MACRO AND MICRO-NUTRIENT STATUS OF SELECTED KENYA SOILS

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ABSTRACT

Over the years there has been a decline in soil fertility in Kenya, which is responsible for low crop yields. Macro and micronutrients should be added to the soil as they ensure healthy produce by supplying the right balance of nutrients to the soil. Most farmers rely on nutrient recycling in their farms which is not sustainable as it leaves the soils depleted of nutrients. A study was therefore conducted to assess the limiting nutrients of soils in Coastal, Eastern, Rift Valley and Western parts of Kenya. Twenty-three soil samples (0 to 30 cm) from 13 counties were collected and evaluated for total nitrogen, total organic carbon, phosphorus, potassium, calcium, magnesium, manganese, copper, iron, zinc, sodium, electrical conductivity, cation exchange capacity (CEC), base saturation and soil pH. The mean values were 0.12%, 1.12, 19.09, 220.43, 1397.39, 163.98, 120, 52, 3.95, 52.78, 1.86, 92.80 mg/kg, 0.11mS/c, 11.98 Cmol (+)/kg, 83.13% and, 5.96, respectively. The soil analysis results indicated that nitrogen, phosphorous and zinc were deficient in most soils in Kenya. Nitrogen and carbon were positively correlated with each other ($P \leq 0.01$). Phosphorous on the other hand was negatively correlated with carbon and nitrogen. Zinc was negatively correlated with soil pH. The exchangeable bases showed significant correlation with each other. It was evident that the inadequate nutrients need to be considered and supplied for restoration of soil fertility and productivity.

Key words: Soil fertility, macro nutrients, micro nutrient status, Kenya.

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INTRODUCTION

In Kenya, agriculture is the backbone of the country's economy which provides livelihood and income for more than 80% of the population. Therefore, agricultural sector is among the key drivers to deliver 10% annual economic growth stipulated in the economic pillar of Vision 2030. Maize is the staple food for Kenya and many parameters affect its production. Gradients of soil fertility within smallholder African farms are the consequence of short and long-term processes associated with land use and management practices, often operating over inherently heterogeneous soil qualities (Tittonell *et al*., 2006). These parameters include the inherent soil condition, cultivar type and environmental condition. In the inherent soil parameter; texture, CEC, soil organic carbon (SOC), N, P, K, soil depth, slope angle, soil moisture, and bulk density play a major role in successful crop production. Cultivar type or variety breeder characteristics and other factors like optimum areas for production, nutrients uptake, response to sunlight or rain precipitation, height/leaf ratio and roots establishment can affect yield. Agro-ecological zones (AEZ) determines the suitable areas for production and include altitude, rainfall and its distribution, sunshine hours' and evapotranspiration rate. Apart from the biophysical parameters, socioeconomic parameters have been shown to influence maize yield. These include but not limited to; planting time, weeding, past management practices, farmers' knowledge, the ability to purchase inputs and access to agricultural extension information. Under optimum soil fertility condition, availability of essential nutrients have been shown to have profound effect on yield (Stewart, 2022).

Poor soil fertility and soil heterogeneity have however, partly contributed to reduction in maize production over the years. The amount of nutrients removed by crop harvests is usually greater than the amount returned as fertilizers. In Kenya, for example, there is an average yearly net mining of 42 kg N/ha, 3 kg P/ha and 29 kg K/ha from the soil (Smaling, *et al.* 1993). There is need for farmers to increase the amount of manure and fertilizers applied to the soil due to poor soil fertility. This, however, is not the case as studies have shown that fertilizer use in Sub Saharan Africa remains low despite the resolution to increase fertilizers use to at least 50 kg/ha (IFDC , 2006). The usage of fertilizer in Sub Saharan Africa is considered the lowest worldwide with an estimate of 8 kg/ha, which is only 10% of the world average (Maatman *et al.,* 2007). High prices of fertilizers have made it difficult for most smallholder farmers to purchase imported fertilizers (Sanchez *et al*., 1997; Bumb *et al.,* 2011). This has contributed to the heterogeneity in farms as most farmers are not applying the fertilizers as recommended. Most of the fertilizer recommendations are based on soil analysis results carried in 1990s, which have since become obsolete (Muya *et al*., 2014). Therefore, the limited quantities of mineral fertilizers which farmers have access to should be pinpointed to niches of highest crop responsiveness (Zingore *et al*., 2007). There is need to conduct soil tests to correlate and calibrate the plant availability of macro and micro nutrients for site and field specific fertilizer recommendations in Kenya. The main objective of this study was to assess the macronutrient and micronutrient status of major agricultural soils and obtain information required for the evaluation of the most limiting nutrients hence the potential fertilizer recommendations in Kenya.

MATERIALS AND METHODS

Site selection and soil sampling

The soils were collected from 23 sites in 13 counties. These were the Kenya Cereal Enhancement Programme sites in Kenya namely: Embu (Agricultural Technology Development Centre (ATDC) Siakago), Bungoma (ATDC, Mabanga), Kibwezi (two sites at the University of Nairobi farm), South Eastern University of Kenya, Kitui (two sites), Nandi (Baraton University), Mwingi (Kyuso university), Taita Taveta (farmers field in Wundanyi, Mwatate and Chala), Voi (farmers field), 11 sites from Kenya Agricultural and Livestock Research Organization (KALRO) stations in Msabaha, Tharaka-Nithi, Kitui, Katumani, Kambi ya mawe, Kiboko, Mtwapa, Matuga, Kitale, Kakamega and Njoro (Table I and Figure 1).

Composite sampling was used, with soils being collected from different points within a sampling area, and a 100 kg constituted from each site. Some soil was sampled from the constitute per site for laboratory analysis. Pearson correlation was used to measure the strength of the linear relationship between various soil properties.

Methods of soil analyses

The soil samples collected were oven dried at 40 ^{0}C, milled and passed through a 2 mm sieve for analysis of available macro and micronutrients following the methods of Hinga *et al*. (1980). The following available nutrient elements were analyzed: C, P, K, Ca, Mg, Mn, Fe, Na, Zn, Cu and total nitrogen. The soil pH was determined in a ratio of 1:1 soil: water (w/v) suspension using a pH meter. The available nutrient elements P, K, Ca, Mg and Mn were extracted using Mehlich Double Acid Method of 0.1 N HCl and 0.025 N H_2SO_4 in a 1:5 soil: volume ratio (w/v) mixture. Ca and K were determined with a flame photometer and P, Mg and Mn were determined calorimetrically. CEC of soil was determined by the Ammonium acetate-KCl method (Mehlich, A. *et al.*, 1962).

The total organic carbon (C) was determined calorimetrically where all organic C in the soil sample was oxidized by acidified dichromate at 150 ^{0}C for 30 minutes to ensure complete oxidation (Anderson and Ingram, 1993).

Total nitrogen was determined using macro-Kjeldahl digestion method where organic nitrogen in presence of H_2SO_4, potassium sulphate (K_2SO_4), and copper sulphate ($CuSO_4$) catalyst, amino nitrogen of many organic materials are converted to ammonium. (Hinga *et al*., 1980; Page *et al*.,1982)

The available trace elements (Fe, Zn & Cu) were extracted with 0.1M HCl in a 1:10 soil: volume ratio (w/v) and determined with Atomic Absorption Spectrophotometer (AAS).

RESULTS AND DISCUSSION

Soil pH

As shown in Table I, soil pH ranged from 4.67 (KALRO Msabaha) to 8.59 (Chala Taita Taveta). The mean pH of the soils was 5.96, which are classified as acidic. In Kenya, the acid soils occupy over 7.5 million hectares of land (Hazelton and Murphy, 2007). Soils from Kibwezi, Chala and Voi were strongly alkaline (Table II).

TABLE I- SITE CHARACTERISTICS OF WHERE SOILS WERE SAMPLED

Sample Site	Latitude	Longitude	Altitude (masl)	Soil type	Rainfall (mm)	Min-Temp (°C)	Max-Temp (°C)
KALRO, Matuga	-4.170172	39.600170	27.00	Gleyic, Luvisols	800-1200	20-23	28-31
KALRO, Mtwapa	-3.937203	39.742103	25.00	Gleyic, Luvisols	800-1200	20-23	28-31
Mwatate	-3.470481	38.400981	860.200	Rhodic, Ferralsols	450-900	20-23	28-31
Voi	-3.394739	38.574961	547.400	Eutric, Fluvisols	300-900	20-23	28-31
Wundayi (Werugha)	-3.376908	38.335617	1647.200	Humic, Cambisols	1000-1600	11-13	23-25
Chala Site	-3.282583	37.740456	894.600	Calcic, Cambisols	450-900	15-17	27-29
KALRO, Msabaha	-3.268474	40.050703	22.00	Gleyic, Luvisols	800-1200	20-23	28-31
KALRO/ICRISAT centre Kambi ya Mawe Makueni	-2.490723	38.040761	865.00	Luvisols	400-600	17-23	29-35
University of Nairobi Kibwezi	-2.310001	38.028503	810.00	Luvisols	400-600	17-23	29-35
University of Nairobi Kibwezi	-2.310001	38.028503	810.00	Luvisols	400-600	17-23	29-35
KALRO, Kiboko	-2.213550	37.714575	929.00	Vertisols	400-600	15-17	27-29
KALRO, Katumani	-1.573069	37.249642	1568.500	Ferric, Acrisols	600-800	11-13	23-25
KALRO Subcenter Kitui Ithokwee	-1.380681	37.969818	1131.00	Ferric, Acrisols	800-1200	15-17	27-29
South Eastern University Kitui	-1.314874	37.757380	1171.00	Ferric, Acrisols	400-600	15-17	27-29
South Eastern University Kitui	-1.314874	37.757380	1171.00	Ferric, Acrisols	400-600	13-15	25-27
Embu, Siakago ATDC	-0.573760	37.637890	1193.00	Ferric, Acrisols	800-1200	15-17	27-29
Kyuso Polytechnic Mwingi	-0.546940	38.214120	889.00	Chromic, Luvisols	400-600	17-23	29-35
Karlo, Njoro	-0.317669	35.938856	2155.00	Mollic, Andosols	800-1200	11-13	23-25
KALRO, Tharaka Nithi	-0.153822	37.971538	588.00	Lixisols	600-800	17-23	29-35
Nandi Baraton University	0.260180	35.083820	1971.00	Humic, Nitisols	1200-1600	11-13	23-25
KALRO, Kakamega	0.282089	34.771296	1525.00	Orthic, Acrisols	1600-2000	15-17	27-29
Bungoma Mabanga ATDC	0.600424	34.622588	1513.00	Acrisols	1200-1600	15-17	27-29
KALRO, Kitale	0.981603	35.016856	1903.00	Rhodic, Ferralsols	800-1200	11-13	23-25

Figure 1: Location map where soils samples were collected

Total Soil Organic Carbon

Total organic carbon varied from 0.21 to 2.80 mg/kg with a mean of 1.12 mg/kg (Table I). Most soils had deficient levels of organic carbon except for KALRO Kakamega which had 2.80% The range shows that the overall organic carbon is deficient in the soils considering the critical value range from 2.66 to 5.32 mg/kg. This concurs with the findings of NAAIAP (2014), where the overall range of soil organic matter content of 75% of the farms sampled in Kenya, was between 0.48 and 2.26%. Organic carbon was positively correlated (r=0.991**) to total nitrogen (Table III). The deficiency in most soils can be attributed to extensive tillage in smallholder farms similar to the report by Pandey *et al*. (2014). Furthermore, it indicates that soil organic carbon losses over years are increasing due to less or non-additions of manure and crop residues to the soil and lack of adoption of conservation farming practices (Branca *et al*., 2013). Soil organic carbon and total nitrogen are most critical indices of soil fertility (Liu *et al.*, 2011) .They are the two major components of soil organic matter which play a key role in crop production and its sustainability (Shibu *et al*., 2012). The C/N ratio in these soils was 9.3 which is way below the normal rating which is between15 to 25.

Total Nitrogen

Total nitrogen varied from 0.04 % (KALRO Mtwapa) to 0.26% (KALRO Kakamega) with a mean of 0.12%. The results given in (Table II) shows that over 98% of the samples had the nitrogen value of less than 0.2% which is below the critical limit, thereby confirming its rating, by NAAIAP (2014) as one of the most limiting nutrients in Kenya, where 86% of the farms sampled country wide were below the critical limit. Nitrogen was deficient in all soils except KALRO Kakamega and Baraton University Nandi considering the critical limit is 0.2 to 0.5%. Total nitrogen was positively correlated to total organic carbon (r=0.991**, Table III).

TABLE II- CHEMICAL ANALYSIS OF SOIL AND MACRONUTRIENTS

Site	Soil PH	N%	C%	p(ppm)	K (ppm)	Ca (ppm)
Ithokwee Kitui KALRO Substation)	5.50	0.09	0.76	15.00	273.00	840.00
South Eastern University Kitui 1	5.21	0.08	0.55	25.00	140.40	600.00
South Eastern University Kitui 2	6.69	0.14	1.44	25.00	117.00	2760.00
Mwatate Taita Taveta	5.40	0.09	0.80	15.00	179.40	800.00
Kibwezi (University of Nairobi 1)	8.35	0.11	0.92	25.00	585.00	2000.00
Kibwezi (University of Nairobi 2)	7.54	0.13	1.12	24.00	460.20	1960.00
Kambi ya Mawe Wote (KALRO/ICRISAT)	5.51	0.08	0.55	20.00	226.20	1180.00
Mwingi Kyuso Polytechnic	5.61	0.06	0.45	20.00	156.00	740.00
KALRO Katumani	5.81	0.10	0.80	5.00	179.40	860.00
KALRO Tharaka Nithi	5.89	0.06	0.40	20.00	132.60	840.00
Embu Siakago ATDC	5.62	0.09	0.69	5.00	140.40	800.00
KALRO Kiboko	5.58	0.08	0.57	20.00	390.00	1600.00
KALRO Msabaha	4.67	0.14	1.54	25.00	117.00	600.00
Chala Taita Taveta	8.59	0.12	1.06	2.00	117.00	5540.00
Wundanyi Taita Taveta	5.20	0.18	1.91	25.00	117.00	600.00
Voi Taveta	8.10	0.13	1.20	18.00	265.20	3400.00
KALRO Mtwapa	6.41	0.04	0.21	30.00	117.00	780.00
KALRO Matuga	5.67	0.09	0.66	25.00	117.00	600.00
KALRO Kitale	4.91	0.15	1.61	20.00	202.80	800.00
KALRO Kakamega	5.08	0.26	2.80	25.00	117.00	1100.00
Bungoma Mabanga ATDC	5.05	0.13	1.19	5.00	117.00	720.00
Baraton University Nandi	4.78	0.21	2.30	20.00	218.40	840.00
KALRO Njoro	5.82	0.19	2.18	25.00	585.00	2180.00
Average	5.96	0.12	1.12	19.09	220.43	1397.39
Adequate level		0.2-0.5	2.66-5.32	30-80	93.6-585	400-3000

TABLE II Contd': CHEMICAL ANALYSIS OF SOIL AND MACRONUTRIENTS

Site	Mg (ppm)	Mn (ppm)	Cu (ppm)	Fe (ppm)	Zn (ppm)	Na (ppm)	S (PPM)	CEC
Ithokwee Kitui KALRO Substation	164.56	195.25	2.66	37.50	1.90	131.1	34.33	7.36
South Eastern University Kitui 1	162.14	96.25	3.32	19.30	0.30	57.50	9.00	6.56
South Eastern University Kitui 2	125.84	222.75	5.36	22.30	0.20	32.20	4.67	23.76
Mwatate Taita Taveta	129.47	137.50	5.45	22.70	0.50	50.60	13.67	10.76
Kibwezi (University of Nairobi 1)	124.63	123.75	5.80	38.40	0.68	273.70	12.00	11.76
Kibwezi (University of Nairobi 2)	121.00	123.75	3.80	23.00	1.36	172.50	8.00	15.20
Kambi ya Mawe Wote (KALRO/ ICRISAT)	140.36	148.50	1.47	25.10	0.34	112.70	16.00	12.80
Mwingi Kyuso Polytechnic	146.41	55.00	4.70	29.70	0.70	32.20	49.67	11.60
KALRO Katumani	156.09	60.50	6.08	32.00	1.15	36.80	5.67	10.00
KALRO Tharaka Nithi	127.05	30.25	1.00	29.50	0.78	62.10	51.43	10.40
Embu Siakago ATDC	135.52	60.50	5.45	31.90	0.67	75.90	3.67	12.80
KALRO Kiboko	121.00	55.00	1.27	20.90	1.45	218.50	11.67	6.36
KALRO Msabaha	176.66	93.50	2.23	17.50	0.47	32.20	7.33	6.00
Chala Taita Taveta	216.59	30.25	4.40	13.60	1.00	23.00	4.33	16.00
Wundanyi Taita Taveta	158.51	44.00	5.40	77.90	1.58	41.40	17.67	9.60
Voi Taveta	490.05	187.00	5.39	147.00	3.89	135.70	7.00	16.60
KALRO Mtwapa	146.41	82.50	1.40	181.00	1.84	55.20	9.00	7.20
KALRO Matuga	180.29	255.75	1.47	18.10	1.27	32.20	14.67	7.60
KALRO Kitale	204.49	148.50	4.30	61.90	1.27	36.80	26.00	16.80
KALRO Kakamega	121.00	52.25	5.65	63.90	5.89	55.20	19.00	18.00
Bungoma Mabanga ATDC	121.00	115.50	6.64	78.30	1.09	23.00	16.00	8.00
Baraton University Nandi	169.40	184.25	5.45	53.40	3.73	103.50	68.00	20.00
KALRO Njoro	133.10	269.50	2.18	169.00	10.8	340.40	22.00	10.40
Average	163.98	120.52	3.95	52.78	1.86	92.80	18.73	11.98
Adequate level	121-363	30.25-550	<1.0	<10	<5.0	0-460	3.67-68	

Phosphorous

Phosphorous varied from 2 mg/kg (KALRO Msabaha) to 30 mg/kg (KALRO Mtwapa) with a mean of 19.09 mg/kg, which is low. Phosphorous deficiency occurs in many soils of East Africa due to not only phosphorous depletion through crop harvest and erosion but mainly due to the prevalence of high P- fixing soils in the region (Nziguheba, 2007). This confirms findings for the whole country, as reported by NAAIAP (2014) that over 65% of the samples taken in the in whole country had values lower than the critical limit, which is 10 to 20 mg/ kg (Table I). Phosphorous showed negative correlations with organic carbon and nitrogen which may indicate a potential for soil P deficiencies. Phosphorous deficiency occurs in many soils of East Africa due to not only phosphorous depletion through crop harvest and erosion but mainly due to the prevalence of high P- fixing soils in the region (Nziguheba, 2007) (Table III).

TABLE III- CHEMICAL PROPERTIES OF SOIL AND THEIR OPTIMAL LEVEL

Properties	Range observed	Mean values	Optimum range
pH		5.96	
CEC		11.98	
Total Organic Carbon (mg/kg)	0.21 – 2.80	1.12	2.66 – 5.32
Total nitrogen (%)	0.04- 0.26	0.12	0.2- 0.5
Macronutrients mg/kg			
P	2.00 -30.00	19.09	30.00-80
K	117.00-585.00	220.43	93.60-585
Ca	600.00-5540.00	1397.39	400-3000
Mg	121.00-490.00	163.98	121-363
S	3.67 - 68	18.73	20
Micronutrients mg/kg			
Na	23.00-340.00	92.80	0-460
Fe	13.60 to 181	52.78	>10
Mn	44.00-255.75	120.52	30.25-550
Cu	1 to 6.64	3.95	>0.2
Zn	0.2 to 10.8	1.86	<7.5

Potassium

Potassium varied from 117 to 585 mg/kg with a mean of 220.43 mg/kg. Critical potassium values range from 93.60 to 585 mg/kg (Hinga *et al.,* 1980). Most of the soils were in the adequate range. Potassium is widely reported as sufficient in Kenya (NAAIAP, 2014). This is supported by the findings by Gikonyo *et al*. (2018) and Kimani *et al*. (2018) which indicated that crop response to potassium application was quite small and no significant effects were observed, being attributed to sufficient level of potassium in the soil.

Sulphur

Sulphur levels ranged from 3.67 to 68 mg/kg with a mean of 18.73 mg/kg. These results are similar to those obtained by Esilaba and Ssali (1987). Considering 20 mg/kg Sulphate sulphur as the critical limit, over 50% of the study soils had sufficient sulphur.

Micronutrients

Calcium, magnesium, sodium, iron, manganese, copper were at adequate levels. Their values are shown in Table III. This was supported by the findings of Lindsay and Norvell (1978), Singh *et al*. (2006), Verma *et al*. (2007), Jiang *et al*. (2009) and Bassirani *et al*. (2011). However, zinc was deficient with levels that ranged from 0.20 to 10.80 mg/kg, with a mean value of 1.86 mg/kg. The critical level is 5 mg/kg (Hinga *et al*., 1980). According NAAIAP (2014), 30% of the farms sampled country wide had zinc value lower than the critical limit. Low soil zinc threatens crop production and food nutrition in most cereal- based cropping systems in Africa (Manzeke *et al*., 2012). Murphy *et al*. (1992) indicated that 90% of children under the age of 2.5 years in Kenya are at risk of zinc deficiency. Malnourishment zinc is often associated with serious physical incapacity, mental impairment, decreased health and parasitic diseases. Nearly 50% of cereal growing areas in the world have soils with low plant available zinc resulting in zinc concentrations in cereal grains of as little as 5–12 mg/kg against a requirement of 40 – 60 mg/kg (Manzeke *et al*., 2012). Zinc is required for structural and functional integrity of about 2,800 proteins hence, contributes to protein biosynthesis and is a key defense factor in detoxification of highly toxic oxygen free radicals (Hati *et al*., 2008). In order to increase its accumulation in grain of nutritional impact, sufficient amount of plant-available zinc must be maintained in the soil.

Cation Exchange Capacity (CEC)

The study showed that CEC varied from 6 cmol (+)/kg to 23.76 cmol (+)/kg with a mean of 11.98 cmol (+)/kg, which suggests that the soils had low and moderate CEC. Metson (1961) reported low and moderate values range of CEC from 6 cmol (+)/kg to 25 cmol (+)/kg. . Soils with a low CEC are more likely to develop deficiencies in K, Mg, and other cations, while high CEC soils can overcome these limitations (Saikat and Geon-Ha Kim, 2021). The exchangeable bases that include calcium, magnesium, potassium and sodium showed significant and positive correlation with each other and also with the sum of cations, base saturation, and Exchangeable Sodium Percentage (ESP) and electrical conductivity.

In general, the most limiting soil fertility attributes of interest were nitrogen, carbon, phosphorous, and zinc. Nitrogen and carbon positively correlated with each other ($P \leq 0.01$). In most soils, more than 90% nitrogen is bonded with carbon in organic forms. This indicates that carbon mineralization should be closely coupled with nitrogen mineralization, hence showing the positive correlation between carbon and nitrogen (Li

TABLE IV- CORRELATION AMONGST THE DIFFERENT SOIL PARAMETERS SOIL

	Soil pH	C%	N%	P	K	S	Mn	Cu	Fe	Zn	Ca	Mg	Na	CEC	SUM	BASE	ESP	Elect Cond mS cm	SAND %	SILT %
C%	0.136																			
N%	0.091	.991**																		
P	0.117	-0.235	-0.255																	
K	0.032	0.059	0.079	0.092																
S	-0.168	0.273	0.286	-0.657**	-0.044															
Mn	0.008	-0.018	-0.040	0.216	0.133	-0.052														
Cu	0.126	0.533**	0.581**	-0.446	0.012	0.343	-0.116													
Fe	0.101	0.152	0.093	0.242	0.014	-0.003	0.252	-0.040												
Zn	-0.042	0.542**	0.504*	0.206	0.281	0.004	0.395	-0.042	0.656**											
Ca	-0.270	0.012	0.050	0.103	0.522*	-0.173	0.118	0.262	-0.132	0.111										
Mg	-0.215	0.005	0.020	0.254	0.283	-0.322	0.176	0.234	-0.161	0.008	.692**									
Na	-0.238	0.039	0.063	0.132	0.712**	-0.197	0.151	0.092	0.033	0.309	.867**	0.718**								
CEC	-0.068	0.456*	0.468*	-0.051	0.163	0.133	-0.123	0.347	-0.249	-0.019	0.212	0.594**	0.299							
SUM	-0.265	0.015	0.051	0.134	0.551**	-0.204	0.138	0.255	-0.130	0.120	0.991**	0.772**	0.903**	0.290						
BASE	-0.289	-0.140	-0.123	0.285	0.615**	-0.190	-0.005	-0.316	-0.079	0.313	0.376	0.239	0.504*	-0.072	0.398					
ESP	-0.160	-0.095	-0.084	0.219	0.768**	-0.260	0.288	-0.061	0.153	0.389	0.809**	0.509*	0.916**	-0.042	0.821**	0.612**				
Elect Cond	-0.324	-0.155	-0.138	0.225	0.539**	-0.354	-0.024	-0.028	-0.172	0.053	0.610**	0.689**	0.752**	0.317	0.669**	0.391	0634**			
SAND %	0.287	-0.452*	-0.472*	0.048	-0.247	-0.321	0.128	-0.205	0.309	-0.207	-0.135	-0.261	-0.164	-0.579**	-0.171	-0.426*	-0.002	-0.207		
SILT %	-0.319	0.565**	0.583**	0.035	-0.029	0.256	-0.178	0.194	0.220	0.518*	-0.133	-0.004	-0.020	0.318	-0.111	0.287	-0.122	-0.095	-0.640**	
CLAY %	-0.187	0.259	0.274	-0.080	0.326	0.263	-0.063	0.151	-0.510*	-0.024	0.243	0.331	0.218	0.555**	0.276	0.379	0.069	0.313	-0.907**	0.257

* ($P \leq 0.05$), ** ($P \leq 0.01$), *** ($P \leq 0.001$), - (corrélation coefficient)

Qianru *et al.*, 2014). Phosphorous on the other hand was negatively correlated with carbon and nitrogen possibly due to Phosphorus fixation, unavailable Phosphorus or deficiencies (Nziguheba, 2007).

Zinc negatively correlated with soil pH (Table IV). While zinc was positively correlated with carbon, this means that reduction or increase in soil pH causes reduction or increase in the levels of these nutrient bases, hence the explanation of the reduced levels of the nutrients with increased soil acidification, caused by the increased rate of chemical degradation in as reported by Muya *et al.* (2014). Therefore, to ensure efficient utilization and uptake of these nutrients, soil pH must be corrected to the optimally favourable limit (Johnston, 2011).

Decreasing soil fertility is a result of imbalance between nutrient inputs and nutrient removals through harvesting, erosion, and leaching (Muthaura *et al.*, 2017). Most of the study soils were acidic in nature. Soil acidity greatly affects crop productivity and is the most yield limiting factor (Sumner and Noble 2003; Fageria and Nascente 2014). The pH affects both the nature and the size of the microbial population, both of which ultimately affect the residue decomposition. In general, decomposition of crop residues proceeds more rapidly in neutral than in acid soils. Consequently, the treatment of acid soils with lime enhances the decomposition of plant residues. Likewise, soil salinity also affects the residue decomposition through its direct influence of osmotic potential on microbial activity or through alterations of pH, soil structure, aeration, and other factors (Yadvinder-Singh *et al*., 2005).

Sulphur was adequate in most soils except in soils with high soil pH>7.5 where deficient levels were observed. High soil pH in soils from KALRO Kiboko, South Eastern University, Kibwezi, Kambi ya Mawe, Mwingi, Tharaka Nithi and all the Coastal regions had low sulphate implying complexing by the high calcium content (Table II).

CONCLUSION

This study increases the understanding of the nutrient status of some Kenyan soils, with a view of knowing the limiting nutrients in the selected soils. The findings can form basis of soil fertility management recommendations. The study sites were spatially heterogeneous in terms of soil quality therefore fertilizer application should differ from field to field. Most of the macronutrients were deficient and varied from site to site. Nitrogen and phosphorous were the most limiting nutrients in all the soils. Most of the micronutrients except zinc were at adequate levels suggesting that a dynamic equilibrium exists among the soils.

RECOMMENDATION

Research should focus on laboratory, greenhouse and field trials to correlate and calibrate the plant availability of macro and micronutrients for site specific smart fertilizer recommendations.

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