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Soil Fertility Evaluation for Coffee (*Coffea arabica*) in Hai and Lushoto Districts, Northern Tanzania

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Authors' contributions

This work was carried out in collaboration between all authors. Author GM designed the study, performed the laboratory, statistical and spatial analysis, wrote the protocol, and wrote the first draft of the manuscript. Author BM directed the field surveys. Authors BM and JM managed the literature searches. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

The aim of this study was to evaluate the soil fertility status of selected coffee growing districts of Northern Tanzania and recommend immediate and long term soil management intervention strategies. The study was conducted in Hai and Lushoto Districts, between May and September, 2011. A total of 116 soil augerings and 10 soil profiles were described, and soil samples analyzed for the key fertility parameters. These were evaluated qualitatively by assigning scores against the requirements of Arabica coffee, and quantitatively by calculating the total soil-available nitrogen, phosphorus and potassium. Spatial assessment of the total soil-available nutrients was done using ArcView GIS 3.2 and ArcGIS 9.3. Soil fertility was found to be considerably low in the study areas, much lower in Lushoto than in Hai. Limitations common to both districts are low P and micronutrients, while the additional ones specific for Lushoto are low cation exchange capacity and exchangeable K. Spatial interpretation revealed interesting trends, which could be explained from the topography of the area and/or the farming practices common in the area. The results are discussed in this paper, and recommendations on appropriate integrated soil fertility management strategies are put forward.

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Keywords: Soil fertility evaluation; Arabica coffee; integrated soil fertility management; Northern Tanzania.

ABBREVIATIONS

APK: African Plantations of Kilimanjaro; CAN: Calcium ammonium nitrate; CEC: Cationexchange capacity; DAP: Di-Ammonium Phosphate fertilizer; DCSMS: District coffee subject matter specialists; ECEC: Effective cation exchange capacity; fN: Correction factor for nitrogen availability; fP: Correction factor for phosphorus availability;fK: Correction factor for potassium availability; GIS: Geographic information system; GPS: Global positioning system equipment; IDW: Inverse distance weighting interpolator; ISFM: Integrated soil fertility management; kE: Kilo-equivalent or kg-equivalent (=kg of available N); MRP: Minjingu rock phosphate, mined at Minjingu, Manyara region; OC: Organic carbon; SA: Sulphate of Ammonia fertilizer; SECAP: Soil erosion control and agroforestry project; SOTER: Soil and Terrain Database; TaCRI: Tanzania Coffee Research Institute; TSA: Total soil-available nutrients (N+P+K) in kE per ha;

1. INTRODUCTION

The importance of coffee in the Tanzanian economy is well documented by [1-4] among others. Coffee is a perennial crop whose average nutrient removal from a 1 ha soil per growing cycle is 135 kg of N, 35 kg of P_2O_5 and 145 kg of K_2O [5]. Considerable amounts of nutrients are also lost through leaching under a heavy rainfall and as a result of fixation and immobilization of nutrients in the soil. Such depletion may lead to the impoverishment of the soil. It is thus essential to plan for replacement of the lost nutrients [6,7].

Soils of Northern zone were described by [8] as originating from volcanic rocks, ash and lava (Kilimanjaro and Meru) and intermediate metamorphic rocks (the Pare-Usambara Fold Mountains). Addressing the problem of soil fertility decline in such diverse soils requires a baseline soil fertility evaluation, to determine location-based soil fertility status and appropriate integrated soil fertility management (ISFM) intervention for sustainable coffee production. The first study [9] described farmers' perception of soil fertility decline as a problem and their attitude towards ISFM. The current study was therefore meant to complement the information gained during the earlier study, by assessing the soil fertility status, performing spatial soil fertility evaluation for coffee and recommending appropriate soil management options.

2. MATERIALS AND METHODS

2.1 Study Area

This study was conducted in Hai District, Kilimanjaro Region and in Lushoto District, Tanga Region. These represent the historical and traditional coffee growing areas of Northern Tanzania [10], but they fall into two different agro-ecological zones [11]. The study area in Hai was confined to the coffee growing area, exclusively north of the Moshi-Arusha Highway, extending to the Kilimanjaro Mountain forest border, and comprises three divisions, Machame. Masama and Lyamungo. It ranges in altitude from 988 to 1873 m. above sea level. The landform is mainly plateau, gently sloping to undulating, moderately to well drained with slight to moderate risk of sheet and rill erosion. The study area in Lushoto was also confined to the coffee growing area, along the West Usambara Mountains, and included

Lushoto, Soni, Bumbuli, Mgwashi, Mtae and Mlalo divisions. It varies in altitude from 1157 to 1961 m above sea level. Landform is mainly plateau, gently sloping through undulating to rolling, moderately to well drained with slight to moderate risk of sheet and rill erosion. From earlier study [9], few people in Hai (one in every four) and very few in Lushoto (one in every six) use industrial fertilizers. Common fertilizer brands for Hai are calcium ammonium nitrate (CAN), NPK 20:10:10, Urea 46N, Minjingu rock phosphate (MRP) and diammonium phosphate (DAP) in a decreasing order of importance, while those for Lushoto are Urea 46N, NPK 20:10:10, DAP, SA and MRP in a decreasing order. By contrast, almost every farmer uses farmyard manure, and at the recommended rate of one tin (approximately 10 kg) per tree.

2.2 Field Sampling and Soil Characterization

A total of 58 auger sites and 5 pit profiles each represented the coffee growing divisions in Hai (Masama, Machame and Lyamungo) and Lushoto (Mgwashi, Bumbuli, Soni, Lushoto, Mlalo and Mtae), making a total of 116 auger sites and 10 profiles. All profiles and augerings were geo-referenced by using a GPS, and later geocoded and input into the GIS database for the areas. In situ soil characterization was done and soil properties such as depth, drainage, colour, texture, structure, consistence, porosity and root distribution were recorded. One profile per district was accorded a Class 1 description for purposes of soil classification, while the description for the other four profiles was of Class 2 for verifying the established SOTER database for the districts. Augerings were accorded a Class 4 description and used for soil fertility evaluation [12].

Bulk soil samples were collected with hand-auger from depths of 0-30cm, 30-60cm and 60-90cm for analysis. In the representative soil profile pits, bulk soil samples were collected from natural pedogenetic horizons. Undisturbed core samples were also taken from the walls of the Class 1 profiles for determination of bulk density and soil moisture characteristics.

2.3 Soil Analysis

The bulk soil samples were air-dried, ground, sieved through 2 mm sieve and analyzed for pH-water and pH-KCl (1:2.5), organic carbon (by Walkley-Black wet digestion method), total Nitrogen (by semi micro-Kjeldahl method), available Phosphorus (by Bray 1 extraction followed by quantification with UV-Vis spectrophotometer). CEC was determined by using the NH_4OAc extraction method at pH 7. Exchangeable cations were determined from the NH4OAc extracts by using flame atomic absorption spectroscopy. Texture was analyzed by using the Bouyoucos Hydrometer method. The micronutrients iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn) were determined by the method of digestion with nitric-perchloric acid followed by quantification by atomic absorption. Sulphur was determined by extraction with NH_4OAc and BaCl; while Boron was extracted with Azomethine H in hot water. Both extracts were quantified with a UV-Vis spectrophotometer at 420 nm [13-15]. Other routine data for pedological characterization of the representative pedons of the study sites were analyzed following the manual of [16].

2.4 Soil Classification

Using both field and laboratory data, the pedons representative of the study sites were classified to the Tier-2 of the World Reference Base for Soil Resources scheme of soil classification [17].

2.5 Soil Fertility Evaluation

Soil fertility was evaluated qualitatively and quantitatively. In the qualitative approach, fertility scores were assigned according to the soil fertility requirement of coffee [5] as shown in Appendix 1. Separate parameters were scored and total scores re-rated [10] without inversion. Final scores ranged from 0 (very poor) to 4 (very fertile) with descriptions shown in Appendix 2. All the analyzed parameters were involved in the scoring.

In the quantitative approach, only a few selected parameters were involved: pH and OC as fertility drivers, and N, P and K as primary macronutrients, as in [18]. These were picked because they are required by plants in amounts large enough to be quantifiable. Soil pH was used to establish the correction factors for available N, P and K (fN, fP and fK). Then relationships were empirically worked out between the correction factors, OC and the amount of total N, available P and exchangeable K to get the total available forms of each in kg ha^{-1} [19]. The nutrient equivalent factors of 1, 0.175 and 0.875 were derived for coffee as suggested by [20] and used to make the amount of nutrients uniform, and therefore additive. Soil fertility was measured in terms of the total number of nutrient equivalents that one ha of soil can make available to plants.

2.6 Mapping of Soil Fertility Status

We used ArcView GIS Version 3.2 to build shapefile database from the original Excel spreadsheets. Base map layers such as boundaries, rivers and road networks were digitized from mosaics of map sheets for Kilimanjaro and Lushoto, and edited by using the field GPS data. Attribute data generated during the fieldwork and laboratory analysis were geocoded into GIS-compatible format and loaded into the attribute tables.

The shapefiles were then exported to ArcGIS 9.3 for spatial interpolation of important fertility attributes. The inverse distance weighting (IDW) interpolator was used, with the option “nearest neighbours” set to 12, the power set to 2.0. The interpolated attribute was the calculated total soil-available nutrients (TSA) in kE ha^{-1}.

3. RESULTS AND DISCUSSION

3.1 Some Pertinent Pedological and Related Features of Representative Soils

A summary of the pertinent pedological and related features of the representative soil profiles for the two districts is given in Table 1.

The other profiles in Hai district were located at Nkwarungo Foo, Machame division (1514 m asl), categorized as high-altitude coffee belt); TemaMboreni, Masama division (1371 m asl) and APK Farm, Lyamungo division (1254 m asl), both categorized as medium altitude belt. The last one was at NarumuOrori, Lyamungo division (1049 m asl, representing the low-altitude coffee belt. Soils in the upper belt are shallow, well drained reddish brown to dark olive sandy loams, with thin dark reddish brown sandy loam topsoils. This upper belt is transitional into either a FibricHistosol or a Humi-UmbricNitisol. Soils in the medium belt are fairly deep, well drained with colours ranging from dark reddish brown to brown sandy clay loam topsoils, and dark reddish brown sandy to silty clay loam subsoils. These are Eutricand/or HaplicNitisols. In the lower belt, soils are very deep, fairly well drained reddish brown to dark reddish brown sandy loams, with thick dark brown sandy loam topsoils. They could also be transitional into a EutricCambisol further south, according to the SOTER database cited by [11].

Table 1. Some pertinent attributes of the representative soil profiles of the study areas

Site	Hai	Lushoto
Profile location	TaCRI Field 46 (37°14'54. 6" E/ 03°13'58.7" S; 1336 m asl.)	Yoghoi Prisons Farm (38°16.246 E/ 04°48.166 S; 1408 m asl.).
Parent material	Colluvial / alluvial derived from volcanic debris.	Colluvial and alluvial derived from metamorphic – gneissic rocks.
Soil properties	Ustic, isohyperthermic, very deep, well drained RB to DRB, SC to SCL, with thin brown clay loam topsoils.	Ustic, hyperthermic, very deep, well drained R to DRB clay to SCL, with thick red to dark red loam topsoils.
Diagnostic properties	AB/SAB subsoil breaking to fine shiny peds. gradual/diffuse and smooth boundary.	Medium and coarse AB and SAB, with clay and sesquioxidecutans in the subsoil.
Analytical indicators	Low CEC (≤ 22 cmol(+) kg^{-1}) and BS of average 32.88% topsoil and 24.09% subsoil	Low CEC (≤ 22 cmol(+) kg^{-1}) and BS of average 23.7% topsoil and 15.65% subsoil
Soil name	HaplicNitisol (Humic, Dystric).	CutanicAcrisol (Humic, Hyperdystric, Profondic)

Colours: R=red, RB=reddish brown, DRB=dark reddish brown. Texture: SCL=sandy clay loam SC=sandy clay. Structure: AB=angular blocky, SAB=subangular blocky.

The other profiles in Lushoto district were located at Nkongoi village, Mgwashi division (1385 m asl) and Ngazi village, Mlalo division (1396 m asl) comparable to the medium coffee belt of Hai. The other two were located at Mbelei village, Soni division (1517 m asl), and Sunga village, Mtae division (1834m asl) representing the high-altitude coffee belt. Soils are generally very deep and well drained. These are the characteristics of an old, well-developed soil like the Acrisol [11], [17]. Soil colour varies from dark brown to orange in Ngazi, red through dark red to dark reddish brown in Mbelei, brown through reddish brown to dark reddish brown in Nkongoi and dark brown to orange in Sunga. Textures are clay to silty clay loams, with clay loam topsoils in all profiles except Nkongoi where subsoils range from loam to sandy clay loam with sandy loam topsoil. The invariable evidence of illuviation of low-activity clays confirms the SOTER database [11] describing the soils as Humi-Umbric and CutanicAcrisols.

3.2 Important Soil Fertility Parameters

The comparative assessment of soil data followed [21], and a summary is given in Appendix 3. Soil texture varied with locations. Of the Hai soils, 38.37% were predominantly sandy clay loam, 37.21% were sandy loam, 8.72% each were clay and clay loam, 5.23% were silty loam, and 1.75% of the farms were sandy clay. Lushoto soil texture is dominated by sandy loam (36.9%) followed by sandy clay loam (22.62%), silty loam (11.9%), sandy clay and silty clay loam (8.93% each), loam (5.36%), silty clay (2.98%), clay (1.13%) and coarser textures (loamy sand to sand, 1.79%).Soil reaction (pH-water) had an overall mean of 6.09 for Hai and 5.85 for Lushoto, both considered ideal for Arabica coffee [22].

Soil organic carbon of 1.37 to 11.34% (average of 3.96%) for Hai is considered normal for coffee, with a minimum above 1%. As for Lushoto, the average of 2.02% is considered normal, though the minimum was far below 1%. Some areas (Wema, Kibandai, Ruvu, Kianga, Tiku and Mwangoi) showed remarkably low OC, (<0.5%), calling for efforts in organic matter enrichment. The mean total N was 0.17% for Hai and 0.08% for Lushoto; while the respective values of available P were 37.9 and 11.52 mg kg^{-1} and those of exchangeable potassium (K) were 0.98 and 0.41 cmol(+) kg^{-1}. The mean content of extractable Fe, Cu, Zn and B were higher in Hai than Lushoto, while those of Mn and S were lower. The effective cation exchange capacity (ECEC) was more or less the same in both districts. Ca/Mg ratios for Hai were between 1 and 90, very similar to the Mg/K ratios in the range of 1 to 80). The Ca+Mg/K ratios had a very wide range of 1.91 to 558.03). As for Lushoto, Ca/Mg ratios were between 1 and 116, lower than the Mg/K ratios in the range of 1 to 280). The Ca+Mg/K ratios had a very wide range of 2.68 to 1030).

3.3 Qualitative Fertility Evaluation

From Fig. 1, only four categories were distinguished in Hai: Low (1 site, 1.72% of total sites surveyed), moderately low, moderate and moderately high (10, 43 and 4 sites; 17.24, 74.14 and 6.9% respectively). The high fertility category (the most ideal soil for coffee production) did not feature in Hai. The absence of ideal soil for coffee indicates that the whole coffee growing area in Hai requires some kind of ISFM intervention for coffee to grow well and yield optimally.

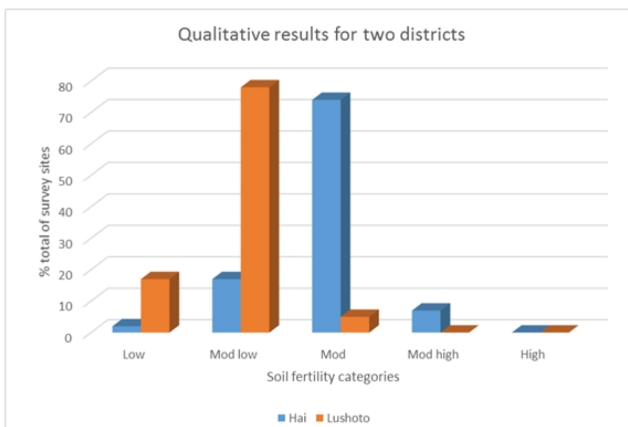

Fig. 1. Summary results of qualitative fertility evaluation, Hai and Lushoto districts

Fewer categories (three) were distinguished in Lushoto: Low (10 sites, 17.24%), moderately low (45 sites, 77.59%) and moderate (3 sites, 5.17%). Dominant limitations are CEC, B, Fe, Cu and Zn. This implies that soils of Lushoto are less fertile than those of Hai, and therefore will require more effort in ISFM.

3.4 Quantitative Fertility Evaluation

The calculated TSA for N, P and K for Hai ranged from 72.02-617.69 kE ha^{-1} (average 216.21 kE ha^{-1}). Lower figures (<100 kE ha-1) were found in Shari Mamba, limited by low N and K; and also in MasamaKyuu, limited by low pH, N and P. If the soil can only supply a sum of primary macronutrients less than 100 kE ha^{-1}, it is considered of very low fertility, which requires substantial ISFM efforts to grow coffee. At the other extreme, MasamaSawe, NarumuOrori, Nkwarungo and Nshara are all capable of supplying over 400 kE ha^{-1}. In Lushoto, TSA ranged from 26.78 to 585.29 kE ha^{-1} (average 152.0 kE ha^{-1}). Lower figures were noted in Galamba, Wema, Dulle, Yeriko, Kwekitui, Kidenya-Mgongo, Kianga, Ludende, Emau, Tiku and Kituja; the most prominent limitation being low K, followed by N, OC and P, in a decreasing order of importance. At the other end only one site (Mlalo- Mwangoi) showed to be capable of supplying over 400 kE ha^{-1}. This quantitative approach simply confirms the findings of the qualitative approach, that the soils of Lushoto are less fertile than those of Hai.

3.5 Spatial Data Interpretation

The spatial variation in total soil-available N, P and K (TSA) in kE.ha^{-1} for Hai is given in Fig. 2. Soil fertility is high at Orori-Nshara-Sawe, followed by Shari-Kyeeri-Kilanya. Lowest soil fertility is at the west (Mbosho-Lemira and Lukani-Mashua).

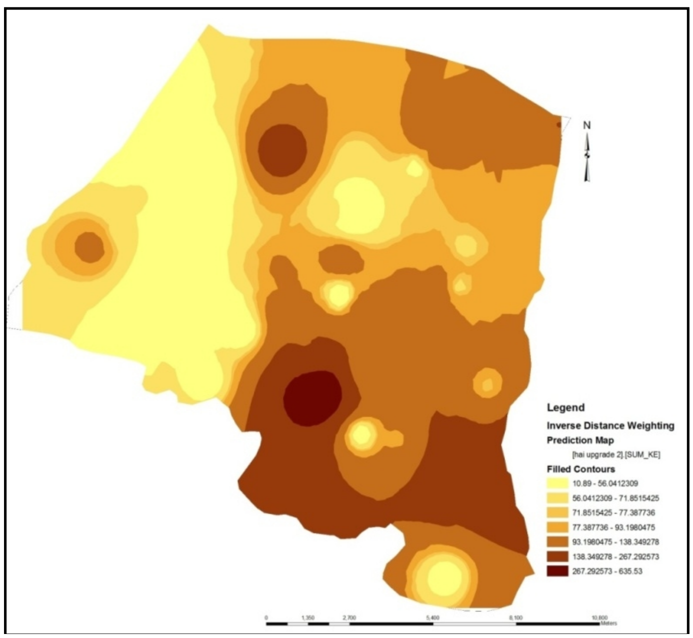

Fig. 2. Calculated soil available nutrients, Hai District

The relatively higher TSA values to the south than north could be explained by the terrain structure whereby nutrients tend to be washed from higher levels and enriched at lower levels. The Shari-Kyeeri and Nkwarungo-Kilanya areas have higher TSA values than their surroundings, and this can be related to organic matter enrichment resulting from the integrated crop-livestock farming system common in those areas. Smallholder farmers run dairy cattle projects as a way of income diversification [23]. They import maize crop residues from lowland farms for feed, and all residue finds its way somehow into the soil. The observed west-east soil fertility gradient is rather difficult to explain. The low fertility to the west (Lukani, Mashua, Mbosho and Lemira) could only be related to the farmers' crop management practices, as noted by [24]. During the baseline survey [9], coffee farms in these areas were almost at a total state of neglect, while in some areas coffee had been replaced by intensive bananas and, specifically for Lukani, Irish potatoes. None of the contacted farmers indicated having used industrial fertilizers in coffee, a practice more common with farmers to the east (Machame and Lyamungo). It seems as if the fertilizers used in the east has had positive impact on nutrient balance (countering the effect of nutrient mining in perennial cropping systems).

The spatial variation in total soil-available N, P and K (TSA) in $kE.ha^{-1}$ for Lushoto is given in Fig. 3.

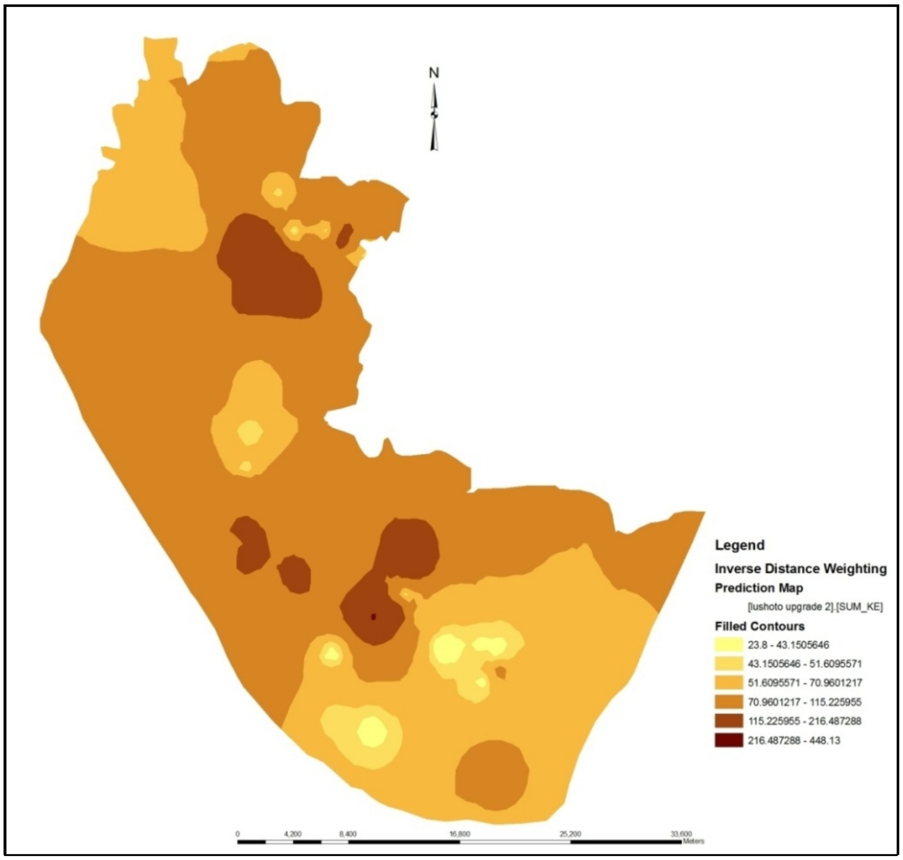

Fig. 3. Calculated total soil available nutrients, Lushoto District

The moderate to high fertility areas included most of Soni, Lushoto and Mlalo, characterized by steep but terraced land (thanks to SECAP Project [25]) intensively used for annual field crops like maize and beans; and high-value horticultural crops (vegetables and fruits). Lower fertility areas covered most of Bumbuli, Mgwashi and about half of Mtae, which are mostly high-altitude areas where bracken ferns are common, indicating low pH soils.

3.6 Discussion

Soil fertility survey, of the type used in this work, has been reported by several literatures including [26-30], at varying detail. Some have made use of remote sensing and GIS [18],

[31]; while others used statistical tools [21]. The bottom-line is the applicability of the results to the intended users. The approaches used in this work were therefore a blend of the two– statistical assessment per division, comparison with the soil fertility requirements of coffee [5], nutrient availability modeling and spatial interpretation. All these approaches agree in principle that soil fertility is being depleted in the coffee growing areas of Northern Tanzania, and call for ISFM intervention. They also agree that Hai is more fertile than Lushoto.

Both this work and the earlier one [9] have helped to prove the stakeholders' outcry [32] that soil fertility decline is an important limitation to coffee productivity. It was noted in the earlier study that few people (about 25% of the sampled farmers in Hai and about 16.67% in Lushoto) use industrial fertilizers. There is therefore an uphill task for TaCRI and the coffee extension machinery at district level to promote the right kind of nutrient management strategy to the farmers. Fertilizers commonly used are CAN, NPK 20:10:10, Urea 46N, MRP and DAP for the former, and Urea 46N, NPK 20:10:10, DAP, SA and MRP for the latter. With the exception of NPK, which TaCRI recommends at onset of season, it appears that farmers are used to apply N and P, but not K. By contrast, almost every farmer uses farmyard manure, and at the recommended rate of one tin (approximately 10 kg) per tree. Factors affecting farmers' decision on fertilizer use have been reported by several authors including [33-36] among others. They should be taken into consideration in devising an ISFM strategy for the coffee farmers. The database created in this work can be very useful in that regard.

Soil fertility is not a distinct soil property, it is rather a combination of many soil properties and therefore, measuring soil fertility requires knowledge about the interactions of those soil properties. Unfortunately, there is no unique technique for studying such interactions [37]. Soil productivity, which is defined as the capacity of a soil to support crop yield [18], is more meaningful to a farmer than soil fertility, though the two have mutual cause-and-effect relationship. To express one in terms of another (and particularly soil productivity in terms of the soil fertility data accrued from soil analysis), crop models become quite useful. It is therefore recommended that future soil fertility evaluation tasks be expanded through modelling to soil productivity evaluation.

4. CONCLUSION

This study has proved that soil fertility is considerably low in the study areas. The qualitative assessment revealed major limitations as low P and micronutrients for Hai, with added CEC and boron for Lushoto. The calculated TSA for N, P and K have shown that soils of Lushoto are less fertile than those of Hai, and therefore will require more effort in ISFM. The spatial interpolation of the key soil fertility parameters (pH, OC, N, P and K) for Hai and Lushoto has showed interesting similarities and differences among the parameters. Most of the observations were explained from either the topography of the area or the farming practices common in the area. A decision support tool for ISFM in coffee will therefore be helpful to farmers in Hai and Lushoto districts and other coffee growing areas in Northern Tanzania.

From this study, the following recommendations are made:

- TaCRI and the District Coffee Subject Matter Specialists (DCSMSs) should continue promoting the right kind of nutrient management strategy (including fertilizer types, rates and timing of application) to the coffee farmers.

- Stockists should consider having some straight K fertilizers (such as muriate of potash) for sale to coffee growers, especially in Lushoto where low K levels have been noted.
- "Integrated Farm Management" strategy which involves keeping livestock should be encouraged among farmers for both income diversification and nutrient cycling.
- Soils which showed remarkably low OC, (<0.5%), call for efforts in organic matter enrichment such as mulching, application of manures and composts.
- In areas of low pH and low CEC, a programme involving lime and organic matter is desirable because lime alone is not effective in soils of low CEC.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Appendix 1. Qualifying criteria for soil fertility scores used in this work

Characteristic	Unit	0	1	2	3	4
pH		<5.0, >7.8	5.0-5.4, 7.4-7.8	5.4-5.6, 6.6-7.4	5.6-5.8, 6.2-6.6	5.8-6.2
Total N	%	<0.05	0.05-0.08	0.08-0.10	0.10-0.12	>0.12
OC	%	<1.0	1.0-1.2	1.2-1.5	1.5-2.0	>2.0
Avail. P	mg kg^{-1}	<5	5-10	10-20	20-30	>30
CEC	$cmol_c$ kg^{-1}	<6.0	6.0-12.0	12.0-25.0	25-40	>40
Exch. Ca	$cmol_c$ kg^{-1}	<1.0	1.0-2.0	2.0-4.0	4.0-6.0	6.0 -12.0
Exch. Mg	$cmol_c$ kg^{-1}	<0.1	0.1-0.2	0.2-0.5	0.5-1.0	1.0-3.0
Exch. K	$cmol_c$ kg^{-1}	<0.05	0.05-0.1	0.1-0.2	0.2-0.5	0.5-1.0
Sulphur	mg kg^{-1}	<5	5-10	10-20	20-50	>50
Boron	mg kg^{-1}	<0.5	0.5-0.8	0.8-1.0	1.0-1.5	>1.5
Iron	mg kg^{-1}	<10	10-20	20-30	30-40	>40
Copper	mg kg^{-1}	<1.0	1.0-1.5	1.5-2.0	2.0-3.0	>3.0
Zinc	mg kg^{-1}	<2	2-4	4-6	6-8	>8
Manganese	mg kg^{-1}	<10	10-50	50-100	100-150	>150

Appendix 2. Description of final soil fertility scores

Total score ranges	New score assigned	Description	Implication to coffee
<20	0	Low	There are more than 3 limitations to coffee productivity and the coffee business is uneconomical
20-30	1	Moderately low	There are 3 limitations to coffee productivity. Intensive ISFM effort can make coffee business economical
30-40	2	Moderate	There are 2 limitations to coffee productivity. Moderate ISFM effort will make coffee business economical
40-50	3	Moderately high	There is 1 limitation to coffee productivity. Slight ISFM effort will make coffee business economical
>50	4	High	Soil is ideal for coffee productivity. Effort needed only to sustain the current soil fertility.

Appendix 3. Summary of soil fertility parameters involved in this study

District	Hai				Lushoto			
Parameter	**max**	**min**	**mean**	**sd**	**max**	**min**	**mean**	**sd**
pH (H_2O)	7.00	5.05	6.06	0.56	6.99	4.48	5.85	0.63
pH (KCl)	6.93	4.60	5.53	0.54	6.57	4.28	5.51	0.61
Ca^{2+}	16.40	1.30	7.95	3.06	23.70	0.60	7.46	5.12
Mg^{2+}	6.57	0.10	1.60	1.01	20.50	0.10	3.38	4.75
K^+	8.16	0.01	0.98	1.69	1.18	0.01	0.41	0.29
Na	1.62	0.02	0.42	0.32	0.53	0.01	0.14	0.10
% BS	160.82	6.66	41.68	37.61	682.97	20.00	137.33	137.97
CEC	90.00	6.00	38.45	17.85	24.00	4.00	9.88	4.20
ESP	6.75	0.00	1.51	1.57	6.58	0.04	1.70	1.34
%OC	11.34	1.37	3.96	1.80	6.72	0.22	2.02	1.44
Total N	1.04	0.01	0.17	0.17	0.18	0.04	0.08	0.03
C/N Ratio	816.75	3.07	87.47	138.62	160.04	1.54	28.93	27.01
Bray 1 P	296.00	0.52	37.90	51.54	73.50	2.70	11.52	11.65
S ppm	31.49	3.17	12.08	5.71	1.46	0.01	0.58	0.34
B ppm	10.31	0.41	1.64	2.20	56.58	1.01	16.63	12.07
Fe (ppm)	51.92	2.18	16.25	8.99	21.92	4.42	12.51	4.37
Cu (ppm)	16.82	0.93	5.11	4.64	3.89	0.00	1.03	0.80
Zn (ppm)	8.63	0.71	2.10	1.69	4.02	0.00	0.72	0.84
Mn (ppm)	41.60	2.23	12.46	7.96	69.43	10.70	44.11	17.90
ECEC	26.74	3.73	10.96	4.80	34.15	1.60	11.40	7.56
Ca:Mg	90.67	0.80	9.85	15.04	116.00	0.03	10.93	19.04
Mg:K	80.57	0.07	6.54	12.01	280.00	0.38	17.72	43.19
Ca+Mg/K	558.03	1.91	40.39	76.96	1030.00	2.68	82.62	187.10

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