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Fertility Mapping of Soil macronutrients of Bako Tibe District, West Shewa Zone of Oromia National Regional State, Ethiopia

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Abstract

This study was conducted to assess the chemical and physical characteristics of soil fertility status of Bako Tibe District in Western Oromia, Ethiopia. Field survey was conducted during the 2014/2015 cropping season, 252 geo-referenced composite samples were collected from top soil (20cm) depth and Data was analyzed during 2015. The particle size distribution was determined by laser diffraction particle size analyzer and clay was found to be the dominant texture of the area. The soil pH value (pH- H_2O) ranged from 4.5 to 6.4, acidic. The exchangeable acidity ranged between 0.04 and 2.8 $cmol_c kg^{-1}$. The mean total nitrogen and percent organic carbon were 0.25% and 2.97% respectively. From this study, deficient areas in terms of available phosphorus and sulfur were about 99% and 98%, respectively. The relative abundance of basic cations in the exchangeable complex of soil was dominated by calcium (Ca) followed by magnesium (Mg), potassium (K), and sodium (Na) with the mean values of 11.85, 4.28, 1.12 and 0.55 $cmol_c kg^{-1}$, respectively. On the other hand, the median of Ca:Mg ratio was 2.81. The mean value of total exchangeable base (TEB) and cation exchangeable capacity (CEC) were 17.79 and 17.38 $cmol_c kg^{-1}$, respectively.

Keywords: soil, macronutrient, fertility mapping, GIS

1. Introduction

Ethiopia is the largest agrarian country in Africa both in terms of area and population. Agriculture is the mainstay of the country’s economic activity for the majority of the population and its contribution to the national economy is significant. But soil fertility decline has been one of the most challenging and limiting factors for food security in the country (MoARD, 2010). Soil fertility decline in all regions of Ethiopia, and some had even suggested that a national disaster is looming on the horizon Wassie and Shiferaw, 2011). It is thus generally accepted that there is a decline in soil fertility, due to reduction in the length of fallow periods, lower levels of fertilizer use and/or inappropriate type of fertilizers application, complete removal of crop residues (70-90%) from fields and/or burning, lack of adequate soil conservation practices, mono cropping and nutrient mining have aggravated the situation (Chillot and Hassan, 2010). Based on the recent report the nutrient balance for nitrogen, phosphorous and potassium was more negative when the balance was studied in different soil fertility classes (Amare *et al*., 2006; Grima *et al*., 2012).

The project involves different activities such as collection of geo-referenced representative soil samples and analyzing them for soil fertility parameters using both wet chemistry and spectral analysis methods. This study was, therefore, initiated to enrich the country's soil database by mapping the fertility status of the soils of Bako Tibe District which was not yet documented and revise the fertilizer recommendation package for the area.

Therefore, this study had general objective of mapping the fertility status of agricultural land of Bako Tibe District in West Shewa Zone. The specific objectives were:

- To assess the macronutrients fertility status and develop the soil fertility map of the study area,
- To enrich the national soil fertility information database; and
- To suggest appropriate fertilizers types for the agricultural land of the study area.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted in Bako Tibe District of West Shoa Zone, Oromia National Regional State, Ethiopia (Figure 1). The geographical extent of the area ranges from $8^0$59' to $9^0$95'North latitude and $37^0$04' to $37^0$29'East longitude with the altitude ranges from1569 – 2633m. Its area coverage is about 638.21 km^2. The soils of the study area are classified as red soil (*biyyoo diimaa*), black soil (*biyyoo guracha*) and brown soil (*biyyoo dalacha*). The ten-year weather data (2004-2014) revealed that the area has a uni-modal rainfall pattern, and mean annual total rainfall was 1244 mm. The mean minimum, mean maximum air temperatures were 13.4 and 28.4°C, respectively (Figure 2).

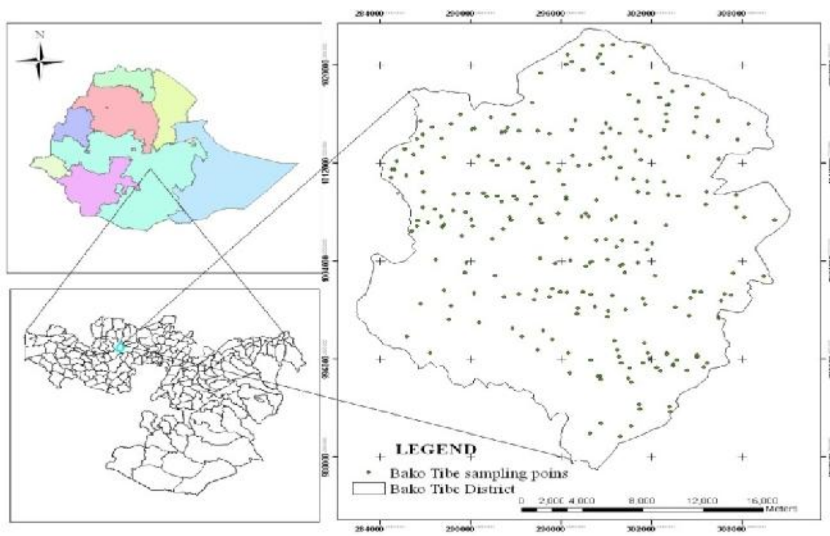

Figure 1. Map of the study area and soil sampling sites of Bako Tibe district.

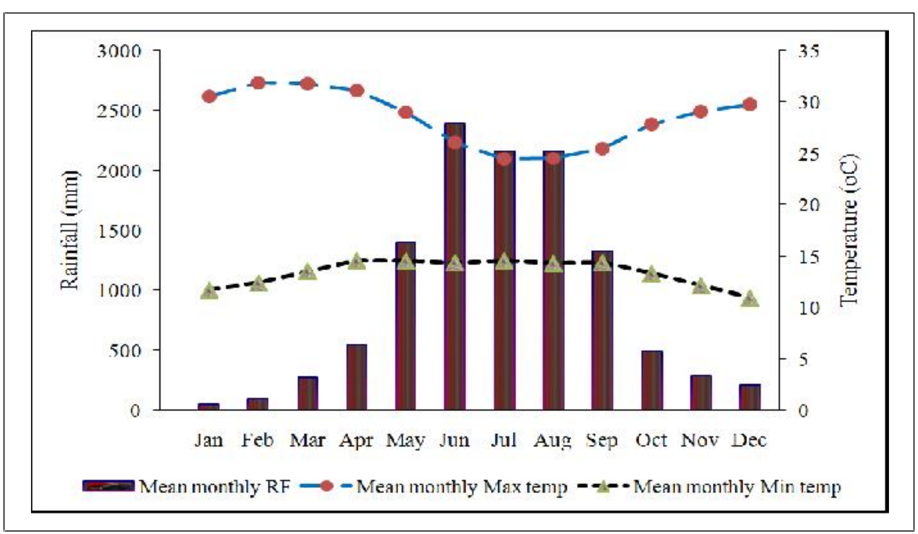

Figure 2. Mean annual rainfall, maximum and minimum temperature of Bako Tibe district

Rain fed agriculture dominates the farming activity in the district and rain fed cultivation includes, maize (*Zea mays L.*), teff (*Eragrostistefi (*zucc.) Trotter), hot pepper (*Capsicum frutescence*), haricot bean (*Phaseolus vulgaris*), mango (*Mangifera indica*), bread wheat (*Triticum aestivum L.*) were known plant vegetation

2.2. Sampling Site Selection, Field Survey and Soil Sampling

At the beginning, pre-defined and randomly distributed sampling points were generated using geographical information system (GIS-ArcGIS10.0). Geo-referenced surface soil samples were collected from randomly distributed pre-defined sample and the exact sampling point was determined by letting the GPS average position for at least between 3-5 minutes. Potentially cultivated grazing land or fallow land was also sampled in certain cases. After the center of the sampling point was identified, between10 to 15 sub samples were taken within the dominant crop type unit having relatively uniform topography, and composite samples were collected (20cm depth) layer using labeled auger for soil chemical analysis.

2.3. Laboratory Analysis of Soil Properties

The collected soil samples were analyzed using standard analytical methods at National Soil Testing Center (NSTC) for SOC, total nitrogen(TN), soil pH and texture and the rest parameters were analyzed in Altic BV laboratory in The Netherlands. Particle size was analyzed using HORIBA 2010 laser diffraction in water dispersed particles. Soil reaction measurement was done in a supernatant suspension of 1:2 soils to water solution ratio as outlined by Van Reeuwijk (1993). For all soil samples, the EC was measured using electrical conductivity meter as outlined by Van Reeuwijk (1993).

The concentrations of C and N were determined from soil MIR spectral analysis. Available phosphorus, available sulfur, exchangeable basic cations (Ca, Mg, K, and Na) of the soil were extracted by Mehlich-III as described in Mehlich (1984) and their concentrations were determined by Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES). For soil samples having the pH-H_2O less than 5.5, exchangeable acidity (Al and H) was determined on 1N potassium chloride (KCl) extract of soil using a 1:10 soil to volume ratio as described by Van Reeuwijk (1993). Moreover, the soils were ground (0.5mm) with mortar grinder and ground samples were loaded in well and for one sample there were four consecutive wells of an aluminum micro plat having 96 wells and smoothed with surface glass rod. Absorbance spectra of entire soil samples were measured to determine concentrations of C and N using OPUS version 7.0 software in the middle infra red (MIR) spectral range of 2500-25000nm.

2.4. Data Analysis

Descriptive statistical and correlation analysis were used for quality analysis and to determine the relation between soil properties SAS 9.2 software were used.

2.5. Soil Fertility Mapping

Spatial prediction were evaluated between predictors and the indices using standard version of kriging (Ordinary Kriging) as the following equation 1 which expanded to equation 2. Highest occurrence probability distribution at threshold (critical value) of the nutrient was mapped to observe the direction of soil fertility variation parameters. The slope of the study area was generated from digital elevation model (DEM) of Ethiopia from 90m × 90m resolution image by using ArcGIS10 special analysis of surface analysis.

$$Ζ(s) = \mu + \acute{\varepsilon}(s) \qquad \text{Equation 1}$$

Where μ is the constant stationary function (global mean) and έ(s) is the spatially correlated stochastic part of the variation.

$$\hat{z}Ok(s_0) = \sum_{i=0}^{n} wi(s0) \cdot z(si) = \lambda T_0 \, z \cdot \qquad \text{Equation 2}$$

Where λT_0 is the vector of kriging weights (wi) of, z is the vector of n observations at primary locations needs to equal one to ensure an unbiased interpolator. Following Mehlich-III extractable nutrients (K, P and S) and MIR detectable (%OC and TN) and pH of the soil fertility atlas of the woreda was generated.

3. Results and Discussion

3.1. Physiographic Characteristics of the Study

The topographic variation of the are strongly sloping plain (> 8%) and gently sloping plain (4-8%) cover about 38.49% and 21.43% of the study areas, respectively. The hill area considered as the slope of greater than 16%, which occupy 19.4% of the study area (gullies, hilly, rolling and undulated) meaning moderately steep (16-30%), steep (30-60%) and very steep (>60%) land forms (Figure 3). The rest (19.63%) was dominated by flat to almost flat slope (0-5%).

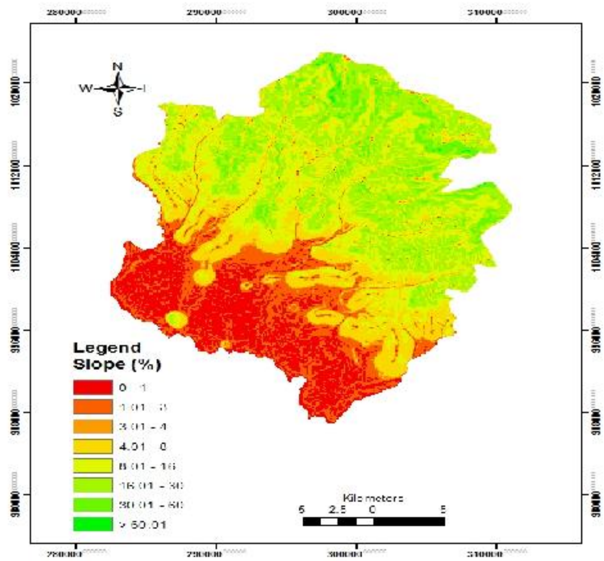

Figure 3. Slope map of the Bako Tibe district

3.1.1. Particle size distribution

Clay was the dominated soil textural class in the study area. The mean of percent clay, silt and sand were 80.35 ±10.19, 13.18 ±5.95, 6.46 ±6.16, respectively (Table 1). The distribution of the percent sand and silt was very small with minimum of 0.01% and 3.15% and maximum 47.59% and 34.82%, respectively. In all of the study area, clay loam, sandy clay loam and clay were the particle identified (Figure 4). The lowest and highest clay percentages were 31.64% and 95.88%, respectively.

Table 1. Descriptive statistics for particle size distribution in the study area

Particle size distribution	Statistics (N = 252)			
	minimum	maximum	mean	SD(±)
Sand (%)	0.01	47.59	6.46	6.16
Silt (%)	3.15	34.82	13.18	5.95
Clay (%)	31.64	95.88	80.35	10.19

N = number of data set; SD (±) = standard deviation

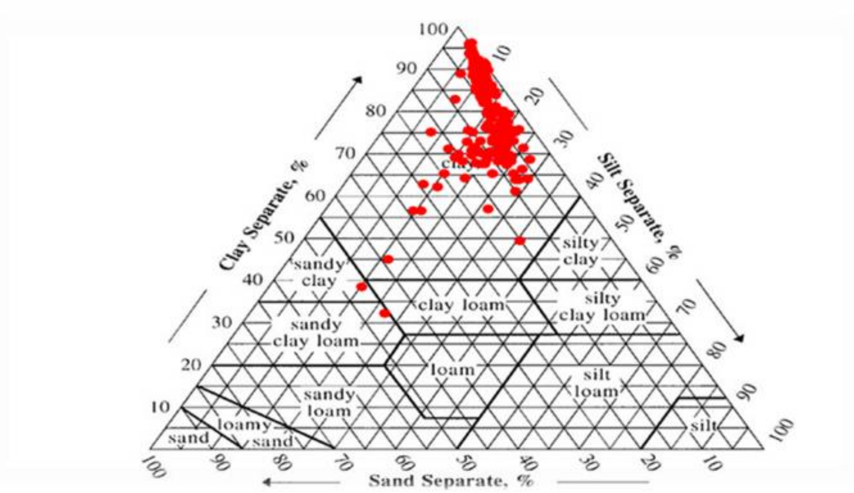

Figure 4. Soil textural class distribution of the total samples on the USDA textural triangle

3.2. Soil Chemical Properties

3.2.1. Soil reaction (pH), electrical conductivity (Ec) and Exchangeable acidity

The pH of the soils of the study area ranged from (4.5 - 6.4) with the mean value of 5.5 ± 0.33. From 252 samples of the study area, 46.12% were strongly acidic whereas 53.89% were moderately acidic. Decreasing of the soil pH in western and southern Ethiopia was due to intensive rainfall leach nutrients such as Ca and Mg and with subsequent replacement by Al and H ions (Abreha et al., 2012). The electrical conductivity (ECe) ranges from 0.066 - 0.67dS/m. According to EthioSIS (2014), the electric conductivity (EC) of the study area was very low. The highest value of electrical conductivity was observed at the flat plane (slope of 0-1%) and the lowest ECe was observed from gently sloping to hilly slope cultivated land (4-8%), this result agreed with the report by Mesfin, (2007).

The exchangeable acidity of 116 samples, which have pH ≤ 5.5 was ranged from 2.8 -0.04 $cmol_c kg^{-1}$. The highest exchangeable acidity was recorded in mono cropping hot pepper cultivated field followed by maize cultivated field. This might be because farmers use high rate of fertilizers (400kg/ha of urea and 200kg/ha of DAP) on hot pepper cultivated land. Similarly, Abreha *et al.* (2012) reports the negative correlation between pH and exchangeable acidity in highland of Ethiopia.

3.2.2. Organic carbon, total nitrogen, Available phosphorus and sulfate-sulfur

The maximum and minimum mean value was 5.08, 1.64 % and 2.94% ± 0.43 respectively had (Table 3). Only two samples have medium value and the rest were low . The standard error map (Figure 6) also estimates the soil OC has the average uncertainty (variation) of 0.36% at maximum distance from sample

The maximum, minimum and mean of the total N was 0.44%, 0.13%, 0.26 (±0.04), respectively (Table 3). The maximum was recorded in potentially cultivable virgin land and/or fallow land and the minimum was recorded from maize cultivated land. According to Havlin *et al.* (2013), about 59.87% samples had high TN content and 40.13% were medium in total N content (Figure 7). This result was in line with the findings of (Tekalign *et al.*, 1991). The minimum, maximum, and mean of C: N recorded was 9.83, 13.24, and 11.57, respectively (Table 3). The C: N in most Ethiopian soils was from 10:1-12:1 (Taye *et al.*, 2003) with the exception of four samples, which were wider than this value.

Available P varied from medium to very low while most of the study area was dominated by very low. About 95, 3.99, and 0.24% had very low, low, and medium in P contents, respectively. The variability of soil P values indicates soil management practices, amount and type of organic and/or inorganic fertilizers applied, the length of fallowing periods, the relatively weathering and fixation capacities of P in soils. Birru (1999) reported that availability of P varied considerably with land use pattern, soil reaction, total P reserves and the particle size distributions of the soils. Achalu *et al.* (2013) reported that more than optimum (highest) available P concentration could be observed from lower concentration of Al-Fe and higher fertilization of inorganic fertilizers and maximum values of organic matter.

Table 2. Descriptive statistics for available phosphorus and sulfur in the study area

Soil properties	Statistics (n= 252 and n= 116 only for soil acidity)							
	min	max	mean	Q_1	Q_2	med	SD(±)	skewness
Soil pH	4.5	6.4	5.55	5.35	5.8	5.58	0.33	-0.205
Soil Acidity	0.04	2.8	0.41	0.14	0.43	0.22	8.57	2.64
O C	1.64	5.09	2.97	2.71	3.23	2.98	2.98	0.447
TN	0.128	0.438	0.258	0.236	0.280	0.26	0.257	0.317
C:N	9.83	13.24	11.57	11.10	12.01	11.47	11.47	0.351
Av. sulfur	3.60	27.80	12.53	10.15	12.45		3.87	0.556
Av. phosphorus	0.050	81.20	5.55	1.90	3.30	3.3	8.57	5.55

n, number of data set; min., minimum value; max., maximum value; med., median value; Q1 first quartile; Q2 second quartile; SD(±) standard deviation; OC, organic carbon content in percent; TN, total nitrogen in percent; C: N, carbon to nitrogen ratio; Av, available

Available S varied from 3.6-27.8 $mgkg^{-1}$ in maize cultivated land and fallow land, respectively. The mean value was 12.52 ± 3.87 (Table 2). Very low, low and medium available S covered 8.78, 91.19 and 0.05%, respectively (Figure 9). Sulfur is taken up by most grain crops in amounts similar to those of P, from 10 to 30 kg/ha (Weil and Mughogho, 2000) but no addition of this nutrient to the agricultural land in organic or inorganic forms are some of the problems for sulfate-S mining from arable land.

3.2.3. Exchangeable bases (Ca, Mg, K, and Na)

The value of exchangeable K varied from more than optimum (very high and high) to less than optimum (low). The maximum, minimum and mean of exchangeable K were 2.45, 0.33, and 1.12 $coml_ckg^{-1}$, respectively (Table 3). According to Karltun *et al.*, (2013), 1.29% of the district were deficient in exchangeable K (Figure 10). Similarly, Tegbaru, (2014) reported K deficiency and sufficiency in Abay-Chomen district western Oromiya. The highest and lowest exchangeable Na content recorded was 0.148 and 1.77 $coml_ckg^{-1}$ with the mean value of 0.55 ± 0.25, respectively (Table 3). The maximum, minimum, and mean Ca values were 27.17, 2.59, and 11.85 $cmol_c\ kg^{-1}$ ±5.19, respectively (Table 3). The Mg content varies from highest to medium were 10.96 $cmol_c\ kg^{-1}$ and 1.11 $cmol_c\ kg^{-1}$ respectively and this accounts 87.96% and 9.35% of the area respectively; whereas the minimum, maximum, and mean values of the Ca: Mg ratio was 1.32, 4.39, and 2.86 ±0.546, respectively (Table 3). The results are in agreement with the findings of Aberu *et al.* (2003). According to the rating made by Eckert (1987), about 97.61% of the district was occupied by low Ca content and only 2.39% have medium contents of Ca and Mg.

Table 3. Descriptive statistics for exchangeable bases (K, Ca, Mg, Na), total exchangeable bases, cation exchangeable capacity and Ca:Mg ratio in the study area

Soil fertility parameters	Statistics (n= 252)							
	min	max	mean	Q_1	Q_2	median	SD(±)	skewness
Ca($cmol_ckg^{-1}$)	2.59	27.17	11.85	8.115	13.74	11.20	5.19	0.983
Mg($cmol_ckg^{-1}$)	1.11	10.96	4.28	2.83	4.81	3.75	2.12	1.26
K($cmol_ckg^{-1}$)	0.333	2.45	1.12	0.728	1.44	1.09	0.47	0.468
Na($cmol_ckg^{-1}$)	0.148	1.77	0.552	0.426	0.578	0.500	0.25	2.05
TEB($cmol_ckg^{-1}$)	4.72	39.08	17.79	12.87	20.74	16.56	7.22	0.919
CEC($cmol_ckg^{-1}$)	4.34	38.50	17.38	12.54	20.08	16.22	7.17	0.907
Ca: Mg ratio	1.32	4.39	2.86	2.50	3.18	2.81	0.546	0.26

n, number of data set; min., minimum value; max., maximum value; med., median value; Q1, first quartile; Q2, second quartile; SD(±) standard deviation; Ca, exchangeable calcium; Mg, exchangeable magnesium; K, exchangeable potassium; Na, exchangeable sodium; TEB, total exchangeable base; CEC, cation exchangeable capacity; Ca : Mg, calcium to magnesium ratio

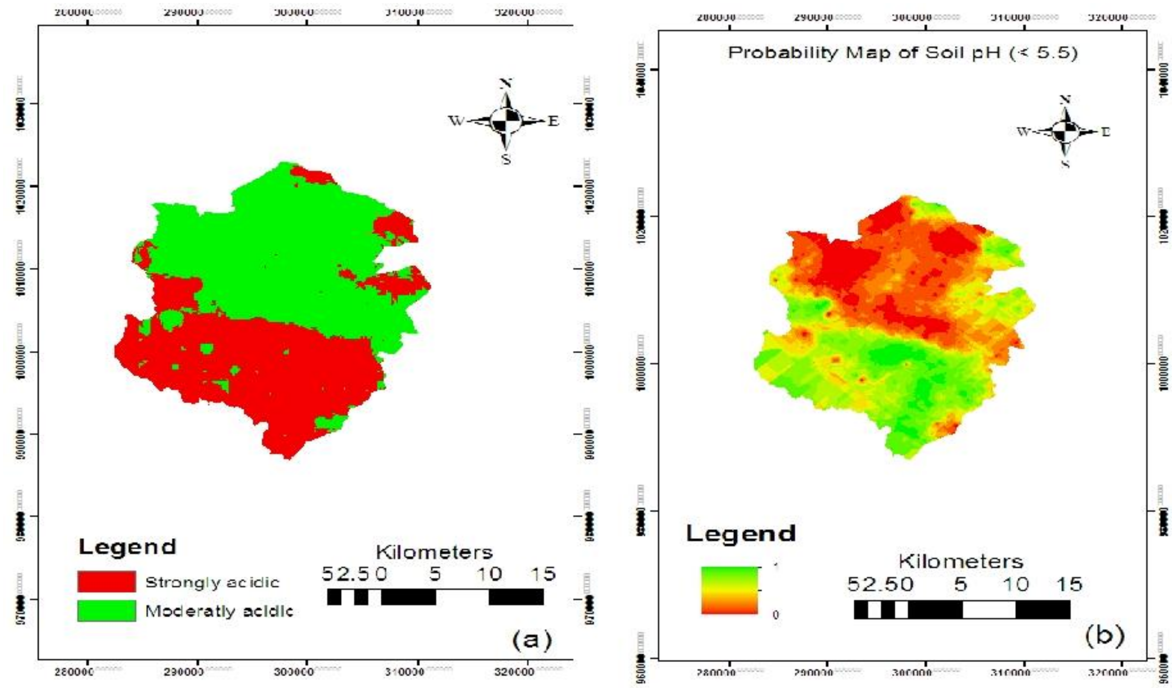

Figure 5. Surface soil pH (a) and probability map (b) of soil pH in soils of Bako Tibe distric

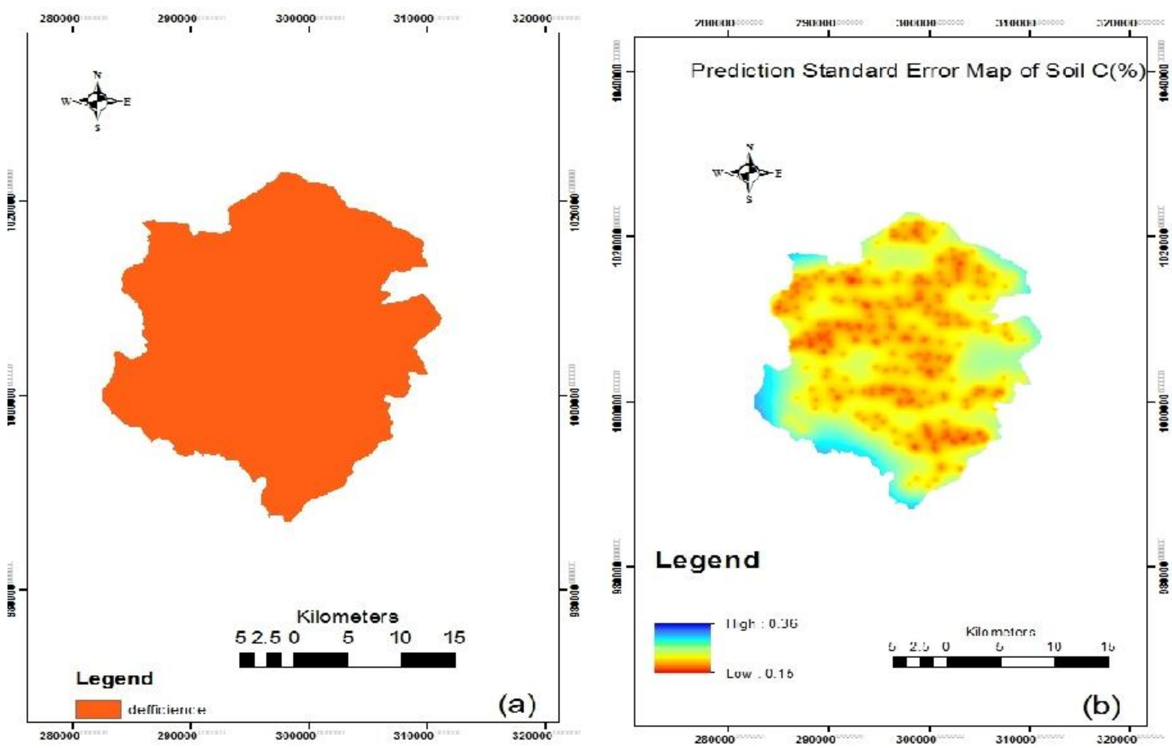

Figure 6. Organic carbon status (a) and prediction standard error map (b) of C in soils of Bako Tibe distric

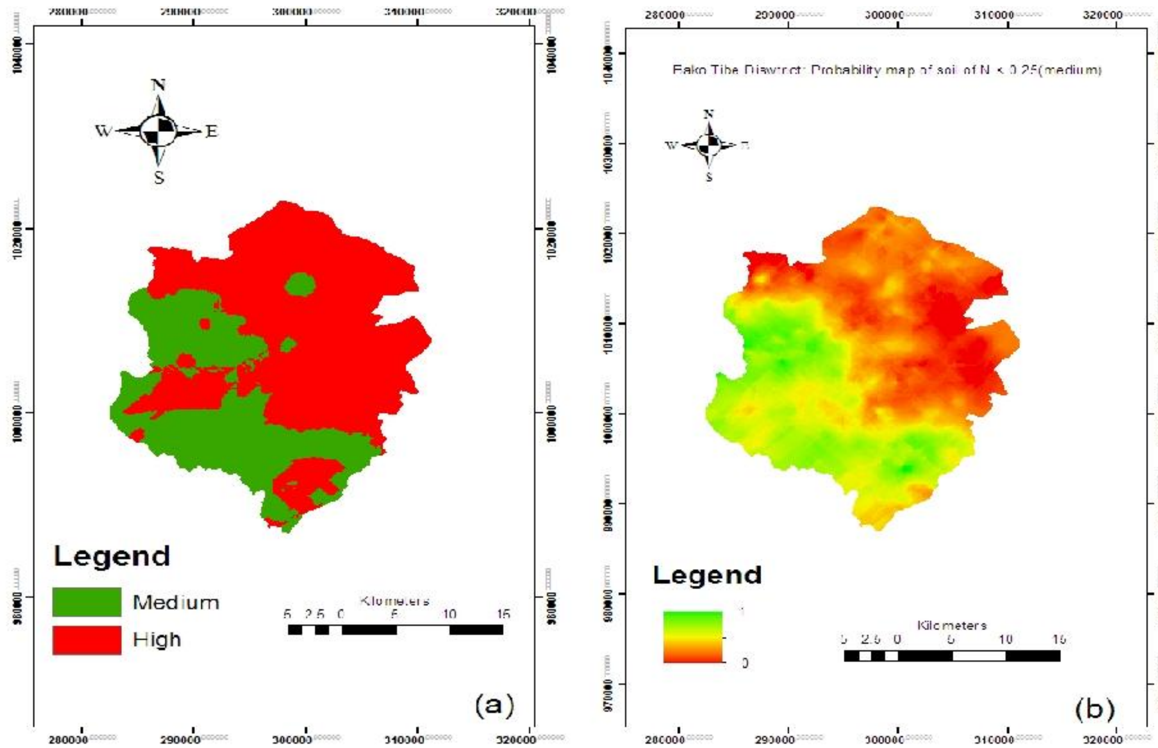

Figure 7. Status of soil nitrogen (a) and probability map (b) of N in soils of Bako Tibe distric

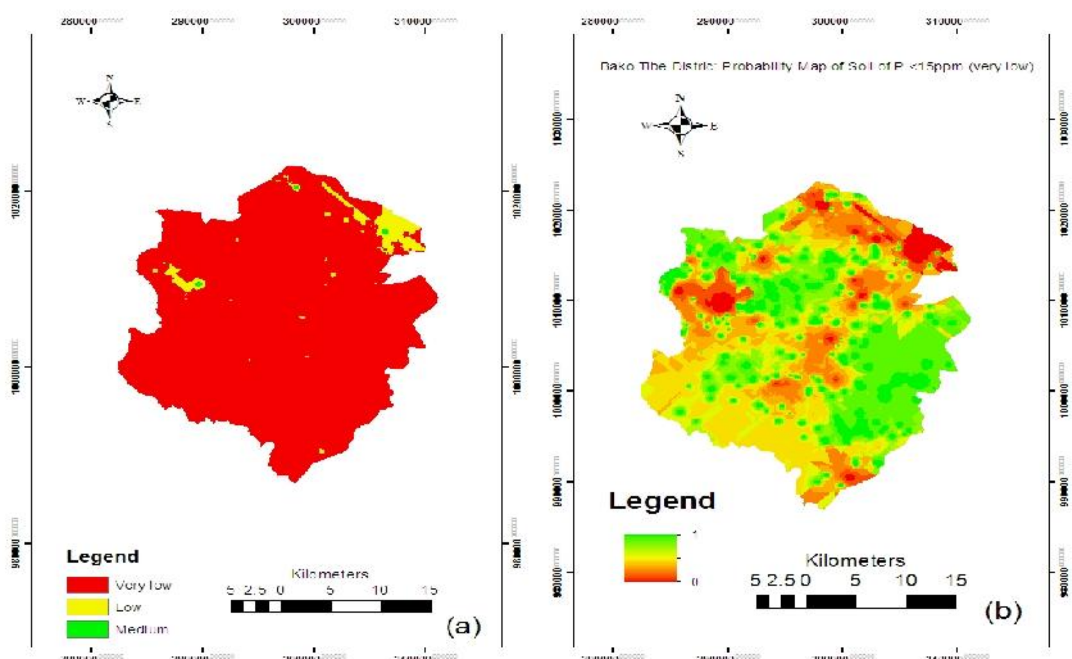

Figure 8. Phosphorus status (a) and probability map (b) of P in soils of Bako Tibe district

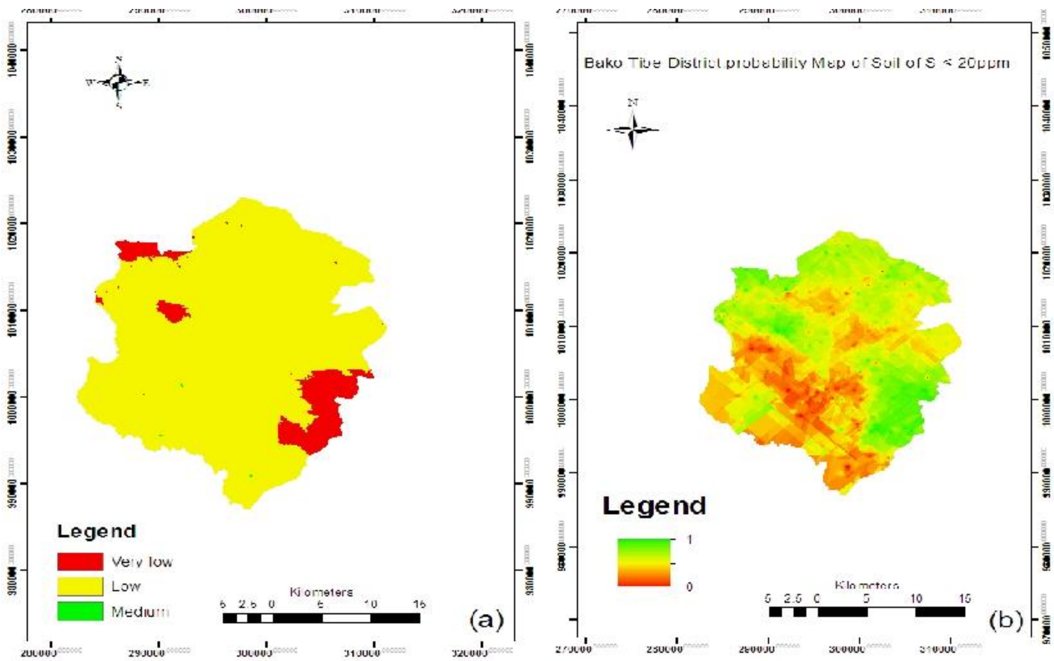

Figure 9. Sulfur status (a) and probability map (b) of S in soils of Bako Tibe district

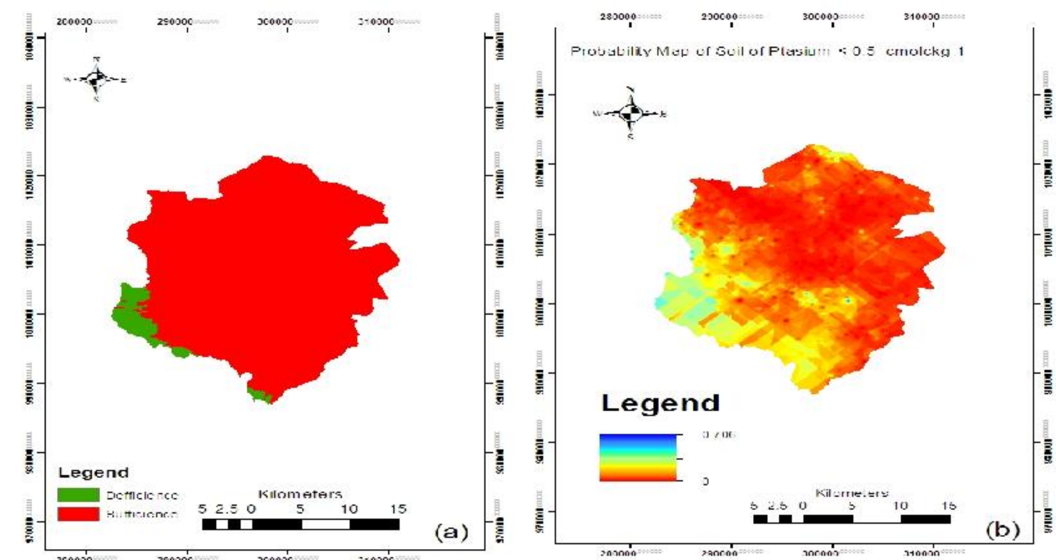

Figure 10. Potassium status (a) and probability map (b) of K in soils of Bako Tibe district

4.2.6. Cation exchange capacity and total exchangeable bases

The highest and the lowest CEC values recorded were 38.50 and 4.34 $cmol_c$ kg^{-1} respectively. The mean was 17.38 ±7.17 (Tab1e 3). The highest, medium, low, and very low were 47.22, 39.68, 12.3, and 0.79% respectively. The minimum, maximum, and mean values of the TEB were 4.72, 39.08, 17.79 ±7.22, respectively (Table 3). From this study, the highest CEC (25-40 cmolc kg^{-1}) was recorded in potentially cultivable virgin land and cultivated black soil. The lowest CEC (5- 25 $cmol_c$ kg^{-1}) was recorded from the cultivated land of red soils that is low in OC content. This is in line with the findings of Mebit (2006) and Teferi (2008) who reported very high CEC on Eutric Vertisols, and Pellic Vertisols, respectively.

4. Conclusion

Soil fertility varies in the landscape due to natural processes,such as erosion and dust deposition, and sedimentation of soil particles with moving water and due to human interventions. The study revealed that the particle size distribution of the soils were dominated by clay. The pH of the study area varied from 4.5 to 6.4 and was dominated by moderately acidic status (53.89%) and 46.12% (116 samples) of the district had pH ≤ 5.5(strongly acidic). The exchangeable acidity obtained varied from 0.04-2.8mg/100g of soil. Soil organic carbon was low in the entire district with mean value of 2.94%. Nitrogen distribution was dominated by medium status. The highest and lowest C: N was 13.24 and 9.83, respectively. P and S were ranged from very low to medium and very low to low status, respectively. A soil with low S status dominates the soil of the district and value varied from 3.6 -27.8ppm. Very low P status dominates the soils of the district and values varied from 0.05- 81.2ppm with mean of 5.5(±8.58). Exchangeable bases (K, Mg, Ca, and Na) have value ranged from very high to medium except for Na, which ranged from high to medium. The CEC also ranged from high to very low. Regarding Ca:Mg ratio, the district was dominated by low Ca content, only 2.39% in the medium range and 97.61% was in the deficiency level.

The study showed that nutrients like K, P, S and OC are found in a low to very low (deficient) ranges. Therefore, the combination of these nutrients in different proportion could be a medicine for a plant to get maximum yield. Depend on their spatial variability, balanced and blended fertilizers are inessential for the study area. In all aspects of this study area, potentially cultivated and cultivated black soil of the district had dominant nutrient availability than cultivated red soil.

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