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Evaluation of the Fertility Status of the Soils under Coffee Cultivation in Moshi Rural District, Kilimanjaro Region, Tanzania

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Authors' contributions

This work was carried out in collaboration between both authors. Author PIM designed the study, wrote the first draft and handled the literature researches. Author JM managed the analysis of the study and made corrections to the first manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: To study the causes of the decline in coffee production in Moshi Rural District, Kilimanjaro Region, Tanzania through evaluating the fertility status of the soils under coffee cultivation.
Study Design: Soils and leaf samples were collected in randomized design.
Place and Duration of Study: This study was undertaken in Moshi Rural District, Kilimanjaro region, Tanzania for the period of 2009/2010.
Methodology: Soils and leaves samples were collected and analyzed in the laboratory using various methods that gave results of physical and chemical properties of soils and leaves respectively.
Results: Some of the physical and chemical properties of the soils from the study area such as

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textural class of the soils were clay loam, CEC was medium, total N was low, available P was low, and available K was medium. The Ca, Mg, Na, Cu, Zn, Mn and Fe were high. Although, the soil samples had been taken from the same area, but variations were observed during samples analysis. The nutrients content in plant leaves were higher than those in the soils indicating presence of biochemical processes on the plant leaves. The leaves samples results indicated adequate to sufficient nutrients content in plants.

Conclusion: Therefore, since the physical characteristics of the Moshi Rural District soils are good for coffee production the improvement on the chemical characteristics of the soils will enhance the maximum production of coffee.

Keywords: Coffee; soil; leaves; nutrients; fertilizers.

1. INTRODUCTION

The economy of Tanzania as is the case for most of the developing countries in Sub-Sahara Africa (SSA) depends much on agricultural production [1]. About 85% of the Tanzania population lives in the rural areas practicing agriculture by cultivating both food and cash crops for their livelihoods [2]. However the yields of most of the crops are very low compared to the world average yields [3]. This situation is probably due to the low fertility status of most of the soils under crop cultivation in Tanzania coupled with inappropriate farming and cropping systems that do not critically address the soil and land resources in relation to crop production. One of the perennial cash crops grown in Tanzania is coffee [2]. There are two species of coffee grown in Tanzania namely *Coffee robusta* and *Coffee arabica. Coffee robusta* is grown in low altitude areas while *Coffee arabica* is grown in high altitude areas. Coffee as a cash crop contributed about 25% to the economy of Tanzania during the late 1960ś to 1980ś [3]. Currently coffee production trends in Moshi Rural District and in other areas in Tanzania are decreasing or on the decline year after year [4]. This is due to continuous depletion of most of the essential nutrient elements in the soils [5]. These nutrients element deficiencies in soils affect both the quality and quantity of coffee produced. Further, coffee as a perennial crop has also influenced some of the physical, chemical and biological conditions and interactions in the soil ecosystem, culminating into reduced availability of the plant nutrients [5]. The above mentioned practice, observation and incidence have resulted in soil degradation, low yields of coffee per unit area and low quality of coffee or coffee beans. Impacts of the decline in coffee production on the livelihoods of the farmers includes diversification where farmers have opted for the cultivation of other crops such as maize, flowers, tomatoes and beans which take short time on the farm to mature, migration of people to the urban areas looking for employment and increase in poverty and food insecurity among the Tanzanian rural population particularly the small scale coffee growers. To overcome the above mentioned constraints associated with soil degradation problems under coffee cultivation, the fertility status of the soils have to be assessed.

The outcome of such an assessment or study will assist the farmers to correctly address the problems associated with the degradation of the soils and reverse the declining trends of coffee production in Moshi Rural District.

2. MATERIALS AND METHODS

The study on the causes of the decline in coffee production in Moshi Rural District, Kilimanjaro Region, Tanzania was conducted/ based at Kibosho Division. Kibosho Division had been selected on the basis that coffee production has declined drastically as from the 1980's hence affecting the livelihoods of the coffee farmers. The study included the analysis of soils and coffee plant leaves for the quantification of the available plant nutrients and nutrient contents respectively and other soil fertility attributes. The soil samples and leaves samples were collected from ten farms at Kibosho Division selected randomly.

2.1 Soil Sampling

Ten soil samples were randomly collected using the simple random sampling technique/ procedure [6], from ten spots of each of the selected farms. The ten spot samples from each farm were mixed to constitute one composite sample from each farm. Thus in total there were ten composite soil samples for analysis. The soil samples were collected within the canopies of the coffee trees/ plants to the depth of 30 cm.

2.2 Soil Preparation for Analysis

The composite soil samples were crushed, air dried, and then ground and sieved through 2 mm sieve. The 2 mm sieved soil samples were used for the determination of total nitrogen by the micro Kjeldahl method, organic carbon determined by the wet digestion (oxidation) method of Walkley-Black, plant extractable phosphorus was extracted by ammonium fluoride, Cation exchange capacity (CEC) was determined by the ammonium acetate (CH_3COONH_4) saturation method, while the leachates from the proceeding steps were used for determination of exchangeable Ca and Mg by atomic absorption spectrophotometer while K and Na were determined by flame photometer, soil pH was measured electrometrically in 1:2.5 (weight/volume) soil: water suspensions, DTPA extractable Cu, Zn, Mn and Fe were quantified by atomic absorption spectrophotometer and particle size analysis using the recommended methods of soil analysis for soil fertility evaluation purpose [7].

2.3 Coffee Leaf Sampling

Five coffee leaves (newly matured leaves) according to Lima Filho [8] were sampled from each coffee tree where the soil samples were taken/ collected. The 50 coffee leaves from ten coffee trees, from each farm constituted the representative leaf sample for each farm. The ten representative leaf samples (from each farm) were washed with clean water, drip dried, air dried and then packed/ placed in paper bags for onward transportation/ delivery to the Department of Soil Science of Sokoine University of Agriculture for further preparation and analysis.

2.4 Plant Material Preparation for Analysis

The air dried coffee leaf samples were oven dried at 65°C to constant weights. The oven dried plant material samples were grounded to fine powder for the determination of various nutrient contents, namely N, P, K, Ca, Mg, Cu, Zn, Fe and Mn. N was determined by the micro Kjeldahl method, P was extracted by ammonium fluoride, Ca and Mg were extracted by ammonium acetate saturation method and determined by atomic absorption spectrophotometer while K was determined by flame photometer, DTPA extractable Cu, Zn, Mn and Fe were quantified by atomic absorption spectrophotometer [7,9].

3. RESULTS AND DISCUSSION

3.1 Physical and Chemical Properties of the Soils

The soils of the study area were sandy to clay textural class which indicated to have medium to high moisture capacity possibly high nutrients retention capacity [10]. The electrical conductivity was categorized by [11] as salt free soils. The pH of the soils showed variation from 5.51 which is acid soil to 7.04 which is neutral and the mean pH was 6.54. The variation in soil pH is probably due to application of acidic fertilizers or weathering of some acidic materials. According to [12], the mean soil pH is slightly acidic and the pH is favourable for coffee growth. Also it is proved that for good coffee yield, coffee crop requires the soils with sufficient drainage, and the pH should be between 5.0-6.5, however, coffee also can grow close to the neutral pH [13]. A study by Wright and Estoby [14] reported that, it is obvious the primary nutrients N, P and K as well as the secondary nutrients such as Ca and Mg are more available at a pH value of 6.5 than at any other pH values. In addition, the minor elements such as Fe, Mn, B, Cu, Cl and Zn are less available at a pH value of 6.5 than at more acidic reaction [15].

The study site had medium organic carbon content [12]. The organic carbon percentage and organic matter percentage are concomitants indicating the mineralization of nutrients and the ability of the soil to hold nutrients cations, structural stability and water holding capacity [16]. In addition, Masdoff and Ray [17] reported that the availability of essentially all major nutrients is influenced by the presence of soil organic matter, which supplies the available nutrient pool via mineralization, and desorption and bind nutrients via immobilization and adsorption reactions.

The total nitrogen content was medium [12]. This condition could be attributed to the high rate of decomposition, mineralization and oxidation of organic compounds and crop residues added to the soil, phenomena which are common in soil under tropical condition [15]. However, the application of nitrogen fertilizers especially urea is recommended due to the fact that coffee is one of the crops, which grow better in slightly acidic soils and therefore seemed to be the solution so as to rise N to the high range.

Table 1. Chemical and physical properties of the ten composite soil samples

Parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
PSD	**%S=48, %Silt=12, %C=40 T.C=sandy clay**	**%S=42, %Silt=12, %C= 46 T.C=sandy clay**	**%S=36, %Silt=14, %C=50 T.C=clay**	**%S =34, %Silt=12, %C=54 T.C=clay**	**%S=30, %Silt=14, %C=56 T.C=clay**	**%S=34, %Silt=14, %C=54 T.C=clay**	**%S=32, %Silt=12, %C=56 T.C=clay**	**%S=32, Silt=12%, %C=56 T.C=clay**	**%S=40, %Silt=12, %C=48 T.C=clay**	**%S=42, %Silt=14, %C=44 T.C=clay**
EC ($mScm^{-1}$)	0.14	0.30	0.28	0.12	0.23	0.21	0.10	0.19	0.24	0.15
pH (water)	6.27	6.73	7.03	5.50	6.84	6.91	5.51	6.86	7.04	6.66
Organic Carbon (%)	2.68	2.75	1.90	2.63	2.41	1.99	2.86	2.89	2.99	2.08
Total N (%)	0.22	0.26	0.16	0.19	0.23	0.14	0.20	0.27	0.29	0.20
Extractable P ($mg\ kg^{-1}$)	17.91	35.31	55.13	55.13	28.08	9.78	13.21	28.96	33.15	20.33
CEC($cmol\ kg^{-1}$)	36	48.6	42.8	42.8	49.0	46.8	49.4	54.6	41.8	45.5
Exchangeable bases										
($cmol\ kg^{-1}$)	15.45	21.19	22.37	10.45	16.11	16.90	8.27	19.08	19.54	15.32
Ca	3.78	6.18	4.73	2.69	4.29	4.96	2.48	4.66	5.06	4.55
Mg	1.38	1.77	3.04	1.38	2.55	2.16	0.99	1.86	3.62	2.06
K	0.94	0.71	0.67	0.78	0.67	0.65	0.67	0.63	0.64	0.63
Na										
DTPA Extractable										
($mg\ kg^{-1}$)	109.89	135.86	35.44	43.59	74.33	86.56	52.85	75.44	233.11	140.70
Cu	10.89	8.10	9.57	6.87	4.84	7.16	2.15	6.97	11.50	5.88
Zn	130.57	127.30	164.36	128.39	160.00	109.86	89.16	109.86	72.81	136.02
Mn	671.13	559.13	542.65	705.56	558.54	529.40	559.87	493.64	321.46	538.68
Fe										

Note: PSD = Particle size distribution, S = sandy, C = clay, T.C = textural class

Available phosphorus content was high according to London [12]. A study by Reed [18] reported that, the less the rainfall the higher the percentage composition of P in the surface soil. Therefore, the soils will still require some amendments so as to sustain and to make availability of phosphorus sufficient to the coffee plants. Also Reed [18] reported and suggested that phosphate to be applied at rate of 125 kg ha^{-1}, and single super phosphate should be applied at a rate of 0.45 kg per thirty paces so as to improve availability of phosphorus in coffee farms. Also a study by Masdoff and Ray [17] reported that, the mineralization of soil organic matter is the primary source of phosphorus in the natural ecosystem of coffee farms.

Cation exchangeable capacity (CEC) of the Moshi Rural District soils was high according to Landon [12]. Masdoff and Ray [17] reported that, soil organic matter is responsible for a large portion of the CEC in the soil. It was estimated that, 20 to 70% of the whole CEC is because of humic substance, and the remainder can be attributed to silicate and non-silicate colloids, which are the primary source of Ca, Mg, Na and K in plant nutrients [14].

The content of DTPA extractable Cu, Zn, Mn and Fe were high according to Landon [12] and therefore, the content is enough for crops growth and development. The extractable micronutrients in the Moshi Rural District soils were high probably due to some agronomic practices such as using micronutrients containing pesticide to control diseases and insect pests in the coffee crop which lead to accumulation of micronutrients residues which degraded slowly naturally when get into the soil.

Also the high content could have been attributed by mineral forming the soils contain moderate extractable micronutrients. On other hand, this condition could have been attributed by soil pH due to the fact that several essential elements tend to become less available when the soil pH is raised from 5.0 to 7.5 the range which include the pH of the study area [14].

3.2 Contents of Nutrients in Coffee Plants in Relation to Soil Fertility

The data in Table 3 show that some of the soils of Moshi Rural District are able to supply quantities of plant nutrients sufficiency to raise a good crop while other soils supply to adequate amounts of nutrients. The sufficiency or otherwise adequate of a nutrient for coffee growth can be indicated by its foliar content, as revealed by leaf analysis and this has been used to guide the fertilizer use programmes.

Leaf nutrient contents are a reflection of the levels of the nutrients in soils [14]. For good growth of coffee, a soil needs to be able to provide nutrients to the extent that leaf contents reach the sufficiency range [19]. The results of plant analysis are often grouped into different categories namely deficient, critical, sufficient/adequate and toxic. The critical concentration is a unique concentration level, which separate the deficient range from the adequate range or the adequate range from the toxic range [14]. A number of factors, such as age of the leaf, climate, shade conditions, and time of the year and the environmental conditions affect the concentration of nutrients in plants. The data given in Table 3 show that while some samples contained nutrient levels lower than the critical values, other had comparable levels. For example, some coffee leaves clearly showed adequate of N, P, K, Ca, Mg, and Mn while other leaf samples had sufficient levels of these nutrients. In the case of Fe and Cu the leaf contents were in the sufficiency to high range as a result of use of copper fungicide sprays.

Robinson [20] reported that visible symptoms of deficiency are known to occur in mature coffee leaves during very dry weather in the absence of irrigation and mulch. However in most cases the condition clears up with onset of rain. This

Table 2. Sufficiency ranges

Macronutrients				
N	**P**	**K**	**Ca**	**Mg**
2.5 – 3.5%	0.15 – 0.30%	2.0 – 3.0%	0.8 – 1.6%	0.30 - 0.50%

Micronutrients			
Cu	**Zn**	**Fe**	**Mn**
10 – 30 ppm	15 – 150 ppm	75 – 300 ppm	50 – 500 ppm

Source: Jones et al. [19]. 4th pair of coffee leaves back from growing tip

Table 3. Nutrients content in the ten coffee plant leaf samples

Parameters	1	2	3	4	5	6	7	8	9	10
N (%)	2.17	2.86	2.59	2.21	2.28	2.24	1.96	2.49	2.14	2.77
P (%)	0.14	0.17	0.15	0.09	0.15	0.16	0.15	0.18	0.08	0.15
Ca (%)	0.59	0.75	0.61	0.91	0.59	0.70	0.64	0.71	0.53	0.78
Mg (%)	1.82	2.72	2.46	2.15	1.87	2.42	1.58	2.67	2.09	2.98
K (%)	1.67	2.50	1.75	1.65	2.21	1.69	1.73	1.75	1.83	2.26
Cu (ppm)	17.2	17.3	11.9	24.5	13.7	13.7	17.2	64.0	13.7	47.8
Zn (ppm)	148.6	140.3	127.8	145.3	184.3	140.3	125.8	171.9	141.1	125.3
Fe (ppm)	61.4	90.0	75.7	82.9	61.4	90.0	125.7	75.7	82.9	118.6
Mn (ppm)	53.3	59.1	73.6	122.9	53.3	67.8	122.9	73.6	53.3	62.0

emphasizes the need to choose a sampling period that will correctly reflect the supply of nutrient to plants. Some nutrient contents were above the critical levels, the high levels were associated with deficiency of some other nutrients. For example, where Mn deficiency was observed, K levels were high implying that K depressed Mn uptake [21]. These observations demonstrate the importance of complimenting soil analysis with plant analysis. However, considering that nutrients are continually removed from the soil by plants, thus continually lowering the fertility levels of soils, frequent monitoring of the plant nutrient contents and/or soil levels is important.

4. CONCLUSION

The fluctuation of coffee production in Moshi Rural District is mainly attributed by the decline of N and P nutrients status in the soils due to the continuous uptake by the coffee plant. The analysis of the coffee leaves sample showed the high concentration of nutrients content than those in the soils indicating some requirement of soil amendments in order to produce optimum coffee production. This should be followed by instituting appropriate management so as to maintain the plant nutrient levels at or above the critical levels.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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