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Influence of Farming Practices on the Chemical Properties of Soil in Small Scale Tea Farms in Kirinyaga and Tharaka-Nithi Counties of Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. Authors IHM and WMM designed the study, performed the statistical analysis, wrote the protocol and the first draft of the manuscript. Authors WMM and JWK managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Soil chemical properties are important for growth of plants as they determine the nutrient availability for their uptake. Farming practices are treatments applied to farms in efforts to maximize crop productivity. Experiments were set up in Kangaita, Kirinyaga County, and Weru, Tharaka-Nithi County using randomized complete bock design to establish the influence of farming practices on the chemical properties of soil in tea production areas. This was aimed at understanding the role of the farming practices on the availability of soil nutrients and their effect on tea productivity. Each study site was divided into three zones depending on elevation and three farming practices identified within each zone namely neglected farms, manure applied farms and chemical fertilizer (NPK) applied farm. Soil samples were collected randomly from farms in each zone and analyzed for chemical properties. Soil acidity increased from neglected farms through manure applied farms to NPK fertilizer applied (standard) farms.

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The soils had generally low levels of K, Mg and Zn due to rapid removal through harvesting of the young shoots and leaves. Manure application is recommended as it is less degrading to the soils.

Keywords: Growth; farms; farming practices; productivity; soil chemical properties.

1. INTRODUCTION

Chemical properties of soil determine availability of nutrients for uptake by plants. The balance of both macro and micro nutrients in any soil play a vital role in plant growth. The interactions of the nutrients also affect the availability of each other either positively or negatively [1,2,3]. Various cultural practices including weeding, fertilizer application and even harvesting of farm produce affect the nutrient composition and balance in the soil which in turn affect the performance of crops in terms of productivity. Other factors like leaching and surface run off also play a role in soil physical and chemical composition.

Tea is cultivated using a number of cultural practices which are aimed at increasing the productivity of the tea plant. These cultural practices include weeding, pruning, fertilizer application and plucking/harvesting rounds [4]. These practices greatly affect biodiversity in the soil [5]. Soil biodiversity is the variety of life below the ground and it's an indicator of sustainable land use [5]. Soil hosts a wide range of microbes (fungi and bacteria), macrobes (termites and earthworms) and mesofauna (acari, collembolan and nematodes) [5,6]. Land use affects soil characteristics like organic carbon (OC) which was highest in least disturbed land [5]. This was attributed to low biological activity in tea husbandry and the monocrop husbandry characteristic in tea growing. The amount of organic matter(OM) in the soil affects the health and performance of the plants. The organic matter acts to suppresses parasitic microorganisms such as nematodes thus improving the health of the tea plants [3,4].

Farmers use chemical fertilizers in the cultivation of tea, mainly Diammonium Phosphate (DAP) during nursery establishment and planting and Nitrogen-Phosphorus-Potassium (NPK) for top dressing [4]. Excessive application of fertilizer can cause imbalance in nutrient uptake and fix some nutrients leading to poor performance of the tea plant [1,2,3]. In Kenya's small scale holder tea farming, the recommended NPK application rate is 50 kgs per 700 bushes [4].

2. MATERIALS AND METHODS

The study was carried out in already established small-scale tea farms in Kirinyaga and Tharaka-Nithi counties of Kenya. The two counties were chosen to allow for comparison between various ecological zones. One tea factory catchment managed by the Kenya Tea Development Agency (KTDA) was chosen per county. Each factory catchment was zoned into three based on elevation, that is, high, medium and low elevation as represented in agro-ecological zones LH0, LH1 and UM1 [7]. Three types of agricultural/farming practices were considered across the ecological zones within the area of study. These were non-cultivated (neglected) farms, cultivated farms with regular application of NPK fertilizer and farms practicing organic farming with organic mulching and/or manure application. The survey was set up in a randomized complete block design. Five sub-samples were randomly obtained from each farm. The soils were scooped from the surface to a depth of 30cm using a soil auger. Twenty-seven samples were collected from the three farming practices replicated three times. The samples were transported in a cool box to the laboratory for analysis.

Two hundred grams of soil from the farms in each zone was analyzed for physical and chemical characteristics. The analysis was aimed at measuring the soil pH, exchangeable acidity, total nitrogen (TN), total organic carbon (TOC), available nutrient elements (phosphorus (P), potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), manganese (Mn), iron (Fe), zinc (Zn) and copper (Cu). The soil samples were passed through a 2mm sieve and oven dried at 40ºC.

Soil pH was determined in a 1:1 (w/v) soil – water suspension with a pH meter.

Exchangeable acidity was determined using titration method. The soil was oven dried at 40º C. Five grams of the oven dried soil sample (< 2 mm) was placed into a 50 ml container. This was followed by addition of 125 mL of 1 M KCl to the container and the contents were stirred using a clean glass rod. The mixture was allowed to stand for 30 minutes. The mixture was filtered through a funnel and leached with 5 successive 12.5mL aliquots of 1 M KCl. Three drops of phenolphthalein indicator solution were added and then titrated with 0.1 M NaOH to the first permanent pink color of the end point. The burette was read and the volume (ml) of NaOH used was recorded.

Total nitrogen was determined using Kjeldahl method. Two grams of the soil sample (< 0.5mm) was oven dried at 40ºC and digested with concentrated sulphuric acid containing potassium sulphate, selenium and copper sulphate hydrated at approximately 350ºC. Total nitrogen was determined by distillation followed by titration with diluted standardized 0.007144M H_2SO_4. [8].

Total organic carbon was determined using the calorimetric method. All the OC in the oven dried soil sample (< 0.5mm) at 40ºC was oxidized by acidified dichromate at 150ºC for 30 minutes to ensure complete oxidation. Barium chloride was added to the cool digests. After mixing thoroughly, the digests were allowed to stand overnight. The C concentration was read on the spectrophotometer at 600nm [9].

Available nutrient elements (P, K, Na, Mg and Mn) were determined using the Mehlich Double Acid method. The oven dry soil samples at 40ºC (< 2mm) were extracted in a 1:5 ratio (w/v) with a mixture of 0.1 M HCl and 0.025 M H_2SO_4. Na, Ca and K were determined using a flame photometer. P, Mg and Mn were determined spectrophotometrically [10].

Fe, Zn and Cu were determined by AAS (atomic absorption spectrophometer). The oven dry (at 40ºC) soil samples (<2 mm) were extracted in a 1:10 ratio (w/v) with 0.1 M HCl. The elements were then determined with AAS (atomic absorption spectrophometer) [10].

Statistical analysis was done using Genstat edition 14.

3. RESULTS

Soil chemical analysis conducted yielded results for soil pH, exchangeable acidity, TN, TOC, P, K, Ca, Mg, Mn, Cu, Fe, Zn and Na. At Kangaita, the figures ranged as follows; pH 3.0-4.95, exchangeable acidity 0.3-0.5, TN 0.54-5.5, TOC 5.6-8.17, P (mg dm^{-3}) 50-180, K 0.2-2.79, (Table 1.1). At Weru, the figures ranged as follows; pH 4.0-5.2, exchangeable acidity 0.2-0.5, TN 0.14-0.4, TOC 1.3-3.95, P (mg dm^{-3}) 5-25, K 0.22-0.78 (Tables 1.1 and 1.2).

There was a significant difference ($P<0.05$) in the three farming practices for soil pH, exchangeable acidity, TOC, P, K, Ca, Mg, Mn, Cu, Zn and Na (Table 1.3 and Table 1.4). There was no significant difference for total nitrogen, and iron in the two sites.

4. DISCUSSION

The farming practices had a significant effect on the soil pH. The soil acidity was highest in inorganic fertilizer applied farms (Standard) followed by manure applied farms and lowest in neglected farms. Similar findings have been reported in various studies [2,3,11,12,13]. It was noted that continuous use of nitrogenous fertilizer increases the soil acidity [3] and application of manure plays an important role in reducing soil acidity which is increased by continuous application of nitrogenous fertilizers [3]. It was also reported that farmers tend to use the recommended fertilizers non-judiciously with the hope of increasing yield but this instead leads to increase in soil acidity, pollution of water masses and poses a challenge to the sustainability of the tea production [12]. Conventional farming systems produced higher level of soil acidity as compared to organic farming systems [13].

Soil pH was also affected by the farming practice probably due to the type and intensity of fertilizer application. High rates of inorganic nitrogenous fertilizers been reported to lead to increased soil acidity [3] while application of manure has been reported to lead to decrease in soil acidity [13]. Large amounts of chemical fertilizers used to increase tea production have been reported to be responsible for environmental risks like ground water pollution and soil acidification [14].

There was a significant difference among the three farming practices in soil pH, exchangeable acidity, total organic carbon, phosphorus, potassium, calcium, magnesium, manganese, copper zinc and sodium. There was no significant difference for total nitrogen, and iron in the two sites. This can be attributed to the interaction of both macro and micro nutrients in the soil [15] and application of the fertilizers affecting soil pH [3]. It was however reported in another study that there was no significant difference in the amount of phosphorus between conventional and organic farming systems [13].

Table 1.1. Soil chemical properties in various zones and farming practices in Kangaita

Zone	Farming practice	Soil pH	EA cmolc dm^{-3}	TN mg/kg	TOC mg/kg	P mg/kg	K cmolc dm^{-3}	Ca cmolc dm^{-3}	Mg cmolc dm^{-3}	Mn cmolc dm^{-3}	Cu mg/kg	Fe mg/kg	Zn mg/kg	Na cmolc dm^{-3}
Upper	Standard	3.00a	0.50a	0.56a	5.86a	125.00d	0.40cd	3.00a	1.67c	0.82f	3.81b	122.00f	3.52c	0.22cd
Upper	Manure	4.05d	0.50a	0.65bc	6.81bc	140.00e	2.72f	10.67g	3.63e	0.43d	0.66a	56.63d	8.62d	1.22f
Upper	Neglected	4.07d	0.50a	0.60b	6.61b	80.00b	0.26b	3.67b	0.56a	0.41d	0.64a	38.00c	3.95c	0.14a
Medium	Standard	3.80c	0.50a	0.65bc	6.62b	150.00f	0.42d	5.00d	0.95b	0.44d	0.54a	24.40a	2.20b	0.20c
Medium	Manure	3.32b	0.50a	0.65bc	6.69b	145.00ef	0.30b	4.00c	1.95d	0.30c	1.12a	145.00h	9.98e	0.17b
Medium	Neglected	4.25e	0.50a	0.56a	5.73a	50.00a	0.20a	3.00a	0.93b	0.60e	1.02a	34.43b	3.48c	0.16ab
Lower	Standard	3.02a	0.50a	0.79e	8.14e	178.30g	0.28b	6.00e	0.95b	0.28c	0.40a	137.00g	1.11a	0.20c
Lower	Manure	4.01d	0.50a	0.69cd	7.06cd	95.00c	1.50e	9.30f	3.80f	0.20b	0.57a	40.70c	13.10f	1.04e
Lower	Neglected	4.08d	0.50a	0.70d	7.25d	85.00b	0.36c	5.00d	0.93b	0.11a	4.90b	68.70e	2.00b	0.24d
	LSD	0.15	-	0.04	0.33	5.36	0.05	0.31	0.02	0.02	2.10	3.00	0.67	0.02
	C.V%	2.40	-	3.80	2.90	2.70	4.10	3.30	0.90	3.90	79.90	2.30	7.30	3.50

Means followed by different letters within the same column are significantly different. EA – exchangeable acidity, TN – Total Nitrogen, TOC – Total Organic Carbon P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Cu – Copper, Fe – Iron, Zn – Zinc, Na – Sodium, Upper - LH0, Medium - LH1, Lower - UM1

Table 1.2. Soil chemical properties in various zones and farming practices in Weru

Zone	Farming practice	Soil pH	EA cmolc dm^{-3}	TN mg/kg	TOC mg/kg	P mg/kg	K cmolc dm^{-3}	Ca cmolc dm^{-3}	Mg cmolc dm^{-3}	Mn cmolc dm^{-3}	Cu mg/kg	Fe mg/kg	Zn mg/kg	Na cmolc dm^{-3}
Upper	Standard	4.33b	0.40a	0.38e	4.05g	10.00b	0.40d	8.23fg	0.46ab	0.71f	1.71ab	49.20h	5.51h	0.21c
Upper	Manure	4.12a	0.50a	0.35d	3.46f	23.33d	0.51e	8.26g	0.81b	0.30c	1.82ab	53.27i	2.22f	0.40e
Upper	Neglected	4.12a	0.50a	0.38e	3.93g	20.00c	0.22a	5.40d	0.50ab	0.18a	1.00a	34.10d	1.08a	0.16ab
Medium	Standard	5.16e	0.20a	0.22b	2.26cd	6.67a	0.28c	6.20e	1.76c	0.46e	2.89b	44.67g	2.08e	0.18b
Medium	Manure	5.02d	0.30a	0.24c	2.46de	23.33d	0.75f	12.20h	1.50c	0.21b	15.67e	23.90c	1.70b	0.35d
Medium	Neglected	4.42bc	0.40a	0.25c	2.65e	10.00b	0.24ab	8.00f	0.50ab	0.41d	1.00a	35.13e	3.22g	0.18b
Lower	Standard	4.47c	0.40a	0.21c	2.01bc	10.00b	0.26bc	5.00c	0.17a	0.71f	9.18d	13.97b	1.75c	0.14a
Lower	Manure	4.10a	0.50a	0.14a	1.34a	5.00a	0.52e	8.26g	0.47ab	0.44e	23.46f	39.50f	2.07e	0.36d
Lower	Neglected	4.16a	0.50a	0.15a	1.81b	10.00b	0.24ab	4.16a	0.57ab	0.88g	4.80c	11.60a	2.00d	0.15a
	LSD	0.11	-	0.01	0.36	3.00	0.02	0.24	0.40	0.02	1.36	0.45	0.05	0.02
	C.V%	1.50	-	2.80	7.90	13.20	3.10	2.10	31.30	2.90	11.50	0.80	1.20	5.60

Means followed by different letters within the same column are significantly different. EA – exchangeable acidity, TN – Total Nitrogen, TOC – Total Organic Carbon P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Cu – Copper, Fe – Iron, Zn – Zinc, Na – Sodium, me – milli equivalents, ppm – parts per million, Upper - LH0, Medium - LH1, Lower - UM1

Table 1.3. Effect of farming practices on soil pH, exchangeable acidity, total organic carbon and micronutrients at Kangaita

Treatment	pH	EA cmolc dm^{-3}	TN mg/kg	TOC mg/kg	P mg/kg	K cmolc dm^{-3}	Ca cmolc dm^{-3}	Mg cmolc dm^{-3}	Mn cmolc dm^{-3}	Cu mg/kg	Fe mg/kg	Zn mg/kg	Na cmolc dm^{-3}
Manure	3.95b	0.40a	0.66a	6.80b	126.70b	1.51b	7.99b	3.13b	0.31a	5.77b	80.80a	10.57b	0.81b
Standard	3.11a	0.50b	1.17a	6.15a	151.10b	0.37a	4.67a	1.19a	0.52b	2.25a	94.50a	2.28a	0.21a
Neglected	4.44c	0.38a	0.67a	7.24c	71.70a	0.28a	3.89a	0.81a	0.38ab	2.19a	47.00a	3.15a	0.18a
LSD	0.24	0.04	0.953	0.24	26.14	0.61	1.93	0.56	0.14	1.89	51.55	1.73	0.28
C.V%	6.20	9.00	114.30	3.60	22.50	84.50	35.00	33.00	34.70	55.60	69.60	32.50	70.10

Means followed by different letters within the same column are significantly different. EA – exchangeable acidity, TN – Total Nitrogen, TOC – Total Organic Carbon P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Cu – Copper, Fe – Iron, Zn – Zinc, Na – Sodium, me – milli equivalents, ppm – parts per million

Table 1.4. Effect of farming practices on Soil pH, exchangeable acidity, total organic carbon and micronutrients at Weru

Treatment	pH	EA cmolc dm^{-3}	TN mg/kg	TOC mg/kg	P mg/kg	K cmolc dm^{-3}	Ca cmolc dm^{-3}	Mg cmolc dm^{-3}	Mn cmolc dm^{-3}	Cu mg/kg	Fe mg/kg	Zn mg/kg	Na cmolc dm^{-3}
Manure	4.41b	0.43b	0.24a	2.567b	17.22b	0.60b	8.36b	0.93a	0.32a	13.65b	38.90a	7.00b	0.37b
Standard	4.23a	0.46b	0.27a	2.22a	8.89a	0.32a	6.48a	0.80a	0.63b	4.60a	35.90a	3.11a	0.18a
Neglected	4.66c	0.34a	0.26a	2.87c	13.33ab	0.24a	5.86a	0.52a	0.50b	2.27a	26.90a	3.43a	0.17a
LSD	0.18	0.05	0.03	0.19	5.79	0.09	1.65	0.44	0.16	4.40	11.17	1.14	0.02
C.V%	4.00	11.80	9.30	7.60	44.10	22.70	24.00	58.40	34.30	64.4	33.00	25.30	8.80
P Value	<.001	<.001	0.07	0.015	0.025	<.001	0.015	0.168	0.004	<.001	0.091	<.001	<.001

Means followed by different letters within the same column are significantly different. EA – exchangeable acidity, TN – Total Nitrogen, TOC – Total Organic Carbon P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Cu – Copper, Fe – Iron, Zn – Zinc, Na – Sodium, me – milli equivalents, ppm – parts per million

There were generally low levels of zinc in the soils across the farming practices. This is consistent with a number of research outputs which have reported low or deficient Zn in soils [14,16,18,19]. Deficiency of zinc in the soil can be induced by a buildup of phosphorus resulting from excessive application of phosphate fertilizers [16]. High levels of iron in the soil leads to copper deficiency and even though iron is found to be sufficient in the soil, it is poorly reflected in the leaves due to high levels of zinc in the leaves [17]. High soil pH results to retention of micronutrients in the soil [18]. The concentration of Mn, Cu, Fe and Zn increases with the increase in organic content in the soil [18]. Where potassium is not matched with nitrogen, there is depletion of starch reserves in the roots, degeneration of feeder roots characterized by die back and buildup of nitrates in the soil [19]. Phosphorus is affected by soil acidity [1]. Phosphorus availability to plants is highest when there is moderate pH of about 5.5 – 7 and becomes exceedingly unavailable at pH above 7 and below 5.5 [1]. In very acidic soils, phosphorus combines with hydroxides of iron and aluminum to form compounds that are unavailable to plants [1].

The availability of nitrogen in the soil is affected by other nutrients and it also affects the availability of other nutrients in the soil. Increase in nitrogen leads to decrease in mature leaf P, K, Ca and Mg due to the acidification of the soil by the ammonia in the fertilizer [15]. A decrease in mature leaf potassium can be attributed by leaching triggered by ammonium nitrate in NPK fertilizer [15].

Manure applied soils had a lower soil acidity. This is consistent with studies which have shown that application of manure leads to improvement in soil pH which is lowered by continued use of chemical fertilizers [3,11,12,13,14]. This is because decomposition improves soil acidity. The manure counters the negative effects of inorganic fertilizer application and reverses soil degradation. This facilitates sustainable farming which increases productivity with minimum environmental degradation [20]. Manure application also improves the nutrient conditions of the soil as well as a more stable C/N ratio and supports greatest biodiversity in soil [21].

5. CONCLUSION

Various agricultural practices have a significant effect on the availability and nutrient balance in the soil. Manure application is less degrading to the soils as compared to the other two farming practices. This knowledge will contribute to sustainable tea production with reduced environmental degradation. There are generally low levels of potassium, magnesium and zinc in soils under tea due to rapid removal through harvesting of the young shoots and leaves. We recommend further study on the effect of the farming practices on the productivity and quality attributes of tea.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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