [33] reported that higher MBC and MBN are mainly attributable to the greater availability of organic matter. Lack of available C (i.e. energy substance) in substrates is a primary constraint to soil microbial growth and activity [34,35,32,36]. Entry of C-rich substrate into soil is therefore a key factor which governs the size and activity of microbial biomass [32,37]. Mohammadi et al. [38] reported that organic manure increased the level of soil microbial biomass due to provision of greater amounts of biogenic materials like mineral nitrogen, water, soluble C and carbohydrates. Weil [39] reported that PR rock was relatively rich in carbonates and had significant liming effect in ameliorating soil pH. Lime application changes soil pH over time and helps to remove negative effects of soil acidity [40].

The higher SMB-N and C in 2010 was as a direct result of residual effects of amendments applied and presence of crop residues left in the field from previous year. This is in addition to enhanced moisture levels due to relatively higher rainfall amounts received in 2010. Crop residues thus contributed to retention of water and provided extra energy source to the microorganisms. The numbers of heterotrophic microorganisms increase rapidly in response to addition of suitable carbon substrates [41]. According to Ross [42], crop residues can have a large effect on soil microbial biomass and activity, which in turn, affect the ability of soil to supply nutrients to plants through soil organic matter turnover. Soil microbial properties are influenced by variations in soil moisture and temperature and nutrient supply [43]. It is under these conditions that organisms colonize organic matter and release enzymes into the soil [41]. Logah et al. [**Error! Reference source not found.**] studying dynamics of microbial biomass under three amendments; poultry manure and inorganic fertilizer and poultry manure + inorganic fertilizer, reported that microbial properties were influenced by variations in soil moisture, temperature and nutrient supply.

3.2 Soil Available Nitrogen during Maize Growth

Soil available N was higher at maize seedling and declined thereafter towards physiological maturity in all treatments (Table 5). The control had the lowest levels of soil available N. Application of amendments increased available soil N content over control for both maize hybrids. The increases were significantly greater with combined (L+PR, L+FYM, PR+FYM, L+PR+FYM) application of treatments (Table 5). Between the two maize hybrids, levels of soil available N were higher in H513 plots than H614 at tasseling and maturity stages of maize growth (Table 5).

For hybrid maize H614, significantly (P<.05)) higher levels of available N in soil were found in L+FYM, PR+FYM and L+PR+FYM treatments and, in the L+PR+FYM, PR+FYM, L+FYM and FYM treatment in 2009 and 2010, respectively at seedling stage of maize growth. Significantly (P<.05) higher amounts of soil available N were recorded in L+FYM, PR+FYM, L+PR+FYM and FYM treatments at seedling stage of maize hybrid H513 in 2009 and 2010 (Table 5).

At tasseling stage of maize growth, the levels of available N in soil were significantly higher in L+FYM treatment in 2009 and L+PR+FYM in 2010 for H614 with H513 registering statistically significant (P<.05) amounts in L+FYM+PR treatment in 2009 and L+FYM+PR and PR+FYM treatments in 2010.

At physiological maturity of maize, there were significantly higher amounts of soil available N levels in the L, PR, PR+FYM and L+PR+FYM treatments in 2009 and in L+PR+FYM treatment in 2010 for hybrid maize H614. While for H513, available N in the soil was significantly higher in PR+FYM treatment in 2009 and L+PR+FYM, PR+FYM, L+FYM and FYM treatments in 2010 at physiological maturity.

The higher available soil N content at seedling stage of maize growth, for both maize hybrids (Table 5) can partly be attributed to flush of nitrates formed at onset of the main rains. The highest nitrate concentrations are typically found in tropical soils during the transition from dry to wet seasons [45]. Nitrate frequently accumulates in tropical soils during the onset of rains following a dry season [46]. Birch [47,48] showed flush of mineral N at the start of wet season in East Africa that was as a result of population dynamics of soil microbes. Immediately after rain, the young population increases rapidly, utilizing relatively easily decomposable materials. These are derived in part; from the drying and death of most of the old population, and in part from soil organic matter made decomposable by physical and chemical changes brought about by wetting and drying [Birch, 47,48].

The low amounts of available N in soil at tasseling and maturity growth stages, for both maize hybrids, could be as a result of uptake by maize. Komoni et al. [30] reported that maize takes up maximum amounts of N at tasseling. A major portion of N applied to a crop is removed as harvested outputs [49]. Immobilization of N due to presence of maize residues left in the field after harvest also caused low available N in soil at maturity of maize. Jensen et al. [50] reported that incorporation of crop residues in soil causes rapid increase in soil microbial biomass which will act as a sink for nutrients. Microbial C and N are closely linked since after adding a C substrate to soil, the energy and growth substances generated by heterotrophic metabolism are used to increase microbial biomass; hence, the N demand for decomposer populations [51]. Other soil processes could have also contributed to the declining level of soil available N with maize growth. Gregory et al. [52] reported that mineralized N may be rapidly lost by various processes including leaching, denitrification and immobilization, depending on rainfall and wetness of soil. Warren et al. [53] observed that after initial wetting and flush of Nitrate-N by rain, increases in soil water were accompanied by decreases in nitrate concentration, while dry periods were accompanied by increases in nitrate.

Low available N in soil in control treatment (Table 5) was due to non-application of amendments coupled with low soil pH which further limited mineralization of organic matter. The main sources of N for crops are from mineralization of soil organic matter, inorganic fertilizers and organic inputs, and biological N fixation [54]. Soil pH affects the activity of microorganisms [55] which in turn have a marked influence on critical soil processes such as degradation of plant and animal residues and nutrient cycling that accompanies this process. The observed higher N content when amendments were applied; especially in combination, was due to mineralization of FYM and the enhanced soil pH after application of L and PR. The latter provided a conducive environment for the nitrifyers. Lyngstad [56] reported that liming of soil increased nitrification rate. PR has a high content of carbonates and therefore has a liming effect [39]. Nekesa et al. [57] reported that liming alone cannot serve to achieve the maximum potential of an acid soil.

The higher available N content in soil for maize hybrid H513 than H614 may be credited to differences in rates and amounts of N uptake with lower uptake by H513. Quaggiotti et al. [58] reported that maize varieties differed in uptake of nutrients and hence this partly explains the lower N uptake by maize hybrid H513.

3.3 Plant Nitrogen Content

The N content in maize was higher at seedling stage of maize growth and declined with progression of maize growth for both maize hybrids (Table 6). The maize hybrid H513 had lower amounts of plant N than H614. Significant increases in plant N content over control were observed with application of soil amendments (Table 6) for all maize hybrids.

The plant N content during maize growth was significantly ($P<.05$) higher in L+FYM, PR+FYM and L+FYM treatments (at seedling and tasseling) and L+PR+FYM (at maturity) stages of maize growth in 2009 for maize hybrid 614. In 2010, the L+PR+FYM, PR+FYM and L+FYM treatments had significantly ($P<.05$) higher amounts of plant N at seedling and maturity stages of maize growth whereas at tasseling stage, plant N contents were higher in treatments PR+FYM and L+PR+FYM (Table 6). The hybrid maize H513 registered significantly higher plant N contents in the L+PR+FYM, PR+FYM and L+FYM treatments across all stages of maize growth and years.

The declining N uptake with progression of plant growth was partly due to dilution effect resulting from increase in plant biomass with plant growth. Aflakpui et al. [59] similarly observed that concentration of N in the leaf, stem and root of maize declined asymptotically from first to the last sampling date. As crops grow, concentration of nutrient per unit of dry mass normally decreases with time as more structural materials are produced [52].

The higher N content in maize hybrid H614 was due to its longer growing period and high nutrient requirement. N content in plant tissues matches the growth-related demand of the plant [60] and consequently varieties with a larger relative growth rate have higher N uptake ability [61]. The observed higher N uptake in treatments where the amendments were combined was a result of increased levels of available N in soil due to FYM mineralization and enhanced pH of the soil due to application of lime and PR. The N content in maize depends not only on peculiarities of varieties of cultivated hybrids, but also on the conditions of cultivation [62].

Table 5. Means of available soil nitrogen (kg ha^{-1}) during plant growth after application of soil amendments

Treatment	H614						H513					
	2009			2010			2009			2010		
	Seed	Tass	Mat	Seed	Tass	Mat	Seed	Tass	Mat	Seed	Tass	Mat
Control	21.3^{e}	8.8^{d}	5.5^{d}	13.2^{c}	6.5^{d}	5.8^{c}	20.4^{a}	8.6^{f}	7.7^{f}	14.1^{c}	7.2^{d}	6.1^{c}
L	38.8^{cd}	11.4^{c}	10.4^{ab}	27.1^{b}	9.1^{c}	8.2^{b}	35.9^{b}	12.6^{e}	11.3^{d}	30.1^{b}	11.1^{c}	9.6^{b}
PR	36.4^{d}	13.4^{c}	10.9^{ab}	25.3^{b}	10.2^{c}	8.2^{b}	37.6^{b}	15.2^{cd}	11.6^{d}	33.2^{b}	12.5^{c}	10.1^{b}
FYM	67.9^{b}	11.5^{c}	8.3^{c}	56.1^{a}	12.7^{c}	10.3^{ab}	68.3^{a}	14.3^{de}	10.7^{d}	59.1^{a}	13.2^{c}	11.3^{ab}
L+PR	48.4^{c}	12.5^{c}	9.9^{bc}	32.3^{b}	10.2^{c}	9.7^{ab}	43.6^{b}	17.1^{c}	12.3^{cd}	34.2^{b}	11.9^{c}	9.1^{b}
L+FYM	72.2^{ab}	27.5^{a}	9.1^{b}	59.1^{a}	17.6^{b}	10.4^{ab}	74.7^{a}	33.1^{a}	17.8^{a}	61.2^{a}	18.5^{b}	11.3^{ab}
PR+FYM	73.5^{ab}	22.5^{b}	10.3^{ab}	64.2^{a}	19.2^{b}	9.2^{ab}	72.3^{a}	24.5^{b}	15.9^{ab}	66.2^{a}	20.3^{ab}	10.2^{ab}
L+PR+FYM	79.1^{a}	23.8^{b}	12.5^{a}	65.1^{a}	23.5^{a}	11.1^{a}	77.1^{a}	25.2^{b}	13.2^{bc}	69.1^{a}	21.4^{a}	14.1^{a}

Key: Seed= seedling; Tass= tasseling; Mat= maturity; L=Lime; PR=minjingu phosphate rock; FYM=Farm Yard Manure. Means in a column followed by the same letter are not significantly different (P<.05)

Table 6. Means of plant N uptake (mg/g) during plant growth after application of soil amendments

	H614						H513					
	2009			2010			2009			2010		
	Seed	Tass	Mat	Seed	Tass	Mat	Seed	Tass	Mat	Seed	Tass	Mat
Control	10.2^{d}	8.2^{d}	7.6^{e}	8.1^{d}	6.8^{e}	6.4^{e}	9.5^{d}	7.8^{c}	6.9^{d}	7.9^{d}	7.1^{c}	5.1^{d}
L	17.1^{c}	15.2^{bc}	8.6^{d}	19.1^{c}	16.7^{cd}	9.2^{c}	14.1^{c}	11.2^{b}	7.1^{b}	14.1^{c}	12.2^{b}	8.1^{c}
PR	15.8^{c}	13.1^{c}	9.8^{c}	17.9^{c}	14.6^{d}	9.4^{c}	13.8^{c}	10.9^{b}	8.1^{b}	12.9^{c}	11.1^{b}	8.5^{c}
FYM	22.8^{b}	18.1^{b}	9.2^{c}	29.7^{b}	20.1^{bc}	10.1^{bc}	20.1^{b}	12.1^{b}	8.7^{b}	24.7^{b}	14.2^{b}	9.2^{bc}
L+PR	19.1^{bc}	17.4^{bc}	9.9^{c}	21.6^{c}	14.7^{d}	9.5^{c}	16.2^{c}	10.8^{b}	8.8^{b}	16.6^{c}	11.6^{b}	8.4^{c}
L+FYM	32.5^{a}	22.7^{a}	11.2^{b}	33.1^{ab}	24.1^{b}	11.2^{ab}	28.1^{a}	16.4^{a}	10.1^{a}	28.1^{b}	19.2^{a}	10.3^{ab}
PR+FYM	33.1^{a}	24.3^{a}	11.1^{b}	35.9^{a}	27.2^{ab}	11.5^{ab}	29.6^{a}	17.1^{a}	10.4^{a}	30.9^{ab}	21.3^{a}	10.9^{ab}
L+PR+FYM	35.2^{a}	25.1^{a}	12.4^{a}	37.9^{a}	31.1^{a}	12.8^{a}	31.2^{a}	19.2^{a}	11.3^{a}	32.9^{a}	23.1^{a}	11.7^{a}

Key: Seed= seedling; Tass= tasseling; Mat= maturity; L=Lime; PR=minjingu phosphate rock; FYM=Farm Yard Manure. Means in a column followed by the same letter are not significantly different (P<.05)

3.4 Maize Grain Yields

Maize grain yields were higher in 2010 than 2009 and higher in maize hybrid H614 than H513 (Figs. 1 and 2). The H614 grain yield (t ha^{-1}) ranged from 1.0-3.9 in 2009 and 1.7-4.1 in 2010. For hybrid maize H513, grain yield (t ha^{-1}) ranged from 0.9-2.1 and 1.1 to 2.4 in 2009 and 2010, respectively. In both seasons and hybrids, the control had lowest grain yields. Application of amendments, especially when combined, gave significant (P<.05) grain yield increments for both maize hybrids above control treatment. The yields of hybrid maize H614 were significantly higher in L+PR+FYM treatment in 2009 and in L+PR+FYM and L+PR treatments in 2010. The hybrid maize H513 yields were significantly higher in L+PR+FYM and L+PR treatments in both growing seasons.

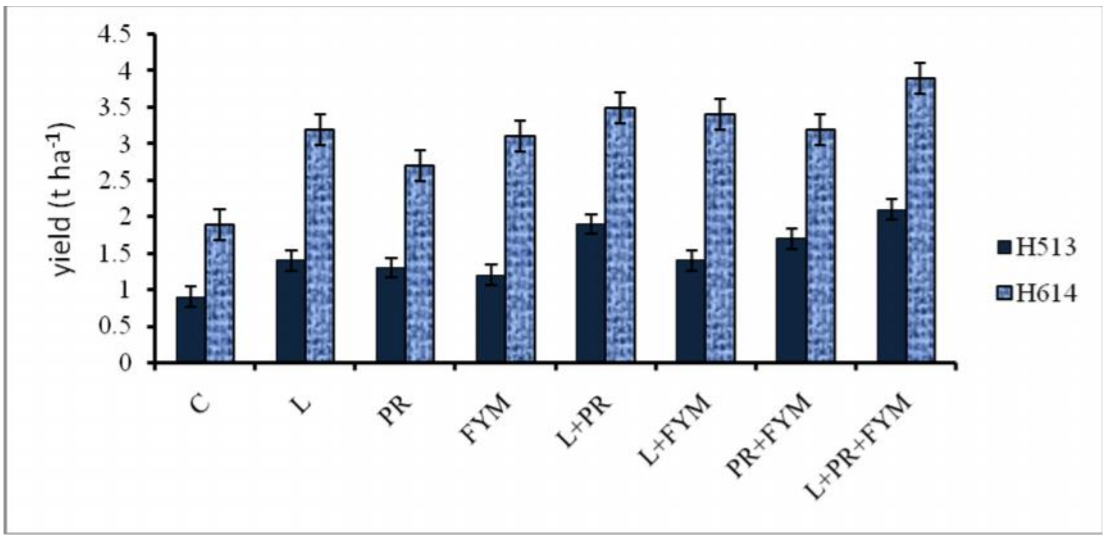

Fig 1. Hybrid maize grain yields in 2009 as influenced by soil amendments

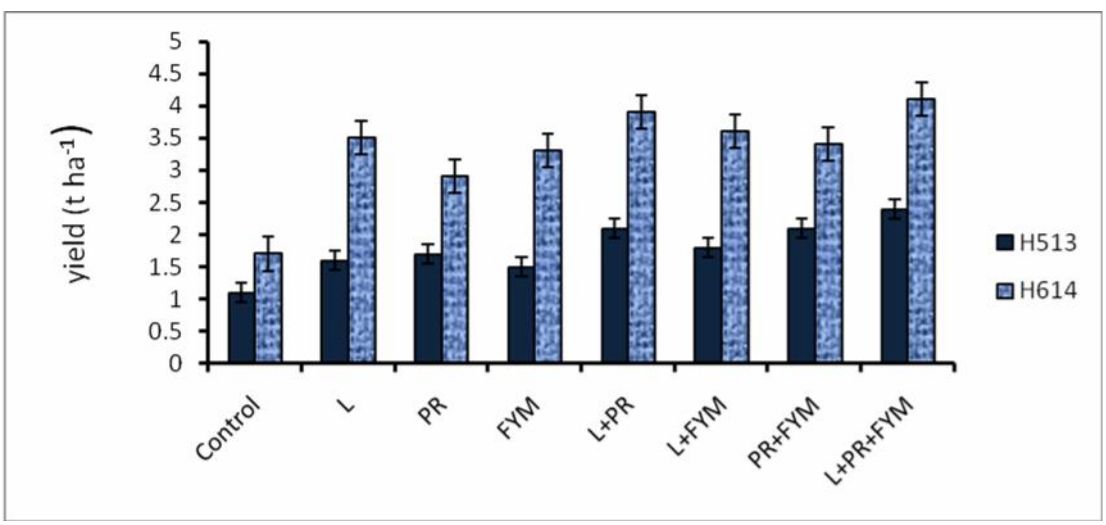

Fig. 2. Hybrid maize grain yields in 2010 as influenced by soil amendments

Higher grain yield of hybrid maize H614 could be attributed to its superior N uptake (Table 6) that subsequently translated to higher yields. N has for long been considered the most influential macronutrient for maize grain yields [63,64]. In a study to determine comparative performance of advanced generations of maize hybrids with a local maize variety in Western Kenya, Macharia et al. [65] observed greater hybrid maize H614 yields (2846 tha-^{1}) than H513 (2641 tha-^{1}) across sites.

The observed grain yield increases with combined application of amendments over control treatment was attributed to increased available N in soil due to improved soil conditions i.e. favourable soil pH and enhanced N mineralization and subsequent uptake by maize. The amelioration of soil acidity after application of L and PR provided a conducive environment for nitrifyers. Nekesa et al. [57] studying the effects of applying Minjingu phosphate rock and agricultural lime to acid soils of western Kenya on yields of maize-bean intercrop observed that amending soil acidity with L and PR gave significant ($P<.05$) maize yield increases above the control. The et al. [66] working on acid soils of Cameroon, reported highest maize yields where L and chicken manure were combined.

The higher maize grain yield in 2010 can partly be explained by residual effects of amendments and maintenance of organic matter through addition of maize residues, senescent leaves and sloughed off roots. Soil organic matter (SOM) is crucial because of its role in maintaining soil fertility and soil structure. Nutrients are stored in the organic form (N, P, and S) and are held in mineral form on exchange sites of SOM [67]. Nekesa et al. [57] reported that soil at the end of second cropping season showed improved conditions. They reported that the second season entirely depended upon residual effect of minjingu PR and agricultural L from the first season. Lime materials have residual effects since they take much longer time in the soil ecosystem [57]. PR can persist in the soil for as long as 10 consecutive seasons [68]. The higher mean annual rainfall amounts received in 2010 (1120 mm) than 2009 (917 mm) may have also played a role. Water is often considered to be the principal factor limiting crop production in rain-fed agriculture [52].

4. CONCLUSION

The application of soil amendments resulted in significant increases in SMB - C and N, available N and N uptake and grain yields of maize over the control. The effect was greater when amendments were combined. All measured parameters were higher in the second year.

The maize hybrids differed in acquisition of N from soil and grain yields. N uptake and grain yields of hybrid maize H513 were lower than H614. The hybrid maize H614 grain yields were significantly higher in L+PR+FYM treatment in 2009 and in L+PR+FYM and L+PR treatments in 2010. For hybrid maize H513 the yields were significantly higher in L+PR+FYM and L+PR treatments in both years. The addition of L+PR+FYM to the acid soils of Molo is a feasible trajectory for improved SMB-C and N, available soil N and uptake and consequently higher yields of maize. Although the hybrid maize H513 gave lower yields, it is recommended for planting in the County considering the reducing rainfall amounts coupled with changing and unpredictable weather seasons. Farmers could thus prefer H513 for its early maturity; maturing when food is scarce, and would escape dry spell effects better than H614 to produce economically acceptable maize grain yield.

CONSENT

Not applicable.

ETHICAL APPROVAL

Not applicable.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Onwonga RN, Lelei J, Freyer B, Friedel JK, Mwonga SM, Wandahwa P. Low cost techniques for enhancing N and P availability and maize (*Zea mays* L.) performance on acid soils. World J. of Agric. Sci. 2008;4(S):862-873.
2. Lukin V, Epplin FM. Optimal frequency and quantity of agricultural lime applications. Agr. Syst. 2003;76:949-967.
3. Yamoah C, Ngueguim M, Ngong C, Dias DKW. Reduction of P fertilizer requirements using lime and mucuna on high P sorption soils of North West Cameroon. Afr. Crop Sc. J. 1996;4:441-451.
4. Rousk J, Brookes PC, Baath E. Contrasting soil pH effects on fungal and bacterial growth suggests functional redundancy in carbon mineralization. Appl Environ Microbiol. 2009;75(6):1589–1596.
5. Garcia C, Hernandez T, Roldan A, Martin A. Effect of plant cover decline on chemical and microbiological parameters under Mediterranean climate. Soil Bio. and Biochem. 2002;34:635-642.
6. Witter E, Martensson AM, Garcia FV. 1993. Size of the soil microbial biomass in a long-term field experiment as affected by different nitrogen fertilizer and organic manures. Soil Biol. Biochem. 1993;25:659-669.
7. Lovell RD, Jarvis SC, Bardgott RD. Soil microbial biomass and activity in long-term grassland: Effects of management changes. Soil Biol. Biochem. 1995;27:969-975.
8. Coleman DC, Reid CP, Cole C. Biological strategies of nutrients cycling in soil systems. Volume 13 of Advances in ecological research; 1983.
9. Smith KA, Li S. Estimation of potentially mineralizable nitrogen in soil by KCl extraction: I. Comparison with pot experiments. Plant Soil. 1993;157:167-174.
10. Marschner H. Mineral Nutrition of Higher Plants. Acadmic Press, London. 1986;674.
11. Sigunga DO, Janssen BH, Oenema O. Effects of improved drainage and nitrogen source on yields, nutrient uptake, and utilization efficiencies by maize (*Zea mays* on Vertisols in sub-humid environments. Nutrient Cycling in Agroecosystems. 2002;62:263-275.

12. Weber G, Chude V, Pleysier J, Oiketh S. On farm evaluation of nitrate nitrogen dynamics under maize in the northern guinea savanna of Nigeria. Expl. Agric. 1995;31:333–344.
13. Kiiya WW, Onyango RM, Mwangi T, Rono. S, Cheruiyot D. Effect of organic and inorganic fertilizers on the performance of maize in north of Rift Valley province of Kenya. p. 1-10. In: Mureithi, JG, Mwendia CW, Muyekho FN, Anyango MA and Maobe SN (editors). Participatory technology development for soil management by smallholders in Kenya. A compilation of selected papers presented at the soil management and legume research network projects conference, Kanamai, Mombasa, Kenya. 2000;24-26.
14. Kiiya WW, Onyango RMA, Mwangi TJ, Ng'eny JMA. Participatory verification of maize varieties for lower highland and upper midland transition zones of the North Rift of Kenya. In: Mureithi JG et al, Editors. Participatory Technology Development for soil management by smallholders in Kenya. Proceedings of the 2nd Scientific Conference of the Soil Management and Legume Research Network Projects, Mombasa. Kenya; 2000.
15. Jaetzold R, Schimdt H, Hornetz B, Shishanya C. Farm Management Handbook of Kenya. Natural Conditions and Farm Mannegement Information. Volume IIA. Nairobi Kenya. 2007;319.
16. Landon JR. Booker Tropical Soil Manual. A Handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman Scientific and Technical Essex, New York. 1991;474.
17. FAO-UNESCO. FAO-UNESCO Soil map of the world. Revised legend. World resources. Report 60, FAO. Rome; 1990.
18. M'mboyi F, Mugo S, Mwimali M, Ambani L. Maize Production andImprovement in Sub-Saharan Africa. African Biotechnology. Stakeholders Forum (ABSF). Nairobi, Kenya; 2010.
19. Walkley A, Black CA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method; Soil Sci. 1934;37:29–38.
20. McLean E. Aluminum. In: Black CA, Editor. Methods of Soil Analysis. Agron. No. 9. Part II. Am. Soc. Agron, Madison, Wisconsin. USA. 1965;978–998
21. Chapman RD. Cation exchange capacity by ammonium saturation. In: Black CA, editor. Methods of Soil Analysis. Agron. Part II. Am. Soc. Agron. Madison; 1965;(9):891–901.
22. Okalebo JR, Gathua KW, Woomer PL. Laboratory methods of plant and soil analysis: a working manual, 2nd edn. TSBF-UNESCO. Nairobi; 2002.
23. Vance ED, Brookes PC, Jenkinson DS. An extraction method for measuring soil biomass-C. Soil Biol. Biochem. 1987;19:703–707.
24. Miller L, Houghton JA. The micro-kjeldahl determination of the nitrogen content of amino acids and proteins. J. Biol. Chem. 1945;159:373-383.
25. Peterburgski AV. Practical Guidance on Agro-chemistry. Kolos Publ., Moscow; 1986.
26. Brookes PC, Kragt JF, Powlson DS, Jenkinson DS. Chloroform fumigation and the release of soil nitrogen: the effects of fumigation time and temperature. Soil Biol. Biochem. 1985;17:831–835.
27. SPSS. Statistical package of the social sciences vol. 10.0. SPSS Inc., Chicago, Illinois; 1999.
28. Brookes PC. The soil microbial biomass concept, measurement and applications in soil ecosystem research. Microbes and Environ. 2001;16;131-140.

29. Snyder CS, Bruulsema TW, Jensen TL, Fixen PE. Review of green house gas emissions from crop production systems and fertilizer management effects. Agric. Ecosyst. Environ. 2009;133:247-266.
30. Kamoni PT, Mburu MWK, Gachene CKK. Influence of irrigation on maize growth, grain yield and nitrogen uptake in a semi-arid environment in Kenya. Paper presented to Soil Science Society of East Africa (SSSEA) conference held in Mombasa, Kenya, 27 November.1 December 2000. SSSEA/ KARI. Nairobi; 2000.
31. Tejada M, Herna´ndez MT, Garcı´a C. Application of two organic amendments on soil restoration: effects on the soil biological properties. J. Environ. Qual. 2006;35:1010–1017.
32. Adeboye MKA, Iwuafor ENO. Soil microbial biomass and water-soluble organic carbon in crop rotation systems in a moist tropical savanna alfisol Nig. J. Soil & Env. Res. 2007;7:45-52.
33. Yang K, Zhu J, Zhang M, Yan Q, Sun OJ. Soil microbial biomass carbon and nitrogen in forest ecosystems of Northeast China: a comparison between natural secondary forest and larch plantation. J. of Plant Eco. 2010;3:175–182.
34. Fontaine S, Barot S, Barre´ P, et al. Stability of organic carbon in deep soil layers controlled by fresh carbon supply. Nature. 2007;450:277–81.
35. Griffiths BS, Ritz K, Ebblewhite N, et al. Soil microbial community structure: effects of substrate loading rates. Soil Biol Biochem. 1999;31:145–53.
36. Tu C, Louws FJ, Creamer NG, Mueller JP, Brownie C, Fager K, Bell M, Hu S. Responses of soil microbial biomass and N availability to transition strategies from conventional to organic farming systems. Agric. Ecol. Environ. 2006;113:206-215.
37. Jin H, Osbert JS, Jianfeng, L. Changes in soil microbial biomass and community structure with addition of contrasting types of plant litter in a semiarid grassland ecosystem. J. of Plant Ecol. 2010;3(3):209–217.
38. Mohammadi K, Heidari G, Tahsin M, Nezad K, Ghamari S, Sohrabi Y. soil microbial responses to fertilization and tillage systems in canola rhizosphere. Saudi J Biol Sci. 2012;19(3):377–383.
39. Weil RR. Soil and plant influences on crop response to two African phosphate rocks. Agron. J. 2000;92:1167-1175.
40. Liu DL, Helyar KR, Conyers MK, Fisher R, Poile GJ. Response of wheat, triticale and barley to lime application in semi-arid soils. Field Crops Res. 2004;90:287–301.
41. Sylvia D, Fuhrmann J, Hartel P, Zuberer D. Principles and applications of soil microbiology. Second edition. Prentice Hall, Upper Saddle River, New Jersey, USA; 2004.
42. Ross DJ. Soil microbial biomass estimated by the fumigation-incubation procedures: seasonal fluctuation and influence of soil moisture content. Soil Biol. Biochem. 1987;19:397–404.
43. Campbell CA, Biederbeck VO, Wen G, Zentner RP, Schoenau J. Hahn D Seasonal trends in soil biochemical attributes: effects of crop rotations in the semi- arid prairie. Can. J. Soil Sci. 1999;79:73–84.
44. Logah V, Safo EY, Quansah C, Danso L. Soil microbial biomass carbon, nitrogen and phosphorus dynamics. West Afr. J. of App. Eco. 2010;17:121-133
45. Wong MTF, Nortcliff S. Seasonal fluctuations of native available N and soil management implications. Nutrient Cycling in Agroecosystems. 1995;42(1):13-26
46. Scherer HW, Werner W, Rossbach J. Effects of pre-treatment of soil samples on N mineralization in incubation experiments. Biol. Fertil. Soils. 1992;14:135-139.
47. Birch H. The effect of soil drying on humus decomposition and nitrogen availability. Plant Soil. 1958;10:9–31.

48. Birch H. Nitrification of soil after different periods of dryness. Plant Soil. 1960;12:81–96.
49. Drinkwater LE, Wagoner P, Sarrantonio M. Legume-based cropping systems have reduced carbon and nitrogen losses. Nature. 1998;396:262-265.
50. Jensen LS, Mueller T, Magid J, Nielsen NE. Temporal variation of C and N mineralization, microbial biomass and extractable organic pools in soil after oilseed rape straw incorporation in the field. Soil Biol. Biochem. 1997;29:1043-1055.
51. Ladd JN, Foster RC. Role of microflora in N turnover. In J.R. Wilson (ed.) Advances in nitrogen cycling in Agricultural ecosystems. CABI Publ., Wallingford, UK. 1988;113–129.
52. Gregory PJ, Simmon LP, Warren GP. Interactions between plant nutrients, water and carbondioxide as factors limiting crop yields. Phil. Trans. R. Soc. Lond. 1997;352: 987-996.
53. Warren GP, Atwal SS, Irungu JW. Soil nitrate variations under grass, sorghum and bare fallow in semi arid Kenya. Exp. Agric. 1997;33:321-333.
54. Hartemink RJ, Buresh PM, van Bodegom AR, Braun C, Jama BI, Janssen BH. Inorganic nitrogen dynamics in fallows and maize on an Oxisol and Alfisol in the highlands of Kenya. Geoderma. 2000;98:11–33.
55. Baath E, Anderson TH. Comparison of soil fungal/bacterial ratios in a pH gradient using physiological and PLFA-based techniques. Soil Biol. Biochem. 2003;35:955-963.
56. Lyngstad I. Effect of liming on mineralization of soil nitrogen as measured by plant uptake and nitrogen released during incubation. Plant and Soil. 1992;144:247-253.
57. Nekesa AO, Okalebo JR, Othieno CO, Thuita MN, Kipsat M, Bationo A, Sanginga N, Kimettu, J,Vanlauwe B. The potential of Minjingu phosphate rock from Tanzania as a liming material: Effect on maize and bean intercrop on acid soils of western Kenya African Crop Science Conference Proceedings. 2005;7:1121-1128.
58. Quaggiotti S, Ruperti B, Borsa P, Destro T, Malagoli M. Expression of a putative high-affinity NO_3^-transporter and of aH+-ATPase in relation to whole plant nitrate transport physiologyin two maize genotypes differently responsive to low nitrogen availability. J. of Exper. Botany. 2003; 57:1023-1031.
59. Aflakpui GKS, Gregory PJ, Froud- Williams RI. Uptake and partitioning of nitrogen by maize infected with Striga hermonthica. Ann. Bot. 1998; 81:287-294.
60. Wiren N., Von Gazzarrini S. Frommer WB. Regulation of mineral N uptake by plants. Plant and Soil. 1997;196:191-199.
61. Niu J, Chen F, Mi G, Li C, Zhang F. Transpiration, and Nitrogen Uptake and Flow in Two Maize (Zea mays L.) Inbred Lines as Affected by Nitrogen Supply. Annals of Botany. 2007;99:53–160.
62. Mengel DB, Nelson DW, Huber DM. Placements of nitrogen fertilizers for no-till and conventional till corn. Agron. J. 1982;74:515-518
63. Bruns AH, Ebelhar WM. Nutrient uptake of maize affected by nitrogen and potassium fertility in a humid subtropical environment. Comm. in Soil Sci. and Plant Anal. 2006;37:275–293.
64. Castleberry RM, Crum CW, Krull CF. Genetic yield improvement of U.S. maize cultivars under varying fertility and climatic environments. Crop. Sci. 1984;43:807-817.
65. Macharia CN, Njeru CM, Ombakho GA, Shiluli MS. Comparative performance of advanced generations of maize hybrids with a local maize variety: Agronomic and financial implications for smallholder farmers. Agron. J. of Animal Plant Sci. 2010;7(2):801-809.

66. The C, Calba H, Horst WJ, Zonkeng C. Three years performance of a tolerant and a susceptible maize cultivar on non-amended and amended acid soil. In: Horst WJ, et al, editors. Plant nutrition – Food security and sustainability of agro-ecosystems. 984~985. Kluwer Academic Publishers. Printed in the Netherlands; 2001
67. Veldkamp E. Changes in soil carbon stocks following conversion of forest to pasture in the tropics. In: Holland EA, editor. Notes from Underground, Soil Processes and Global Change. NATO ASI Series Berlin, Springer, in press. Vladimir V, Francis L. Epplinb M. 2003. Optimal frequency and quantity of agricultural lime applications Agric. Syst. 1999;76:949–967.
68. Noordin Q. Icraf's Soil Fertility Management Strategies For western Kenya. In: Musyoka WM, Mukhwana, EJ, Woomer, PL, editors. Soil Fertility Management in Western Kenya. Stakeholders Workshop Proceedings; 3rd Nov; 2002.

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