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Original Research Article

Evaluation of the fertility status of the soils under coffee cultivation in Moshi Rural District, Kilimanjaro region, Tanzania.

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: Randomized soil and leaf sampling.
Place and Duration of Study: This study was undertaken in Kibosho Division, Moshi Rural District, Kilimanjaro region, Tanzania for the period of 2009/2010
Methodology: This study was prompted by the continuous decline of coffee production in this area, seriously affecting the livelihoods of the farmers. Soils and leaves samples were collected and analysed 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 area of study such as textural class of the soil were clay loam, CEC was medium, total N was low, available P was low, and available K was medium. However, the soil samples had been taken from the same area, but variations were observed during data analysis.
Conclusion: Therefore, since the physical characteristics of the Moshi Rural District soils are good for coffee production the improvement of the chemical characteristics of the soils will enhance the maximum production of coffee in Moshi Rural District.

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 (Chauvin *et al.*, 2012). About 85% of the Tanzania population lives in the rural areas practicing agriculture by cultivating both food and cash crops for their livelihoods (Sarris, 2006). However the yields of most of the crops are very low compared to the world average yields. 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 (Sarris, 2006). There are two species of coffee grown in Tanzania namely *Coffee robusta* and *Coffee arabica. Coffeae robusta* is grown in low altitude areas while *Coffeae 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. Currently coffee production trends in Moshi Rural District and in other areas in Tanzania are decreasing or on the decline year after year. Possible reasons for the decline in coffee production in Moshi Rural District and Kilimanjaro at large include: (i) decline in the fertility status of the soils due to the continuous coffee cultivation with little or no replenishment of the nutrients removed from the soils by the coffee trees (ii) low prices of coffee in the world market due to over production in other countries like Brazil (iii) poor quality of the coffee produced due to the inadequate nutrient supply to the coffee plants (iv) lack of subsidies to agricultural inputs such as fertilizers, pesticides and herbicides (v) lack of stable markets for the coffee beans and (vi) irregular and inadequate rainfall. The above mentioned practices, observations and incidences 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. The probable major cause of decline in coffee production in Moshi Rural District and Kilimanjaro at large is low soil fertility due to the effect of continuous cultivation of the same crop on the same piece of land for years. This has led

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to depletion of most of the essential nutrient elements in the soils (Mekuria *et al*., 2004). These nutrient element deficiencies in soils affect both the quality and quantity of coffee produced hence price of the coffee beans and consumable coffee bean products, increase of pests and diseases. Climatic changes for example increase in temperature due to over utilization of natural vegetation that also leads to depletion of water sources. 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(Mekuria *et al*., 2004). 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 under coffee production. Therefore, there is a need to assess the fertility status of soils in Moshi Rural District, Kilimanjaro Region as an attempt to reverse the declining trends of coffee production in Moshi Rural District. The main objective of the study was the identification of soil attributes contributing to low coffee yields and poor quality of the coffee in Moshi Rural District. The specific objectives of the study thus involved, assessment of the contents and availability of the macronutrients and micronutrients in the soils in question, determination of other soil properties/ attributes that influence soil productivity, like soil pH, CEC, soil structure, soil texture, soil temperature, soil moisture etc and determination of the nutrients contents in coffee plants (leaves) in relation to the quantities of nutrients available in the soils. By correctly addressing the above specific objectives, then one would be in a better position to suggest strategies for the enhancement and sustaining coffee production in Moshi Rural District, Kilimanjaro Region, Tanzania.

2. MATERIAL 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 villagers or 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 (Petersen, 1986), from ten spots from 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 30cm.

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, organic carbon, plant extractable phosphorus, plant available sulphur, exchangeable bases (Ca, Mg, K and Na), cation exchange capacity, soil pH, exchangeable acidity, DTPA extractable Cu, Zn, Mn, Fe and particle size analysis using the recommended methods of soil analysis for soil fertility evaluation purpose (Moberg, 2001) as in table 1

2.3 Coffee Leaf Sampling

Five coffee leaves (newly matured leaves) 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, SUA, for further preparation and analysis.

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2.4 Plant Material Preparation for Analysis

The air dried coffee leaf samples were oven dried at 65 ^{0}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, Na, Ca, Mg, Cu, Zn, Fe, Mn and S using the recommended methods for plant material analysis for various nutrients (Moberg, 2001; Okalebo *et al.,* 1993).

Table 1: Summary of Method used in Analysis of Soil and Plant Samples

PARAMETER	METHOD USED	REFERENCE
(i) Particle size analysis	Hydrometer method	Juo (1979)
(ii) pH	1:2.5 soil/water suspension using pH meter	Mc Lean (1982)
(iii) Organic carbon (OC)	Walked-Black method	Nelson and Sommer (1982)
(iv) Total N	Kjeldahl method	Bremner and Mulvarey (1982)
(v) Available P	Olsen method (bray-1-p)	Olsen et al (1954)
(vi) Available S	Sodium acetate/acetic acid extraction buffered to pH 4.5	Juo, A.S.R (Editor); (1979)
(vii) Exchangeable cation (Ca2+,Mg2+, K+ and Na+)	In neutral 1M-ammonium acetate extract and sodium determined by atomic absorption spectrophotometer	Moberg (2001)
(viii) Cation exchange Capacity (CEC)	1M by saturation by 1M NHAOAC at pH 7.0	Moberg (2001)
(ix) DTPA Extractable (Cu, Zn, Mn, and Fe)	DTPA extraction and atomic absorption spectrophotometer	Lindsay and Norvel (1978)
(x) Total N in plants	Wet acid digestion	Okalebo et al (1993)
(xi) P in plants	Wet acid digestion and determined by Spectrophotometer at 882nm	Okalebo et al (1993)
(xii) Ca, Mg, K, Na, Cu, Zn, Fe, and Mn in Plants.	Wet acid digestion and determined by Atomic absorption spectrophotometer	Okalebo et al (1993)
(xiii) Sulphur in plants	Wet acid digestion and determined by Spectrophotometer at 882nm	Okalebo et al (1993)

3. RESULTS AND DISCUSSION

Table 2: 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
ECs	0.14	0.30	0.28	0.12	0.23	0.21	0.10	0.19	0.24	0.15
pH	6.27	6.73	7.03	5.50	6.84	6.91	5.51	6.86	7.04	6.66
O.C	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	17.91	35.31	55.13	55.13	28.08	9.78	13.21	28.96	33.15	20.33
CEC	36	48.6	42.8	42.8	49.0	46.8	49.4	54.6	41.8	45.5
Exch bases										
Ca	15.45	21.19	22.37	10.45	16.11	16.90	8.27	19.08	19.54	15.32
Mg	3.78	6.18	4.73	2.69	4.29	4.96	2.48	4.66	5.06	4.55
K	1.38	1.77	3.04	1.38	2.55	2.16	0.99	1.86	3.62	2.06
Na	0.94	0.71	0.67	0.78	0.67	0.65	0.67	0.63	0.64	0.63
Exch Acidity										
Al^{3+}	-	-	-	0.05	-	-	0.05	-	-	-
H^{+}	-	-	-	0.1	-	-	0.1	-	-	-
ECEC	21.54	29.85	30.80	15.41	23.62	24.67	12.56	26.22	28.88	22.55
DTPA Extract										
Cu	109.89	135.86	35.44	43.59	74.33	86.56	52.85	75.44	233.11	140.70
Zn	10.89	8.10	9.57	6.87	4.84	7.16	2.15	6.97	11.50	5.88
Mn	130.57	127.30	164.36	128.39	160.00	109.86	89.16	109.86	72.81	136.02
Fe	671.13	559.13	542.65	705.56	558.54	529.40	559.87	493.64	321.46	538.68
Available S	7.25	23.48	6.69	12.26	10.59	11.15	13.94	4.46	12.64	12.82
PBS	59.83	61.42	72.30	36.00	48.20	52.71	25.43	48.02	69.09	49.88
OM (%)	4.58	4.75	3.27	4.54	4.15	3.43	4.94	4.99	5.16	3.58

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Table 3: Ratios of the soil parameters.

Soil sample #	C:N	Ca :Mg	Ca :K	Mg :K	Ca+Mg :K
1	12:1	4:1	11:1	3:1	14:1
2	10:1	3:1	12:1	3:1	15:1
3	12:1	5:1	7:2	2:1	9:1
4	14:1	4:1	8:1	2:1	10:1
5	10:1	4:1	6:1	2:1	8:1
6	15:1	3:1	8:1	2:1	10:1
7	14:1	3:1	8:1	3:1	11:1
8	11:1	4:1	10:1	2:1	12:1
9	10:1	4:1	5:1	1:1	6:1
10	10:1	3:1	7:1	2:1	9:1

The C: N ratios, organic matter contents, percentage base saturation, and exchangeable sodium percentage, the exchangeable Ca: Mg; Ca: K; Mg: K and the Ca + Mg: K ratios were calculated from the analytical data generated/obtained.

Table 4: Nutrient contents in the ten coffee plant leaf samples

Parameters	1	2	3	4	5	6	7	8	9	10
N (mg/kg)	2.17	2.86	2.59	2.21	2.28	2.24	1.96	2.49	2.14	2.77
P (mg/kg)	0.14	0.17	0.15	0.09	0.15	0.16	0.15	0.18	0.08	0.15
S (mg/kg)	5.34	7.93	6.15	5.53	5.72	5.14	8.20	5.57	5.26	7.11
Ca (mg/kg)	0.59	0.75	0.61	0.91	0.59	0.70	0.64	0.71	0.53	0.78
Mg (mg/kg)	1.82	2.72	2.46	2.15	1.87	2.42	1.58	2.67	2.09	2.98
Na (mg/kg)	0.16	0.18	0.16	0.16	0.18	0.18	0.18	0.20	0.18	0.18
K (mg/kg)	1.67	2.50	1.75	1.65	2.21	1.69	1.73	1.75	1.83	2.26
Cu (mg/kg)	17.2	17.3	11.9	24.5	13.7	13.7	17.2	64.0	13.7	47.8
Zn (mg/kg)	148.6	140.3	127.8	145.3	184.3	140.3	125.8	171.9	141.1	125.3
Fe (mg/kg)	61.4	90.0	75.7	82.9	61.4	90.0	125.7	75.7	82.9	118.6
Mn (mg/kg)	53.3	59.1	73.6	122.9	53.3	67.8	122.9	73.6	53.3	62.0

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3.1 Soil texture

The percentage sandy, silt and clay for the ten soil composite samples, ranged from 30-48%, 12-13% and 40-56% with mean values 37%, 13% and 50% respectively. Sandy to clay have medium to high moisture capacity possibly high nutrient retention capacity. These soils are suitable for coffee production given that other growth factors being constant (Cardozier, 1957).

3.2 Electric conductivity

Electrical conductivity of the soils from the area of study ranged from 0.1mS/cm to 0.3mS/cm and the mean soil electrical conductivity of the study area was 0.2mS/cm. FAO-UNESCO (1973) categorized this electrical conductivity as salt free soils. Therefore, the soils under study area are good for agriculture production.

3.3 Soil pH

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 Landon (1991), the soil is slightly acidic and the pH is favourable for coffee growth (Ngungi *et al.,* 1982). 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 (Rehm *et al.,* 1984). Therefore, the fluctuation in coffee production in Moshi Rural District is not due to soil pH because it is between the required ranges, which can give optimal yields. Donahue, *et al.,* (1971) reported that, it is obvious the primary nutrients N, P, K as well as the secondary nutrients S, 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 (Woomer and Swift, 1994).

3.4 Organic carbon percentage

Organic carbon contents from Moshi Rural District soils varied from 1.90% to 2.99% and the mean of 2.52%. ILACO (1981) categorized this soil organic carbon level as low. Also it is known that organic carbon percentage and organic matter percentage are concomitants, which ranged from 3.27% to 5.16%, giving organic matter percentage content of the area of study as 4.34%, which according of Landon (1991) reported as high. This indicates that, the soil is good for coffee production, since soil organic matter is central to the maintenance of soil fertility, mineralization of N, P and S, the soil ability to hold nutrients cations, structural stability and water holding capacity (Rowell, 1994). This justifies that all the above parameters are present in the soils at the level, which can support coffee production. In addition, Magdoff and Weil (2004) 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. Since the percentage organic matter levels in Moshi Rural District soils have found to be high, the decline of coffee production in Moshi Rural District is not contributed by the organic matter levels in the soils. However, the addition of organic matter is very important in order to sustain the chemical and physical conditions of the soils. This will be achieved through application of manures, incorporation of crop residues and controlling soil erosion (Cardozier, 1957).

3.5 Total Nitrogen

Total nitrogen content at the area of study varied from 0.14 to 0.29% giving the mean of total nitrogen content of 0.21%, which according to Landon (1991) is medium**.** This condition could be attributed to the high rate of decomposition, mineralization and oxidation of organic compounds and non residue added to the soil, phenomena which are common in soil under tropical condition (Smith and Sanchez, 1980; Uchara and Gillman, 1980), because of the high temperature and humidities, hence high microbial activities. Therefore, from this analysis we can say coffee production decline in Moshi Rural District could have not been attributed mainly by nitrogen deficiency in soils because the nitrogen contents in the soils are at the medium range. However, the application of nitrogen fertilizers seemed to be the solution so as to make to be at the high range. Keeble (1932) reported that, the nitrogen fertilizers, phosphates and salt of potash must be supplied to the soils in order to maximize the yield of the coffee crop.

The natural supplies of the three nutrients in soil are, except in rare cases, not large enough to enable plants to produce high yield. If the natural supplies inexhaustible, the fertilizers must be added to the soil to replace those nutrients which are removed by growing crops. Otherwise, there will be decrease of fertility status of the soils. In order to increase and maintains the nitrogen contents in the soils for optimum coffee production, sulphate of ammonium, and urea are recommended due to the fact that coffee is one of the crops, which grow better in slightly acidic soils (Martin and Leonard, 1967). The rate of application depends on the fertility status of the soils, but NPK fertilizer has been used in the ratio of 20:10:10 with positive response in coffee production. Also too much Nitrogen fertilizer encourages vegetative growth, and extends the vegetation period (Rehm, 1984).

The addition of organic matter in the soil is another way which could be used to improve total nitrogen in Moshi Rural District soils, also Donahu, *et al.,* (1971) reported that, the Nitrogen, Phosphorus and Sulphur in soils are constituents of organic matter. Approximately 95% of the soil total nitrogen, 5% to 60% of total phosphorus and 10 to 80% of total soil sulphur are present in organic matter.

3.6 Available phosphorus

Available phosphorus content in the area of study varied from 9.78me/100g to 55.13me/100g giving mean content of available phosphorus to be 29.7me/100g, which according to London (1984) report categorized as a high level. Also Buckman, *et al.,* (1969) reported that, in general, the less the rainfall the higher the percentage composition of total P, K, Ca and Mg 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. Thus, cattle manure and phosphate fertilizers are the most important materials in soil fertility of the area. Reed (1968) reported and suggested that phosphate to be applied at rate of 125kg/ha, and single super phosphate should be applied at a rate of 0.45kg per thirty paces.

However, cattle manure should be applied at the rate of 7.5 metric tones per hectare (Reed, 1968). Not only these but also incorporation of crop residues and other vegetation remains in the soil as source of organic matter will be required so that to improve availability of phosphorus. Magdoff and Weil (2004) reported that, the mineralization of soil organic matter is the primary source of available nitrogen, phosphorus and sulphur in the natural ecosystem.

3.7 Cation exchangeable capacity

Cation exchangeable capacity content of the Moshi Rural District soils ranged from 36.0Cmol/kg to 54.6Cmol/kg giving the mean cation exchange capacity to be 45.7Cmol/kg, which according to Landon (1991) is high. However, the soil still require some amendments in order to ensure that its exchanging cation is continuously sufficiently for high soil fertility which can lead to achieve high yielding in coffee production. These amendments can be achieved by applying organic matter in the soil. Fred and Weil (2004) reported that, soil organic matter is responsible for a large portion of the C.E.C in the soil. It was estimated that, 20 to 70% of the whole C.E.C 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 and K in plant nutrients (Donahue *et al.,* 1971).

3.8 Available calcium

Calcium contents from the area of study varied from 8.27 Cmol/kg to 22.37 Cmol/kg giving the mean calcium content of the area of study to be 16.47 Cmol/kg. According to Landon (1991), the calcium content in the soil is medium. The condition could have been attributed by the level of C.E.C in the soil or low Ca rock minerals content (Brady *et al.,* 1996). Therefore, to make the soil supplying the optimum Ca^{2+} amount, liming by using $CaCO_3$, $CaMg(CO_3)_2$ and $CaSO_4$ (gypsum) which are the good sources of Ca^{2+} in the soil, and if are not available, ashes and slurry should be applied.

3.9 Available magnesium

From the area of study, magnesium content ranged from 2.48Cmol/kg to 6.18Cmol/kg of exchangeable bases, giving the mean exchangeable base of Mg as 3.72Cmol/kg, which is categorized by Landon (1991) as high. This condition have been attributed by pH level, since as pH of the soil approaches neutrality (pH = 7), Mg^{2+} in the soil solution decreases due to fixation of the Mg^{2+} by soluble silica or aluminium chloride. Therefore to make the soil supply optimum Mg^{2+} to plants , amendment could be

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done, this will be achieved by applying $CaMg(CO_3)_2$ and through improving water management and conservation such as fallowing, mulching, which reduce leaching processes of the magnesium in the soil.

3.10 Available Potassium

From the area of study, potassium content varied from 0.99mol/kg to 3.62Cmol/kg giving the mean content of the area to be 2.08Cmol/kg, which according to Landon (1991), the level is high which might have been attributed by the minerals forming the soils. Since clays mostly are high in available potassium (Donahue *et al.,* 1971), as the textural class shows. Therefore, K^+ has no limitation in coffee production because the supply is at the optimal level.

4.11 Available sodium

Exchangeable Na^+ content in the area of study ranged from 0.63Cmol/kg to 0.94Cmol/kg giving the mean content of the study area to be 0.70Cmol/kg. According to Landon (1984) reported that the exchangeable sodium content in the soil is low. Therefore, problems related to sodium accumulation will not be encountered in this soil. However, the soil amendments should be done in order to increase level Na^+ in the soil for optimum coffee production.

3.12 Exchangeable acidity

The exchangeable acidity of the Moshi Rural District soils was 0.2C. According to London (1984) the exchangeable acidity of the soils were very low, this is due to the fact that the exchangeable acidity depends on the pH of the soils where the pH of the entire area ranged from 5.51 to 7.04 this could have low possibility to cause the exchangeable acidity of the soils to be high. As the soil pH decreases less than 5.50 there are increased of exchangeable acidity this could have been contributed by weathering of some materials that contain high amount manganese or application of the acidic fertilizers in the soils. However, the high the exchangeable acidity the less the nutrients available for plant uptake although some plant nutrients are available at the low pH in the soils.

3.13 Effective CEC.

The effective cation exchange capacity of the Moshi Rural District soils ranged from 12.56Cmol/kg to 30.80Cmol/kg and the mean of effective CEC was 23.61Cmol/kg. According to London (1991) the amount of ECEC in the soil is in the medium category. This is because ECEC depends much on the CEC of the soil. Therefore, in order to produce the optimum coffee some soil amendments should be done to increase ECEC of the soil. This can be achieved through applying organic matter, incorporation of crop residues in the soil or application of inorganic fertilizers in the soil that contain mainly the cations

3.14 DTPA Micronutrients

3.14.1 DTPA extractable copper

The content of DTPA extractable Cu at the study area ranged from 35.44mg/kg to 233.11mg/kg, giving the mean DTPA extractable Cu to be 98.78mk/kg, this level of extractable copper content according to Landon (1984) categorized as high, therefore, the content is enough for crops growth and development. The extractable copper in the Moshi Rural District soils is very high probably due to some agronomic practices such as using blue copper pesticide to control diseases and insect pests in the coffee crop which lead to accumulation of copper residues which degraded slowly naturally when get into the soil.

3.14.2 DTPA extractable Zinc

The content of DTPA extractable Zn at the area of study range from 2.15mg/kg to 11.50mg/kg, which gives the mean DTPA extractable Zn to be 7.39mg/kg, the amount of extractable is moderate and is good for growth and development of the coffee plant (Landon, 1984). This condition could have been attributed by mineral forming the soils contain moderate extractable Zn. Also Foth *et al.,* (1978) reported that, Zn are released in weathering Zn^{2+} absorbed by plants, absorbed on cation exchange. 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 and Zn is being one of the elements (Donahue *et al.,* 1971). Therefore, for high yielding of

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coffee, amendment should be done to increase the Zn to the high level for coffee plants uptake. Amendment can be done by applying sludge as fertilizer in the field. Donahue *et al.,* (1971) reported that both kinds of sludge are especially high in percentage of Zn and low K and also, application of organic matter in the soil through incorporation of crop residues, mulching by cleared grasses, etc. However, Christianson (1988) reported that, the extent of Zn deficiency increases with increased soil organic matter.

3.14.3 DTPA extractable manganese

The content of DTPA extractable Mn at the area of study ranged from 72.80mg/kg to 164.36mg/kg, giving the mean DTPA extractable Mn to be 122.83mg/kg, where according to Landon (1984) categorized as a moderate range. Since the Mn is one of the elements which are required by plants in relatively small quantity then, there is no need for amendments of extractable Mn in the soils. Therefore, there is no limitation of coffee production caused by Mn in Moshi Rural District soils.

3.14.4 DTPA extractable Iron

From the area of study DTPA extractable Fe ranged from 321.46mg/kg to 705.56mg/kg, giving the mean DTPA extractable Fe content of the area to be 548.01mg/kg. According to Lindsay and Narvell (1978) reported as a high rate. This means that the amount is enough for optimal crop yielding, however, this condition could have been attributed to mineral content rocks forming the soil at the area of study (Gee and Bander, 1986). Also Landon (1991) reported that the major form of Fe in soil are very sparingly soluble ferric oxides which occur as coating of aggregate or a separate constituents of the clay fraction. Republic of China (1984) reported that Fe deficiency is common in leaching tropical soils, particularly in calcareous soil derived from limestone and in poorly drained soils.

3.15 Base Saturation Percentage (BSP)

The base saturation percentage content of the study area ranged from 25.43 to 72.30% giving the mean content of BSP to be 52.29%. According to Varley (1983) the BSP range is moderate and therefore the soil is less fertile for coffee production. The base saturation percentage can be increased by addition of organic matter, mulches, incorporation of crop residues and application of ashes in the soils.

3.16 Available sulphur

The available sulphur content in the Moshi Rural District soils ranged from 4.46mgS/kg to 23.48mgS/kg giving the mean available sulphur of the area to be 11.53. According to Landon (1991) the available sulphur was medium. The condition which could have been attributed to the moderate organic matter percentage in the soil as Donahue *et al.,* (1971) reported that a large part of the sulphur that plants use comes from sulphate, which are a by product in super phosphate fertilizer and through biological release from decomposing organic matter. It's also possible that the condition could have been attributed to the climatic condition of the area of study of high temperature which can quicker decomposition of organic matter. Since the nutrient supplying power of the soil for almost all of the nitrogen and for valuable amount of phosphorus and sulphur is dependent upon the total amount of organic matter and its rate of decomposition in relation to the time that plant require these nutrients (Donahue *et al.,* 1971). Therefore, application of sulphate of ammonia, FYM, composite manure, green manure and incorporation of crop residues in the field could raise sulphur level in the soil, consequently high yielding can be achieved.

3.17 Contents of nutrients in coffee plants in relation to soil fertility.

The sufficiency or otherwise 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. For good growth of coffee, a soil needs to be able to provide nutrients to the extent that leaf contents reach the sufficiency range. 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. 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 above table shows that while some samples contained nutrient

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levels lower than the critical values, other had comparable levels. For example, the data given in table 4 show that some coffee leaves clearly showed a deficiency 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 (1964) 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 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 (Calton *et al.,* 1961). These observations demonstrate the importance of complimenting soil analysis with plant analysis. The data in table 4.2 above 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 inadequate amounts of nutrients. 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. This should be followed by instituting appropriate management so as to maintain the plant nutrient levels at or above the critical levels, for high coffee yields. This monitoring has not been undertaken in Moshi Rural District previously, but it is high time that such a strategy is instituted because nutrients in many coffee growing soils have been mined continually for a long time without much replenishment.

4. CONCLUSION

Generally the fluctuation of coffee production in Moshi Rural District is mainly attributed by the decline of nutrients status in the soils due to the continuous uptake by the coffee plant, a perennial crop. However, there are some other factors that increase the fluctuation which includes; low prices of coffee in the world market, high prices of inputs such as fertilizers, pesticides, increases of diseases and insect pests incidence to the coffee crop, increase of global warming for example shortage of rainfall with poor distribution, increase of temperature that affect growth and development at different stages for coffee such as: at flowering and fruits formation. Also poor government policies that do not encourage coffee research and support the agricultural sector by provision of subsidies and financial support to the coffee farmers as the result coffee farmers abandoned from the cultivation of coffee crops and hence low coffee production. The analysis of the coffee leaves sample showed the high concentration of nutrients content than those in the soils, although they were at the inadequacy level and hence required some soil amendments in order to produce optimum coffee production.

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