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Soil Properties and Fertility Management within Ruiru Peri-Urban Area in Kiambu County, Kenya

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Abstract: Peri-urban agriculture is a common practice around many towns and cities in Africa because of the ready urban market for farm commodities. However, it is constrained by a myriad of factors like lack of land tenure and poor soil fertility management strategies. This study focussed on soil physicochemical properties and fertility management in Ruiru Sub County, which is a peri-urban area, in Kiambu County of Kenya. Data was obtained from soil samples that were collected from ten small contact farms identified by the Sub-County Ministry of Agriculture and analysed for selected physicochemical parameters critical in soil fertility management. The results from this study indicated that most farmers were tenants growing leafy vegetables on small farms ~0.1 ha. Soil fertility was mainly maintained using organic manures, while tillage was done by hand. Both practices signal the limitations imposed by the small farm size and lack of land ownership. The soil pH was 6.3 ±0.87, which was ideal for proton transfer reactions in the soil and availability of nutrients for plant uptake. Soil fertility was mostly limited by the interaction of soil pH, K and Ca (30%), total N, OC and Zn (27%) and Cu (15%), Mg (10%) and P (9%). Therefore, the management of Ca fertilisation in this area is key because it is the Ca concentration of the soil solution that influences K and pH through ion exchange and K release.

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Peri-urban farming is a reality that will not go away soon. Its main attraction is the ready market with better prices that is provided by the ever-rising urban populations especially in market towns (Mochache *et al.,* 2020). Although it has significant potential to reduce poverty and increase food security and sovereignty in urban households (Chihambakwe *et al.,* 2018) poor soil fertility management is a major cause for low crop productivity. Moreover, most farmers in peri-urban areas are squatters and are faced with urbanisation pressures (Opitz *et al.,* 2016). Lack of land tenure for many peri-urban farmers makes soil fertility management even more complicated. For example, little attention is put on the diagnosis of soil fertility and requisite amelioration measures especially in developing countries (Bossio *et al.,* 2010). However, routine use of organic manures based on tacit knowledge of crop husbandry is popular. Furthermore, safety of food grown in urban and peri-urban systems is compromised by use of polluted wastewater for irrigation. Therefore, an integrated approach in soil fertility management and food safety should inform the future of urban and peri-urban agro-ecosystems (Vanlauwe *et al.,* 2014; Lal *et al.,* 2015). Nevertheless, evidence-based use of organic resources has potential to enhance urban food security commensurate with the increasing population (Decock *et al.,* 2015). However, the choice and use of soil fertility management strategies by peri-urban growers is not only determined by profits but personal values such as happiness, comfortable life, independence, good health and achievement of life goals Okello *et al.,* (2014). Macronutrients are often the focus by small-scale farmers in soil fertility management in the tropics. However, their availability from organic manures, which are the main source of plant nutrients in peri-urban cropping systems, often fluctuates and is low (Nciizah and Wakindiki, 2012a). Moreover, Bationo and Waswa (2011) noted that use of local available organic fertilizers was limited by their low quality and quantity, which supports the need for appropriate fortification. Whereas the contribution of macronutrients in soil fertility management in Africa is extensively studied, little is known about micronutrients. Nevertheless, there is evidence suggesting that micronutrients play a crucial role in plant nutrition. For example, Kihara *et al.,* (2017) observed a 25% increase in maize yield when S and

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micronutrients were applied compared to macronutrient only treatment. It was concluded that sulphur and micronutrients limit crop yield in soils where response to macronutrients is low. Besides plant nutrients, the soil physical properties have a profound influence on soil fertility management, but they are less studied. Materechera (2016) studied soil properties and their constraints on peri-urban agriculture within Mahikeng city in the North West Province of South Africa. In that study it was found out that the effects of the soil physical properties extended to the subsoil. Most values of the physical properties were extreme thereby impeding plant root growth and necessitating deep ploughing and incorporation of organic matter. In this study it was hypothesised that the soil physicochemical properties have a similar effect on soil fertility. Therefore, the objective was to establish the effect of selected soil physicochemical properties on soil fertility management within Ruiru peri-urban area.

MATERIALS AND METHODS

The study area: This study was conducted in Ruiru Sub-County, a peri-urban area, which is in Kiambu County, Kenya. The area is about 1564m above mean sea level, between 1.08˚ Sand 1.15˚ S: 36.96˚E and37.16˚E. Ruiru peri-urban area is about 201 square km and is divided into eight administrative wards namely; *Mwiki, Mwihoko, Kiu, Kahawa-Wendani, Gatongora, Githotua, Biashara* and *Kahawa-Sukari* (KNBS, 2019). Ruiru peri-urban area has a humid highland sub-tropical climate with distinct dry and wet seasons. The area receives about 1065 mm of bimodal annual rainfall. The wet seasons are between March and May and between October and December. The rest of the year is dry. The monthly mean temperature is 18.9˚C. Maximum temperature is about 24.9˚Cin January and February while the minimum temperature is 13.0˚C in July and August.

Socioeconomic characteristics in the Ruiru peri-urban area: Data on the socio-economic characteristics of sites was obtained from the respective contact farmers in the Wards using an interview schedule. Additional information was obtained key note respondents who were mainly the Ward Agricultural Officers. Data was obtained about farm size, land tenure, source of plant nutrients, tillage, and type of crops grown.

Soil sampling and analyses: Soil sampling was done from one cultivated plot (small farm) measuring ~0.1 ha in each ward except in *Kahawa Sukari* and *Gatongora* where two plots were sampled. The zigzag method (Beater, 1962) was used to sample soils from a depth of 0 – 200 mm using a soil auger. From each site, three subsamples were collected and bulked to obtain a representative composite sample. Each composite sample was put in a plastic bucket and labelled accordingly and then taken to the Kenya Agricultural and Livestock Research Organisation laboratories at Kabete in Nairobi for various physicochemical analyses. At the laboratory, each composite sample was spread on benches to dry at room temperature for a week. It was then sieved to pass through a 2 mm sieve, divided into three ~1 kg-subsamples and kept in airtight plastic bags and used for the analyses of the soil physicochemical properties. The soil samples were analysed for pH, Organic carbon, total N, available P and exchangeable bases: Ca, Mg, K, and Na. Micronutrients Mn, Cu, Fe and Zn were also determined. Standard procedures for soil analysis as described by Okalebo *et al.,* (2002) were used.

Data analysis: Socioeconomic data was analysed using descriptive and inferential statistics (Freund and Wilson, 2003). The variability of the physicochemical properties in the study area was tested using Microsoft Excel (2007). Mean separations were done using Fisher's protected least significant differences (LSD) at $P \leq 0.05$. Principal component analysis (Lever et al., 2017) was used to determine the relationships between the soil physicochemical properties with respect soil fertility. The Pearson product moment correlation coefficient (r) was used to measure the strength of linear dependence between the variables (Freund and Wilson, 2003).

RESULTS AND DISCUSSION

Socioeconomic characteristics in Ruiru peri-urban area: Farm size was either small or micro. Except in Gatongora ward where the farm size was ~0.45 ha, the rest were ≤ 0.1 ha. This farm size is typical of a peri-urban area that is almost turning into a full unban area. Gatongora ward had the largest farm size (~0.45 ha) compared to the rest of the wards (≤ 0.1 ha) because it boarders the rural Kiambu county. All plots, except in Kahawa-Sukari and Gatongora, were either public, along streams or owned by absentee landlords. Soil fertility was maintained by adding organic manures and there was no evidence of using inorganic fertilizers. Land tenure influenced the latter because farmers were reluctant to invest in costly fertilizer input. Leafy vegetables, beans and maize were the main crops that were grown. The choice of the crops was influenced by the market demand habits of the non-farming urban and peri-urban working populations. Tillage was entirely done by hand because the small farm sizes limited mechanisation.

Soil fertility in Ruiru peri-urban area:

Table 1. Selected physicochemical properties of soils from the 10 sampled sites in the Wards

		meq/100g				g/kg			mg/kg				Soil Texture
Site/Ward	pH	K	Ca	Mg	Na	*N	OC	P	Mn	Cu	Fe	Zn	
Mwihoko 1	7.60	1.50	14.40	41.00	3.08	36.30	4.24	2.99	1.40	2.29	43.00	22.80	Clay
Mwihoko 2	6.20	0.90	7.90	30.00	0.80	17.30	3.56	1.32	1.18	1.12	68.10	4.18	Clay
Kahawa-Sukari	6.80	1.50	16.80	190.00	2.16	11.40	4.03	0.70	0.65	2.27	65.60	18.00	Clay
Kahawa-Wendani	5.80	2.30	24.80	45.00	1.42	21.90	4.18	0.56	4.18	1.79	138.00	30.40	Clay
Gatongora 1	6.80	1.20	11.90	45.00	1.24	12.70	2.06	1.54	0.25	1.47	81.20	3.69	Clay
Gatongora 2	6.50	1.70	17.90	45.00	1.28	21.00	4.09	0.68	0.61	2.12	76.10	4.72	Clay
Gitothua	5.50	2.50	27.00	50.00	0.95	14.70	3.90	1.28	0.55	1.62	151.00	9.00	Clay
Kiu	7.50	2.20	22.80	89.00	3.44	35.50	2.23	1.44	0.20	2.21	63.80	19.40	Clay
Biashara	5.20	1.50	17.10	25.00	1.50	3.80	3.00	0.22	0.35	3.27	48.70	5.89	Clay
Mwiki	5.30	1.70	17.60	130.00	0.60	13.00	4.00	1.40	0.65	1.80	145.00	9.36	Clay
Mean	6.30	1.65	18.76	3.53	1.00	1.70	17.80	69.00	1.21	2.00	88.05	12.74	Clay
SD (±)	0.87	0.95	10.38	0.82	0.76	0.50	5.82	52.80	1.18	0.59	40.70	9.29	
Variance	0.76	0.91	107.69	0.66	0.59	0.3	3.38	2788	1.39	0.35	1662.08	86.32	

*SD = Standard Deviation; *Total*

Selected physicochemical properties of soils from the ten sampling sites in the eight wards used in this study are shown in Table 1. The soils were mostly acidic, and the dominant textural class was clay. Both macronutrients (e.g. phosphorus and calcium) and micronutrients (e.g. iron and zinc) exhibited high variability (≥ 86.32). The high variability of these plant nutrients indicated that soil fertility management in the Ruiru peri-urban area is specific to the individual cultivated plot/small farm. Secondly, availability of plant nutrients; phosphorus, calcium, iron, and zinc varied from excess to inadequate. A tabulation of the results of the correlation coefficients between each pair of variables is presented in Table 2.

The linear relationship between pH and other soil physiochemical properties was either strong with low probability (K: $r = 0.80$, $P = 0.01$; Ca: $r = 0.75$, $P = 0.01$; Fe: $r = -0.67$, $P = 0.06$ and Na: $r = 0.59$, $P = 0.07$) or weak with high probability (N: $r = -0.17$, $P = 0.64$; OC: $r = -0.24$, $P = 0.50$; P: $r = 0.14$, $P = 0.71$; Mg:$r = -0.24$, $P = 0.51$; Mn: $r = -0.15$, $P = 0.68$; Cu-: $r = 0.03$, $P = 0.92$; Zn: $r = 0.32$, $P = 0.36$).So, either way, the soil pH did not have significant linear relationship with the other soil physicochemical properties. The mean soil pH in the study area was 6.3 ±0.87 (Table 2), which was within the preferred soil pH for the availability of most plant nutrients (Brady and Weil, 2008).

Table 2. Correlation coefficients (r) between the soil physicochemical properties in the study area

	Statistic	pH	*N	OC	P	K	Ca	Mg	Mn	Cu	Fe	Zn	Na
pH	r	1	-0.17	-0.24	0.14	0.80	0.75	-0.24	-0.15	-0.03	-0.67	0.32	0.59
	P		0.64	0.50	0.71	0.01	0.01	0.51	0.68	0.92	0.06	0.36	0.07
N	r		1	0.99	0.06	0.17	0.26	0.17	0.28	0.10	0.59	0.49	-0.15
	P			0.00	0.87	0.64	0.47	0.65	0.43	0.77	0.07	0.15	0.67
OC	r			1	0.10	0.13	0.14	0.17	0.26	0.19	0.58	0.46	-0.26
	P				0.78	0.71	0.69	0.64	0.46	0.60	0.08	0.18	0.46
P	r				1	0.16	-0.12	0.17	-0.20	0.06	0.11	0.22	-0.10
	P					0.67	0.74	0.65	0.59	0.87	0.77	0.54	0.78
K	r					1	0.72	-0.22	-0.07	0.43	-0.58	0.58	0.41
	P						0.02	0.55	0.85	0.21	0.08	0.08	0.24
Ca	r						1	0.04	0.21	-0.10	-0.22	0.57	0.65
	P							0.92	0.56	0.78	0.55	0.09	0.04
Mg	r							1	0.48	-0.04	0.32	0.32	0.03
	P								0.16	0.92	0.37	0.37	0.94
Mn	r								1	-0.19	0.35	0.70	-0.10
	P									0.59	0.32	0.03	0.7
Cu	r									1	-0.47	0.14	-0.27
	P										0.18	0.70	0.45
Fe	r										1	0.09	-0.18
	P											0.77	0.62
Zn	r											1	0.18
	P												0.62
Na	r												1
	P												

**Total*

Total N had a significant positive linear relationship ($r = 0.99$) with OC but with low P value (0.00). In general, total N content depends on the OC in the soil because up to 95% of soil total N comes from soil organic matter. Ideally OC in tropical clay soils could be as much as 30 g/kg (Nciizah and Wakindiki, 2012b). In this study area with clay soil, OC was 17.8 ±5.82 g/kg (Table 1), which was below average and probably accounting for the low P value. Moreover, most farmers were growing leafy vegetables, which left little organic matter available for decomposition after harvesting. The linear relationship between total N and rest of the physicochemical properties was weak (P: *r* = 0.06, *P* = 0.87; K: *r* = 0.17, *P* = 0.64; Ca: *r*= 0.26, *P* = 0.47; Mg: *r* = 0.17, *P* = 0.65; Mn: *r* = 0.28, *P* = 0.43; Cu: *r* = 0.10, *P* = 0.77; Fe: *r* = 0.59, *P* = 0.07; Zn: *r* = 0.49, *P* = 0.15; Na: *r* = -0.15, *P* = 0.67). Similar weak linear relationships were observed between OC, P, K, Ca, Mg, Mn, Cu, Fe, Zn, Na, and the rest of the physicochemical properties (Table 2). From the foregoing, the linear relationship between the soil physicochemical properties was obscure. A multivariate model that was used in the principal component analysis (Lever *et al.,* 2017) generated eigenvalues corresponding to each principal component. The eigenvalues represent a partition of the total variation. In this study, the first five principal components explained 94% of the cumulative variation observed among the sampled small farms (Table 3). Each of the five principal components had an Eigen value > 1.0, which since the work by Kaiser (1960) has been the standard used to select principal components with influential variables.

Table 3. Summary statistics for principal component analysis

Statistics	Principal Component									
	1	2	3	4	5	6	7	8	9	10
SD	1.81	1.80	1.24	1.08	1.04	0.72	0.31	0.18	0.17	0.00
POV	0.30	0.29	0.14	0.11	0.10	0.05	0.01	0.00	0.00	0.00
CP	0.30	0.59	0.73	0.84	0.94	0.98	0.99	1.00	1.00	1.00
EV	3.56	3.29	1.78	1.20	1.13	0.65	0.29	0.08	0.03	0.00

**SD = Standard deviation Standard deviation, POV = proportion of variance, CP = cumulative proportion; EV = Eigenvalues*

Table 4 Eigen vectors variables that contribute to the principle components

Variables	Eigenvectors									
	1	2	3	4	5	6	7	8	9	10
pH	0.4973	0.0232	-0.0681	0.0535	-0.1527	-0.1659	0.3554	0.43	-0.6053	0.0841
Total N	-0.0755	-0.4774	0.198	0.3498	0.0056	0.1146	0.1229	0.1078	0.0569	-0.4083
OC	-0.1128	-0.4629	0.2739	0.2922	0.0043	0.0936	0.1191	0.2507	0.0269	-0.0349
P	0.0188	-0.0735	0.2138	-0.2463	-0.8419	-0.1879	-0.0761	-0.2017	-0.0159	-0.2891
K	0.4804	-0.1359	0.2499	-0.001	0.0098	-0.0443	-0.0438	0.0787	0.387	0.3533
Ca	0.4225	-0.232	-0.2039	0.1642	0.0746	0.1005	0.2931	-0.7535	-0.0396	-0.0363
Mg	-0.1181	-0.2463	-0.2307	-0.5458	-0.1322	0.5998	0.3814	0.1426	0.0854	0.1391
Mn	-0.0622	-0.3577	-0.3054	-0.3764	0.3398	-0.3812	-0.1058	0.0045	-0.2138	-0.374
Cu	0.0939	-0.0109	0.6235	-0.2873	0.2501	0.3395	-0.2807	-0.1929	-0.4744	-0.0085
Fe	-0.3621	-0.2996	-0.2087	0.2615	-0.2213	0.0085	-0.2374	-0.1686	-0.404	0.5513
Zn	0.2152	-0.4482	-0.0141	-0.2804	0.0192	-0.2667	-0.3309	0.0862	0.1909	0.2835
Na	0.3472	0.0074	-0.3903	0.1804	-0.1319	0.4601	-0.5912	0.1802	-0.0189	-0.2677

The most important variables in principal component one were pH, K and Ca, based on their positive influence (Table 4; Figure 1). This was probably because pH is a soil solution buffer for all proton transfer reactions in the soil (Brady and Weil, 2008). Furthermore, Ca concentration of the soil solution influences K and pH through ion exchange and K release or fixation (Schneider, 2008). Calcium concentration in the soil solution in this study area was 18.76 ±10.38meq/100g, which was ideal to affect K release from the available pools under the prevailing soil pH of 6.3 ±0.87 (Table 1). Total N, OC and Zn had a high negative influence on principal component two (Table 4; Figure 1). Whereas the association between total N content and OC in the soil is naturally positive (Brady and Weil, 2008), their interaction with Zn was not clear. So, management Zn micronutrient and organic matter in the study area is of interest. Alternatively, Zn influenced soil fertility when OC content was below average in the soil.

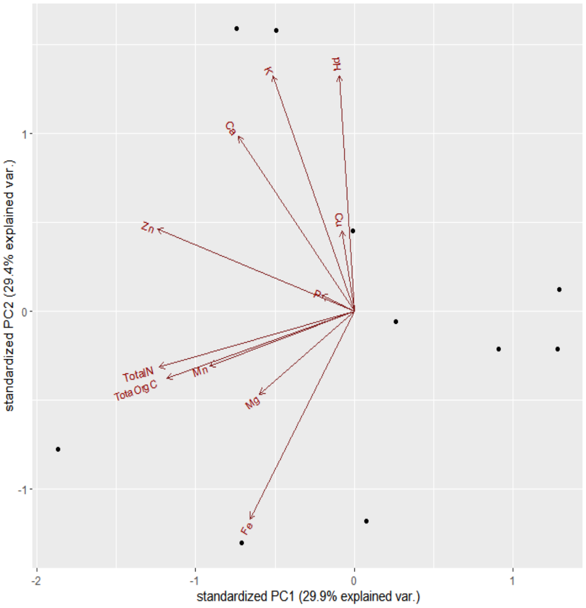

Fig 1. Two-dimensional relationships of the soil physicochemical properties between PC1 & 2

Copper had a strong influence on component three while Mg strongly influenced component four (Table 4; Figure 1). Copper is known to influence Fe and Mn concentrations in the soil as well as to be affected by N and P (component five) while Mg is affected by K and Ca (Brady and Weil, 2008), which were instrumental in component one. Phosphorous had the highest effect of any of the variables, and this was in component five (Table 4; Figure 1). The fact that P does not have a strong influence on either component one or two suggests that its quantities (69 ±52.80mg/kg) in soil was adequate. Nonetheless P concentration in the soil is influenced by Ca (component one) and Fe while it affects K (component one) and micronutrients Fe, Cu (component three) and Zn (component two) (Brady and Weil, 2008).

Conclusions: Calcium, potassium and soil pH were responsible for proton transfer reactions in the soil, while organic carbon, Nitrogen and Zinc were strongly associated with soil organic matter content and micronutrient Zinc. Soil reaction, Ca fertilisation and organic carbon management deserve closer attention in the study area.

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