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Full Length Research Paper

Effects of crop rotation on soil macronutrient content and pH in potato producing areas in Kenya: Case study of KARI Tigoni station

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Proper crop rotation might help to conserve soil fertility among small scale potato farmers in Kenya. A study was carried out at KARI Tigoni station between April 2007 and May 2010 to evaluate the effect of crop rotation on soil pH and macro nutrient levels. Rotations involved maize, potatoes and cabbages. Results showed that, soils at KARI Tigoni station are generally acidic with pH ranging from 4.3 (extreme acidity) to 5.59 (medium acidity). Cultivation reduced pH further probably due to increased organic matter decomposition. Percent organic carbon was low and was significantly (P = 0.05) increased by the rotation. Percent total nitrogen was adequate for potato production. Phosphorus was generally low. Proper crop rotation should be employed which should include a legume. This study should be carried out over a longer period of time to get more comprehensive results.

Key words: Crop rotation, soil pH, soil macronutrients; potato production, KARI Tigoni.

INTRODUCTION

Crop rotations are effective in improving soil physical, chemical and biological characteristics (Verma and Shekhawat, 1991). The physical characteristics include increased soil aggregate stability, decreased crusting of soil surfaces, increased granular structure and friable consistence (Bullock, 1992). Rotations that include sod, pasture, or hay crops also help to decrease bulk soil density, which can greatly impede root growth and nutrient flow (Tian et al., 2000). The effect of crop rotations on soil nitrogen (N), phosphorous (P), potassium (K) and carbon (C) is very complex (Bullock, 1992). It has been reported that including deep-rooted cover crops in rotations helps to distribute phosphorous and potassium from deep within the soil profile to the soil surface, where plant roots have better access to them (Marschner, 1990; Clark et al., 1998).

A shallow-rooted crop like onions or carrots, may be followed by a deeper-rooted crop like maize to recover nutrients that were unused by the shallow feeders and may have leached by irrigation or rainfall to lower depths in the soil profile. Conversely, a deep-rooted heavy feeder may be followed by a shallow-rooted light feeder to scavenge nutrients that may remain after heavy applications of nutrients (Clark et al., 1998; Bullock, 1992). Examples of heavy feeders are maize, potatoes, vegetables and soybeans while light feeders include grass sods, legume sods, wheat, barley and oats (Clark et al., 1998). Table 1 shows the effective root zone depth (in inches) of some commonly grown crops.

In addition, legumes in crop rotations supply biologically fixed atmospheric nitrogen to the soil thus as a replacing or supplementing inorganic nitrogen fertilizer. The amount of nitrogen in legume cover crops varies among species, but legumes generally contribute 50 to 200 pounds of nitrogen per acre (Flint and Roberts, 1988; Clark et al., 1998). This nitrogen is mineralized over an extended period of time, so that any surplus of it does not readily run off into streams and underground water supplies. Researchers estimate that from 40 to 75 percent of the total nitrogen contained in a legume cover crop is available in the soil for subsequent crops,

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Table 1. Effective root zone depth (in inches) of some commonly grown crops.

Field crops	Vegetable crops	Forage crops	Fruit crops
Barley, 24	Asparagus, 24	Alfalfa, 24	Apples, 24
Maize (field), 24	Beets, 12	Bluegrass, 18	Blueberries, 18
Cotton, 24	Broccoli, 12	Bromegrass, 24	Cane fruits and grapes, 18
Flax, 24	Cabbage, 12	Ladino clover, 18	Peaches, 18
Oats, 24	Cantaloupes, 18	Orchardgrass, 24	Pears, 18
Peanuts, 24	Carrots, 12	Red and sweet clovers, 24	Strawberries, 6
Rye, 24	Cauliflower, 12	Sudan grass, 24	
Sorghum, 24	Celery, 12	Ryegrass, 24	
Soybeans, 24	Corn (sweet), 24	Bermuda grass, 18	
Sunflower, 24	Cucumbers, 18	Tall fescue, 18	
Tobacco, 18	Kale, 18		
Wheat, 24	Lettuce, 6		
	Lima beans, 18		
	Onions (bunch), 6		
	Onions (dry),12		
	Peas, 18		
	Peppers, 18		
	Potatoes, 18		
	Radish, 6		
	Beans, 18		
	Spinach, 6		
	Squash, 18		
	Tomatoes, 18		
	Watermelons, 24		

Source: Flint and Roberts, 1988.

depending on environmental conditions (Clark et al., 1998; Utomo et al., 1992). Legume cover crops may contribute from 30 to 60 kgN/ha (Utomo et al., 1992) to 110 kgN/ha (Marschner, 1990; Tian et al*.,* 2000) to the subsequent maize compared to continuously grown maize. Thus proper crop rotation especially with inclusion of a legume might help to conserve soil fertility in small scale farms managed by resource poor potato farmers in Kenya. Low soil fertility among small scale potato farmers in Kenya is mainly caused by continuous cultivation without a fallow period (Kiiya et al., 2006). This is worsened by inadequate crop rotation due to small farm sizes (Kaguongo et al., 2008).Crop rotations practiced in potato growing parts of Kenya mainly involve maize, cabbages and potatoes in that order or an intercrop of maize and beans or potatoes and beans (Kanyanjua and Agaya, 2006). Besides this rotation, fertilizers are usually applied below the recommended rate for potato production (90 kg N ha^{-1} + 230 kg P_2O_5 ha^{-1}) (Kaguongo et al., 2008).

Furthermore, application of organic matter to the fields is limited since crop residues are used as fodder; where cattle manure is used, the quantities applied are below the recommended rates and the quality is questionable Kanyanjua and Agaya, 2006). Nitrogen and phosphorus are the major nutrients limiting potato production in Kenya (Recke et al., 1997). Soil phosphorus in major potato growing parts of Kenya is as low as 2.9 ppm (modified Olsen) while total nitrogen may be lower than 0.15% (Recke et al., 1997). In addition to low soil fertility, high soil acidity limits potato production in Kenya. The high soil acidity is mainly caused by acidic parent rock and the situation maybe worsened by continuous application of Di-ammonium phosphate (DAP) ($18N:46P_20_5$) fertilizer (Kiiya et al., 2006). Most of potato growing areas in Kenya have a soil pH of less than 5.5 while values of 4 to 5 are most common (Recke et al., 1997; Kiiya et al., 2006). A pH of less than 5.5 severely limits availability of potassium, nitrogen, phosphorus, sulphur, calcium and magnesium, and excessive levels of aluminum, manganese, boron, iron copper and zinc (Recke et al., 1997; Kanyanjua and Agaya, 2006).

At the Kenya Agricultural Research Institute (KARI) Tigoni station, crop rotation involves potatoes, maize, and cabbages in any order and the fields are rarely fallow. In addition, DAP ($18N:46P_20_5$) is the only fertilizer used in all these crops. Cattle manure is not used because the quantities needed would be too high and are unavailable (Kaguongo et al., 2008). Continuous use of DAP might have partly contributed to high acidity at the station.

The situation might have been worsened by the fact that the soil type at KARI Tigoni is nitisol which is inherently acidic (Recke et al., 1997; Kanyanjua and Agaya, 2006; Jaetzold et al., 2006). Guided by this background, a study was initiated at KARI Tigoni station in 2007. The objective of the study was to evaluate the effect of crop rotation on soil pH and macro nutrient levels at KARI Tigoni.

MATERIALS AND METHODS

The KARI-Tigoni station is located 40 km North-west of Nairobi city center, at an altitude of 2131 masl, latitude of 1°15' S and longitude 23° 46' E (Jaetzold et al., 2006). The average annual rainfall is 1096mm with a bimodal distribution. Long rains season occurs between March and May while short rains season is between October and December (Jaetzold et al., 2006). The mean annual air temperature is 18℃ ranging between 12 and 24℃. The soil type is humic nitosol (alfisol) derived from quartz trachyte (Jaetzold et al., 2006). The soil is very deep and well drained with a pH range of 5.5 to 6.5. The soil is of medium inherent fertility with organic carbon content of 1.65%. Exchangeable bases of potassium, calcium and magnesium are moderate to high with available potassium being about 21.2 ppm (Jaetzold et al., 2006).

The experimental field at the station which is (approx. 15 hectares) was divided into 20 rotation blocks based on the crop rotations that were planted. Crop rotation program which is normally employed at KARI Tigoni was monitored for six consecutive seasons. This includes maize, potatoes and cabbages. The DAP ($18N:46P_20_5$) was applied on these crops at the recommended rates. Long rains season crop was planted in April and harvested in August while short season crop was planted in October and harvested in February. The uncultivated blocks served as the control. The experiment ran from April 2007 to May 2010. Soils were sampled and analyzed for macronutrients and pH after every two seasons on March 2008, March 2009 and March 2010. In each block, 15 to 20 soil cores were taken depending on block size. These soil cores were then bulked, thoroughly mixed and a sample of about 0.25kg was taken for analysis to represent the block. Soil samples were taken from 0 to 25cm depth using a hand hoe. The samples were air dried and sieved with a 2mm sieve and then sent for laboratory analysis within the same day. Soil pH was determined in water (1:2.5 soil to water ratio) with the ELL glass-electrode pH meter (Maclean, 1965). Organic carbon (OC) was determined using dichromate wet oxidation method (Walkey and Black, 1934) as modified by Piper (1942). Total nitrogen (N) was determined using the macro Kjeldahl method as described by Jackson (1958). Available phosphorus (P) was determined using Bray II method as described by Bray and Kurtz (1945). Exchangeable acidity was determined by the titration method (Anderson and Ingram, 1993). Exchangeable cations (K and Ca) were extracted with ammonium acetate and then determined with a flame photometer (Anderson and Ingram, 1993).

Trends in change of pH and macronutrients were assessed between the two sampling interval i.e. 2008 to 2009 and 2009 to 2010. In all the rotation blocks that showed an increase in pH and macronutrient in the two sampling intervals, the % increase in pH and macronutrients was calculated and subjected to analysis of variance. Analysis of variance was done in a randomised complete block design where the two sampling intervals were the blocks and the rotation blocks were the treatments.

RESULTS AND DISCUSSION

Crop rotation pattern in the station for three years is shown in Table 2. This rotation did not include a legume. The soils are generally acidic (Table 3). This was expected since the inherent soils, the nitisols, are acidic. The pH ranged from 4.3 (extreme acidity) to 5.59 (medium acidity). There was no definite trend in change in pH over time although the uncultivated area (F9 and F10) had higher pH than the cultivated area (Table 3). Cultivation is likely to increase soil acidity due to increased oxidation of organic matter (Bullock, 1992). The rotation program as well the sampling intervals did not significantly ($P = 0.05$) increase soil pH (Table 5a) although F5A gave the highest percent increase (Table 5b). Percent organic carbon was low although there was a general increase over time (Table 3). Low organic carbon was probably due to continuous cropping coupled with removal of crop residues and no use of organic manures.

However, the general increase in organic carbon in this study was probably due to increase in organic matter, probably from increases in plant roots resulting from continuous application of DAP. The rotation program used as well as sampling time led to a significant ($P = 0.05$) increase in soil organic carbon (Table 6). Percent total nitrogen was adequate and there was a general increase over time (Table 4). The seemingly adequate and increasing levels of nitrogen were probably due to continuous use of DAP in high doses on short duration crops leading to build-up of residual effect. The % increase in nitrogen was significantly different ($P = 0.05$) for the various rotation blocks (Table 8). There was no definite trend in phosphorus changes over time although there was a general decline (Table 4). Where there was an increase, the percent increase was also not significant (Table 7a and b). This was unexpected because it was assumed that continuous application of DAP, as practiced in the experimental field, would lead to an accumulation of phosphorus. Maybe this will be achieved in the long run. There was a general increase in potassium and calcium over time (Table 4). Percent increase in potassium was not significant for the rotation blocks (Table 9). Percent increase in Calcium was significant for the rotation blocks (Table 10).

Nitrogen and phosphorus are the two nutrients limiting potato production in the Kenyan highlands (Recke et al., 1997). The rotations used in this study did not show any significant increase in either nitrogen or phosphorus. Maybe the study needs to be carried out over a longer period of time to come up with conclusive results.

RECOMMENDATIONS

Proper crop rotation should be employed which should include a legume. Less acidifying fertilizers such Single Superphosphate, Triple Super Phosphate or NPK should be used instead of DAP since the soil is inherently acidic. Well decomposed manure or compost should be applied. This study should be carried out over a longer period of

Table 2. Crop rotations at KARI Tigoni station.

Block	Crop rotation					
	Long rains crop 2007	Short rains crop 2007	Long rains crop 2008	Short rains crop 2008	Long rains crop 2009	Short rains crop 2009
F1A	Cabbages	Potatoes	Maize	Cabbages	Potatoes	Maize
F1(a)	Maize	Potatoes	Maize	Potatoes	Maize	Potatoes
F1B	Cabbages	Potatoes	Maize	Cabbages	Potatoes	Maize
F1(b)	Potatoes	Maize	Maize	Potatoes	Maize	Potatoes
F1C	Cabbages	Potatoes	Potatoes	Cabbages	Potatoes	Maize
F1c	Fallow	Fallow	Fallow	Fallow	Potatoes	MAIZC Cabbages
F2	Fallow	Potatoes	Maize	Potatoes	Maize	Maize
F3	Potatoes	Maize	Fallow	Cabbages	Fallow	Potatoes
F4	Cabbages	Fallow	Potatoes	Flowers	Flowers	Flowers
F5A	Flowers	Flowers	Flowers	Flowers	Flowers	Flowers
F5B	Flowers	Flowers	Flowers	Flowers	Flowers	Flowers
F5C	Flowers	Flowers	Flowers	Flowers	Flowers	Flowers
F6A	Flowers	Flowers	Cabbages	Cabbages	Potatoes	Maize
F6B	Cabbages	Potatoes	Cabbages	Cabbages	Potatoes	Maize
F7A	Cabbages	Potatoes	Potatoes	Cabbages	Potatoes	Potatoes
F7B	Cabbages	Potatoes	Potatoes	Potatoes	Fallow	Potatoes
F7C	Potatoes	Fallow	Potatoes	Fallow	Fallow	Potatoes
F8	Fallow	Fallow	Fallow	Potatoes	Maize	Maize
F9	Uncultivated	Uncultivated	Uncultivated	Uncultivated	Uncultivated	Uncultivated
F10	Uncultivated	Uncultivated	Uncultivated	Uncultivated	Uncultivated	Uncultivated

Table 3. Soil pH and % organic carbon concentrations at KARI Tigoni station.

Blocks	Soil pH				% organic carbon			
	2008	2009	2010	Direction of change	2008	2009	2010	Direction of change
F1A	4.81	4.76	4.64	Decrease	1.12	1.28	1.5	Increase
F1(a)	4.82	4.86	4.89	Increase	1.10	1.28	1.51	Increase
F1B	4.71	4.67	4.41	Decrease	1.08	1.27	1.48	Increase
F1(b)	4.71	4.67	4.3	Decrease	1.09	1.27	1.51	Increase
F1C	4.51	4.41	4.73	No trend	0.89	1.17	1.47	Increase
F1c	4.48	4.44	4.41	Decrease	0.92	1.26	1.45	Increase
F2	4.71	4.76	4.9	Increase	1.08	1.29	1.47	Increase
F3	5.77	5.72	5.59	Decrease	0.86	1.27	1.66	Increase
F4	4.65	4.81	5.01	Increase	0.76	1.12	1.59	Increase
F5A	4.72	4.81	5.54	Increase	0.98	1.31	1.6	Increase
F5B	4.84	4.81	4.78	Decrease	1.02	1.31	1.69	Increase
F5C	5.32	5.38	5.52	Increase	0.66	1.31	1.86	Increase
F6A	4.80	4.82	4.84	Increase	0.91	1.29	1.56	Increase
F6B	4.52	4.65	4.92	Increase	1.02	1.31	1.49	Increase
F7A	4.65	4.75	5.03	Increase	1.12	1.38	1.64	Increase
F7B	4.90	4.94	4.96	Increase	1.21	1.4	1.65	Increase
F7C	5.30	5.02	4.71	Decrease	1.23	1.49	1.65	Increase
F8	4.42	4.46	4.66	Increase	1.02	1.25	1.39	Increase
F9	5.71	5.65	5.6	Decrease	0.96	1.55	2.03	Increase
F10	6.22	6.1	5.82	Decrease	0.98	1.58	1.94	Increase

Table 4. Soil macronutrient concentration at KARI Tigoni station.

	Phosphorus (ppm)				Total N %				Potassium (me %)				Calcium (me %)			
Block	**2008**	**2009**	**2010**	**Direction of change**	**2008**	**2009**	**2010**	**Direction of change**	**2008**	**2009**	**2010**	**Direction of change**	**2008**	**2009**	**2010**	**Direction of change**
F1A	12	23	52	Increase	0.15	0.25	0.31	Increase	1.33	1.39	1.43	Increase	3.8	4.2	4.7	Increase
F1(a)	26	23	13	Decrease	0.15	0.25	0.32	Increase	1.19	1.39	1.52	Increase	4.3	4.2	3.7	Increase
F1B	29	27	24	Decrease	0.14	0.25	0.31	Increase	1.25	1.35	1.52	Increase	3.9	4.0	4.1	Increase
F1(b)	31	27	26	Decrease	0.22	0.25	0.28	Increase	1.15	1.35	1.62	Increase	4.2	4.0	3.7	Decrease
F1C	26	21	13	Decrease	0.33	0.36	0.38	Increase	1.09	1.29	1.68	Increase	3.2	3.2	4.9	Increase
F1c	25	19	11	Decrease	0.33	0.33	0.38	Increase	1.11	1.31	1.74	Increase	2.6	3.4	4.3	Increase
F2	31	22	11	Decrease	0.36	0.34	0.32	Decrease	1.03	1.23	1.46	Increase	2.9	3.4	4.7	Increase
F3	38	29	22	Decrease	0.33	0.33	0.35	Increase	1.19	1.59	2.06	Increase	6.3	6.6	6.9	Increase
F4	19	18	18	No trend	0.30	0.31	0.35	Increase	1.15	1.35	2.02	Increase	3.5	4.8	7.1	Increase
F5A	12	18	61	Increase	0.29	0.31	0.33	Increase	1.07	1.37	2.1	Increase	4.2	5.4	7.9	Increase
F5B	17	18	18	No trend	0.28	0.31	0.35	Increase	1.17	1.37	1.6	Increase	4.4	5.4	6.1	Increase
F5C	13	34	72	Increase	0.30	0.31	0.35	Increase	1.27	1.37	2.22	Increase	3.2	5.4	9.1	Increase
F6A	39	27	18	Decrease	0.30	0.31	0.31	Increase	1.03	1.03	1.2	Increase	4.2	4.0	4.7	No trend
F6B	37	22	13	Decrease	0.28	0.31	0.32	Increase	0.91	0.97	1.08	Increase	3.0	3.2	3.3	Increase
F7A	11	16	28	Increase	0.30	0.33	0.37	Increase	1.13	1.43	1.72	Increase	2.1	3.4	5.7	Increase
F7B	22	19	15	Decrease	0.32	0.35	0.37	Increase	1.19	1.49	1.82	Increase	4.3	4.8	5.1	Increase
F7C	13	17	21	Increase	0.30	0.32	0.33	Increase	1.29	1.59	1.84	Increase	5.2	5.5	6.3	Increase
F8	23	21	20	Decrease	0.30	0.31	0.31	Increase	1.21	1.21	1.12	Decrease	4.0	4.0	4.6	Increase
F9	11	16	24	Decrease	0.52	0.52	0.66	Increase	1.81	1.91	2.02	Increase	4.1	5.4	6.9	Increase
F10	17	23	31	Decrease	0.44	0.49	0.55	Increase	1.49	1.69	1.92	Increase	4.3	5.2	6.1	Increase

Table 5a. Analysis of variance for % pH increase.

Variate: % pH increase Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sampling intervals	1	36.367	36.367	4.51	0.063
Rotation blocks	9	108.092	12.010	1.49	0.281
Residual	9	72.605	8.067		
Total	19	217.064			

Table 5b. Table of means for % pH increase.

Grand mean 2.09							
Rotation blocks	F1 (a)	F4	F22	F5A	F5C	F6A	F6B
	0.72	3.80	2.00	8.54	1.87	0.42	4.34
Rotation blocks	F7A	F7B		F8			
	4.02	0.61		2.69			

Table 6. Analysis of variance for % increase in % organic carbon content.

Variate: % increase in % carbon					
Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Sampling intervals	1	1508.0	1508.0	12.72	0.002
Rotation blocks	19	7686.3	404.5	3.41	0.005
Residual	19	2252.4	118.5		
Total	39	11446.7			

Table 7a. Analysis of variance in % increase in phosphorus.

Variate: % increase in phosphorus					
Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Sampling intervals	1	2922	2922	1.18	0.31
Rotation blocks	7	36502	5215	2.10	0.174
Residual	7	17355	2479		
Total	15	56779			

Table 7b. Tables of means in % increase in phosphorus.

Grand mean 72							
Rotation blocks	F1A	F5A	F5B	F5C	F7A	F7C	F9
	109	144	14	137	60	27	48
Rotation blocks	F10						
	35						

Table 8. Analysis of variance in % increase in nitrogen.

Variate: % increase in nitrogen					
Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Sampling intervals	1	284.4	284.4	1.55	0.23
Rotation blocks	18	8413.8	467.4	2.54	0.027
Residual	18	3306.5	183.7		
Total	37	12004.7			

Table 9. Analysis of variance for % potassium increase.

Variate: % increase in nitrogen					
Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Sampling intervals	1	398.9	398.9	3.07	0.098
Rotation blocks	17	3661.5	215.4	1.66	0.153
Residual	17	2206.2	129.8		
Total	35	6266.5			

Table 10. Analysis of variance for % increase in Calcium.

Variate: % increase in nitrogen					
Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Sampling intervals	1	39.31	39.31	1.01	0.33
Rotation blocks	14	12134.18	866.73	22.30	<.001
Residual	14	544.11	38.86		
Total	29	12717.60			

time to get more comprehensive results.

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