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Full Length Research Paper

Fertility mapping of some micronutrients in soils of Cheha District, Gurage Zone, Southern Ethiopia

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Although micronutrients are required in minute quantities, they have the same agronomic importance as macronutrients and play vital roles in plant production. Therefore, the study was conducted to assess and map the status of micronutrients in soils of Cheha District, Southern Ethiopia. Accordingly, about 249 composite soil samples were collected from cereal and perennial crops, respectively. The extractable micronutrients were determined using Mehlich-III soil test extraction procedure. ArcMap 10 with spatial analyst function of ArcGIS software was used to prepare nutrient maps. The study shows that the mean values of extractable micronutrients (Fe,Mn, Cu, Zn and B) were 150.98, 108.4, 1.81, 2.36 and 0.57 ppm and ranged from 52 to 379, 31 to 290, 0.62 to 10.4 and 0.27 to 0.98 ppm, respectively. Based on the analysis, the extractable Fe, Mn and Cu values were high and above the critical levels in 100% of the samples. Furthermore, it is found that about 80% and 3% of samples were optimum in extractable Zn and B, respectively. As a result of this study, it is recommended that, future research should focus on assessing the availability of these and other micronutrients based on large number of soil and plant samples along with field trials.

Key words: Soil fertility; micronutrients, Geo-statistics, Mehlich-III, critical level.

INTRODUCTION

Soil fertility is one of the primary constraints affecting agricultural production in Sub-Saharan Africa (SSA) (Sanchez et al. 1997; Bationo et al. 2006; Sanginga and Woomer, 2009; Vanlauwe et al. 2010). Increasing population pressure in the continent has contributed to this constraint by reducing sizes of land holdings and fallow periods. This is particularly true where population densities are high, such as highland areas of East Africa. The scenario with regard to soil fertility and productivity in Ethiopia is similar to other neighboring eastern and central African countries that have high annual rates of nutrient depletion (i.e. > 40 kg N ha^{-1} and > 30 kg K_2O ha^{-1}) (Esilabaet al*.,* 2000). It was also identified that the three primary biophysical limitations, among others, which decrease agricultural production in Ethiopia are poor soil health, low soil fertility, and crop nutrient imbalances (Gete et al*.,* 2010). Core constraints of Ethiopian soils include depletion of soil organic matter (SOM) due to widespread use of biomass as fuel, depletion of macro and micronutrients, removal of top soil by erosion, change of soil physical properties, and increased soil salinity with time (IFPRI, 2010). On top of these, the usage of fertilizers in the country is not based on soil test results and below the recommended level; farmers do not fully implement the recommended soil management practices. These have resulted in a steady decline of nutrient levels in the soil (Diriba et al., 2013).

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Depletion of soil fertility leads to declining crop yields and a rise in the number of food insecure people (Chillot and Hassan, 2010). As compared to other causes of soil degradation, for example soil erosion and soil nutrient mining can be easily reversed through the addition of organic and inorganic fertilizers. Nonetheless, in Ethiopia, where 50 – 80% of the animal manure and 70 – 90% of the crop residues are removed from the farm and/or used for fuel, current soil fertility seriously limits feed and construction purposes (Chillot and Hassan, 2010), replacement of soil nutrients.

In the first groundbreaking soil macronutrient survey conducted by Murphy (1968), it was found that nitrogen (N) and phosphorus (P) were found to be deficient in many parts of the country. Subsequent fertilizer demonstration studies conducted by FAO through Freedom from Hunger Campaign also proved that while crops responded to DAP and urea in many locations, their response to potash fertilizer was inconsistent. Therefore, a recommendation was made to use the two fertilizers (DAP and urea) across all agricultural areas. As a result, application of fertilizers containing N and P (urea and DAP) began in the late 1960s, producing dramatic increases in the yields of several crops (Wassie and Tekalign, 2013). Since then, little or no attention has been given to other macro and micronutrients, thus leading to unbalanced fertilization and poor nutrient management and crop quality (Wondwosen and Sheleme, 2011). Desta (1989) carried out a study on the micronutrient status of Ethiopian soils. He collected limited samples from different areas of the country and reported that the contents of Fe and Mn were usually at an adequate level, while Mo and Zn contents were variable. Fisseha (1992) found that the micronutrient content of the soil is influenced by several factors among which soil organic matter content, soil reaction, and clay content are the major one. Similarly, in a separate study, over 75 percent of Vertisol, Cambisol, and Fluvisol soil samples were analyzed and reported to be Zn deficient (Asgelil et al., 2007). Moreover, Tekluet al. (2003a, 2003b, 2005), reported that Fe and Zn were in sufficiency and deficiency ranges, respectively, while Cu, B and Mo showed varied concentration gradients in Nitisols of western Ethiopia. Analogous study reported that Mn toxicity was noted (Yifru and Mesfin, 2013). On the other hand, Wondwosen and Sheleme (2011), in their study conducted in southern Ethiopia, stated that Fe, Mn, Zn, B and Mo were sufficient to support good plant growth.

It is apparent that, until recently, the use of commercial fertilizers in Ethiopia has not been in harmony with the economyof the farmers mainly since farmers were not using the fertilizer based on soil and crop requirements, while at the same time, the yield return from the applied fertilizers was low. This is because blanket application of DAP and urea was not based on crop need, soil nutrient dynamics and agro ecological factors (Abreha and Yesuf, 2008), which leads to either nutrient toxicity or deficiency (Ray et al., 2000). Recent studies have indicated that elements like N, P, K, S and Zn levels as well as Bo and Cu are becoming depleted and deficiency symptoms are being observed on major crops in different areas of the country (ATA, 2013). In order to apply nutrients, it is necessary to know the site-specific variability in nutrient supply to overcome the mismatch of fertilizer types and crop nutrient demand (Dobermann and Cassman, 2002). Geographical Information Systems (GIS) and Ground Positioning System (GPS) are important to generate spatial maps of nutrients status, which help in good agricultural management systems and formulating plans for sustainable agricultural development (Sood et al., 2009). In this regard, the Ethiopian Soil Information System (EthioSIS) project in collaboration with several other stakeholders, is pursuing a rapid development program on assessment of the soil resources of the country to establish a national soil resources database and assess of the nutrient status of agricultural lands to produce soil fertility map of many Districts in the country to come up with solid, evidence-based and targeted recommendations for fertilizer applications and other management interventions (ATA, 2013). The project also aims at identifying the groups of fertilizers needed as a country while the ultimate objective is to identify the specific fertilizer(s) per District. The project has released the list of one compound and five blended fertilizers to be disseminated to the mapped Districts beginning 2014. In view of these, this paper addressed the status of micronutrients (Mn, Fe, Cu, Zn and B) and their spatial variability in soils of Cheha District.

MATERIALS AND METHODS

Site Description

The study was conducted in Cheha District, Gurage Zone, Southern Nations, Nationalities and Peoples Regional State (SNNPRS),Southern Ethiopia, which is located between 8° 00' 18.9" to8° 15' 28.53" N latitude and 37° 35' 46.48" to 38° 03' 59.59" E longitude (Figure 1) with an estimated area of 57309.8ha and the elevation ranges between 900-2812m ((SNNPRS, 1996). As it is true with the other parts of Ethiopia, rainfall and temperature conditions depend on elevation. According to the Ministry of Agriculture (MoA) (1998), the agro-ecology of the area is classified into three traditional agro-ecological zones. These agro-ecological zones include *Dega* **(**high altitude) *Waina Dega* **(**mid altitude)and *Kolla* **(**lowlands) (EIAR, 2011).The mean annual rainfall obtained from the monthly data on the bases of ten years of records at the neighboring meteorological station is about 1268.04 mm. The average maximum and minimum temperature for the last ten years were 24.97 ^{o}C and 10.69 ^{o}C, respectively (Fig. 2).

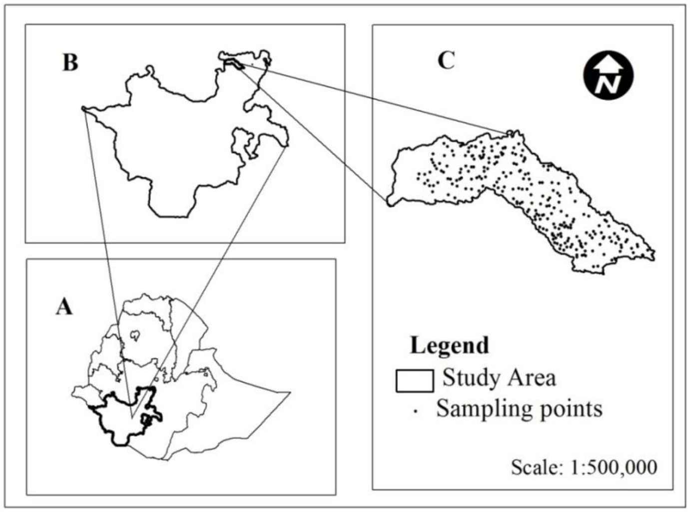

Figure 1. Map of the Ethiopia showing the location of SNNPRS (A), map of SNNPRS showing the location of the study area (B) and map of the study area showing the location of soil sampling points (C).

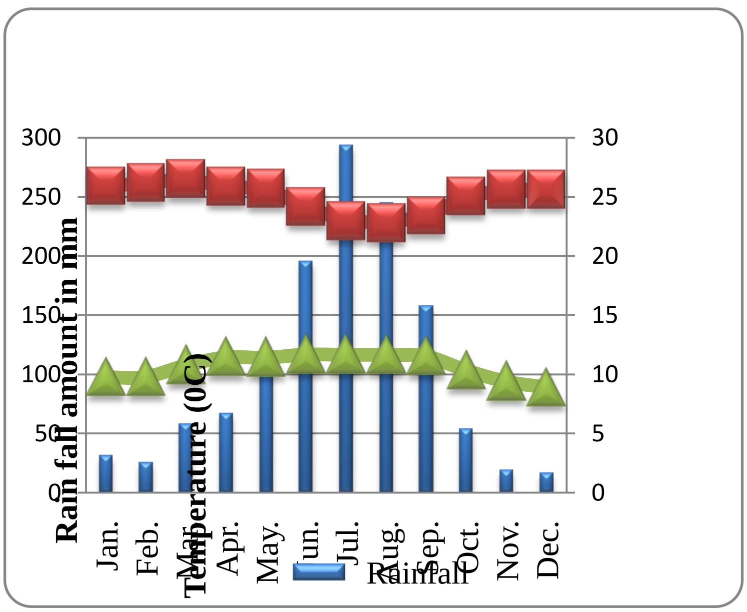

Figure 2. Mean monthly rainfall and monthly minimum and maximum temperatures of Cheha District for the years 2001 to 2010 (Office of Ethiopian Metrological Agency).

The current production system in the area is dominated by traditional subsistence mixed crop livestock farming.The major crops grown in the area include maize (*Zea mays* L.), wheat (*Triticum aestivum* L.),barley (*Hordem vulgare* L.), teff [*Eragrotistef (Zucc.) Trotter*], sorghum (*Sorghum bicolor* L.), chickpea (*Cicerarietinum* L.), onion (*Allium cepa*); root and tubers including enset (*Ensete ventricosum*), and potato (*Solanum tuberosum*); fruits (banana, citrus, papaya,mango and avocado); stimulants, such as coffee (*Coffee arabica*), and khat (*Catha edulis*). The dominant trees in the area are *Juniperus procera, Eucalyptus globules* and *Acacia abyssinica*as homestead and farm forest. Besides these, *Olea africana, Rosa abyssinica, Dodonia viscose, Carissa edulis,* bushes and shrubs are found on steep slopes and along river valleys as well as edge of eroded areas (Bekalu and Digafe, 1996).

The digital soil map of the world (version 3.6) that was cross referenced and generated from the small scale (1: 5,000,000) FAO (1984) soil map of the world indicated that the soils of the District are dominated by eutric Cambisols (13.7%), eutric Fluvisols (2%), eutric Nitisols (0.67%), Leptosols (0.74%) and pellic Vertisols (82.4%). Pellic Vertisols are characterized by high smectite clay mineral content (Mesfin, 1998).The color of the soils in the area ranged from red to reddish brown (high elevation areas) through light brown (midland areas) to dark (lowland areas).

Soil Sampling

At the beginning of the study, a preliminarysoil survey and fieldobservationwere carried outusingthe topographicmap(scale 1:50,000)and satellite image dated April 2013.Once the topographic map was interpreted, pre-defined sampling locations were navigated and the exact sampling points were determined by letting the GPS mean position for at least three to five minutes. However, as some pre-defined points were found in unsuitable places for sampling (*e.g.* road, waterway, and household) they were re-located in alternate locations within nearby cropping fields mostly inside a radius of 50 to 100 meters. Each location was recorded with a Garmin Map 70 S GPS using Adindan_UTM_ Zone_37N projected coordinates with 3 to 5 meter accuracy.

After reading the coordinate points and elevation of sampling points, slope gradient (%) of the study area was measured using clinometer by standing in the center of the plot.Then, 10 to 15 sub-samples were taken based on the complexity of topography and heterogeneity of the soil type.In order to address effective root depth of most annual crops, composite soil samples were collected from the top soil (0-20 cm) for chemical analysis. For perennial/tree crops such as fruit trees, coffee, etc sampling depth was extended to 0-50 cm downwards. During collection of sub-samples, maximum care was taken to address variability of the surrounding in terms of the dominant topography and soil type; for those landscapes having uniform topography and homogenous soil type (basically similar soil colour and texture) a minimum of 10 sub-samples were collected and composited within 10 to 50 m distance between each sub-plots using random sampling technique. Accordingly, about 249 points were successfully sampled in the thirty-nine *kebeles* (or peasant associations) of the District: 156 samples were taken from cereal fields and 76 samples from perennial crops during the off-season of 2013 cropping season.

An Edelman soil auger marked at 20 cm and 50 cm, labeled plastic bags (with durable ink or mark), a mixing trowel, a permanent marker and buckets were used during sampling.

Soil Sample Preparation and Laboratory Analysis

Sample preparation was conducted at the National Soil Testing Center (NSTC), Addis Ababa, Ethiopia. The samples were air-dried and crushed using a mortar and pestle and passed through a 2 mm mesh sieve. In order to abide by the procedure of EthioSIS, the chemical analyses of the soil samples was conducted using the Mehlich-III multi-nutrient extraction procedure (Mehlich, 1984), of the analysis of the soils was conducted at Altic B.V., Dronten, The Netherlands. On the other hand, particle size distribution and pH analyses of all the samples were conducted at NSTC. Soil particle size analysis was analyzed by laser scattering particle size distribution analyzer using a HORIBA Partica (LA-950V2)with a detectable size range of 0.01-3000 µm in wet mode (Arriaga et al., 2006) using 1% sodium hexameta phosphate (Calgon) as a dispersing agent. Soil pH was measured by a pH meter using soil to water ratio of 1:2 as outlined by Van Reeuwijk (1993).

Geo-statistical Analysis

Out of different Kriging techniques, the ordinary Kriging (OK) method was used in the present study since means were unknown (Vieira, 2000) and the interest of the study was to predict each variable on un sampled points, rather than to interpolate over areas (Cressie, 1993). The semi-variogram model obtained from the semi-variance analysis was to estimate observations in the un-sampled locations within the field. The semi-variogram, γ (h), of n spatial observations z (xi), i = 1, n, was calculated using the following Equation:

$$\gamma\,(\mathrm{h}) = \frac{1}{2\mathrm{n}}\sum_{\mathrm{n}=1}^{\mathrm{n}} [\mathrm{z}\,(\mathrm{xi}) - \mathrm{z}(\mathrm{xi}+\mathrm{h})]^2$$

Where, n is the number of pairs of sample points of observations of the values of attribute z separated by distance h. A plot of *y (h)* against the distance *h* or the *lag* is known as an experimental variogram and provides useful information for interpolation. The variograms were subsequently used for constructing the ordinary kriging models. The basic equation for interpolation by kriging at an un-sampled location $S_0$is given by:

$$\hat{\mathrm{Z}}(\mathrm{S0}) = \sum_{\mathbf{i}=\mathbf{1}}^{\mathrm{N}} \lambda\mathrm{i}\mathrm{Z}(\mathrm{Si})$$

Where, Z *(*S_i*)* = the measured value at the i^{the} location, λ_i= an unknown weight for the measured value at the i^{th} location, S_0= the prediction location and N= the number of measured values. The values of the nutrients input in Microsoft Excel and saved in comma delimited (csv) file format was added as a layer on the map in ArcMap in the Projected Coordinate Systems WGS 1984 UTM Zone 37N. The pixel size of the outputs was 100 x100 meter, assuming the smallest discernible is 1 x 1 mm on the map.

Table 1. Descriptive statistics of soil pH and particle size distribution in the agricultural soils of Cheha District in Ethiopia.

Parameter	Range	Mean	Median	Standard deviation
Soil pH	4.5-6.5	5.6	5.5	0.55
Sand (%)	0.2-20	8.2	7.4	3.98
Silt (%)	4- 39	20.5	19.5	9.5
Clay (%)	46-93	71.4	73.2	12.88

Table 2. Descriptive statistic of micronutrients (ppm) in the agricultural soils of the study District

Micronutrient	Range	Mean	Median	Standard deviation
Fe	52-379	151.0	111	84.3
Mn	31-290	108.4	101	49.6
Cu	0.6-4.8	1.8	1.7	0.6
Zn	0.6-10.4	2.4	1.9	1.6
B	0.3-1.0	0.6	0.5	0.3

RESULTS AND DISCUSSION

Soil Reaction (pH)

The soil pH ranged from 4.5 to 6.5 with mean and median values of 5.6 and 5.5, respectively (Table 1). The soil pH value of the area was low and ranged from strongly acidic (pH ≤ 5.5) to moderately acidic (5.6 - 6.6) as per the pH rating category suggested by Karltun et al., (2013) (Figure 3A). Based on this, 70 %, and 30 % of the soils were strongly and moderately acidic in reaction, respectively. Thus, in the former case, it is pertinent to raise the soil pH through liming to increase crop productivity in the study area.

The first reason for the lowest values of soil pH at the study sites could be high rainfall (1268.4 mm) that results in loss of base forming cations through leaching and drain to streams in runoff generated from accelerated erosion. This enhances the activity of Al^{3+} and H^+ in the soil solution, which reduces soil pH and thereby increases soil acidity. Although soil acidity is naturally occurring in some areas, human activity can change the pH of a soil too; agricultural practices have accelerated the process of soil acidification (Kizilkaya and Dengiz, 2010). Hence, the second reason might be continuous use of ammonium based fertilizers such as diammonium phosphate, $(NH_4)_2HPO_4$, in such cereal based cultivated fields, which upon its oxidation by soil microbes produce strong inorganic acids. These strong acids in turn provide H^+ ions to the soil solution that in turn lower soil pH (Abebe and Endalkachew, 2012). Moreover, long-term usage of urea, replacement of ammonium with basic cations and production of hydrogen ion during nitration process, decreases the amount of pH (Juo et al., 1996). The soils in the high altitude and higher slopes had low pH values, probably suggesting the washing out of basic cations from these parts (Mohammed et al., 2005). Continuous cultivation practices, excessive precipitation and steepness of the topography could also be some of the factors responsible for the reduction of pH in soils at the middle and upper elevation areas (Ahmed, 2002).

Soil Texture

The mean values of the particle size distribution in the study area are presented in Table 1. Accordingly, the textural class across all locations was clay. The median values of sand, silt and clay contents of the soil samples collected from the agricultural soils of the District were 7.4, 19.5 and 73.2 %, respectively with standard deviations of 3.98, 9.5 and 12.9 %, respectively. Generally, clay size fraction followed by silt fraction dominated the study area. The high clay content is an indication of complete alteration of weatherable minerals into secondary clays and oxides (Buol et al., 2003).

Status of Extractable Micronutrients

The concentration of extractable micronutrients were found to be in the order Fe >Mn> Cu > Zn >B in almost allagricultural soils of the study area (Table 2). The results of extractable Fe ranged from 52 to 379 ppm with a mean andmedian value of 150.98 and 111 ppm, respectively. Different authors reported 4.8 and 4.5 ppm as critical level of DTPA extracted Fe (Teklu et al., 2003b), Lindsay, and Norvell (1978), respectively. However, Monterroso et al. (1999) found that Mehlich-III extracted Fe was three times higher than DTPA extracted Fe. From this relationship and by taking the mean values of the two, nearly 13.95 ppm inferred as a cut of point

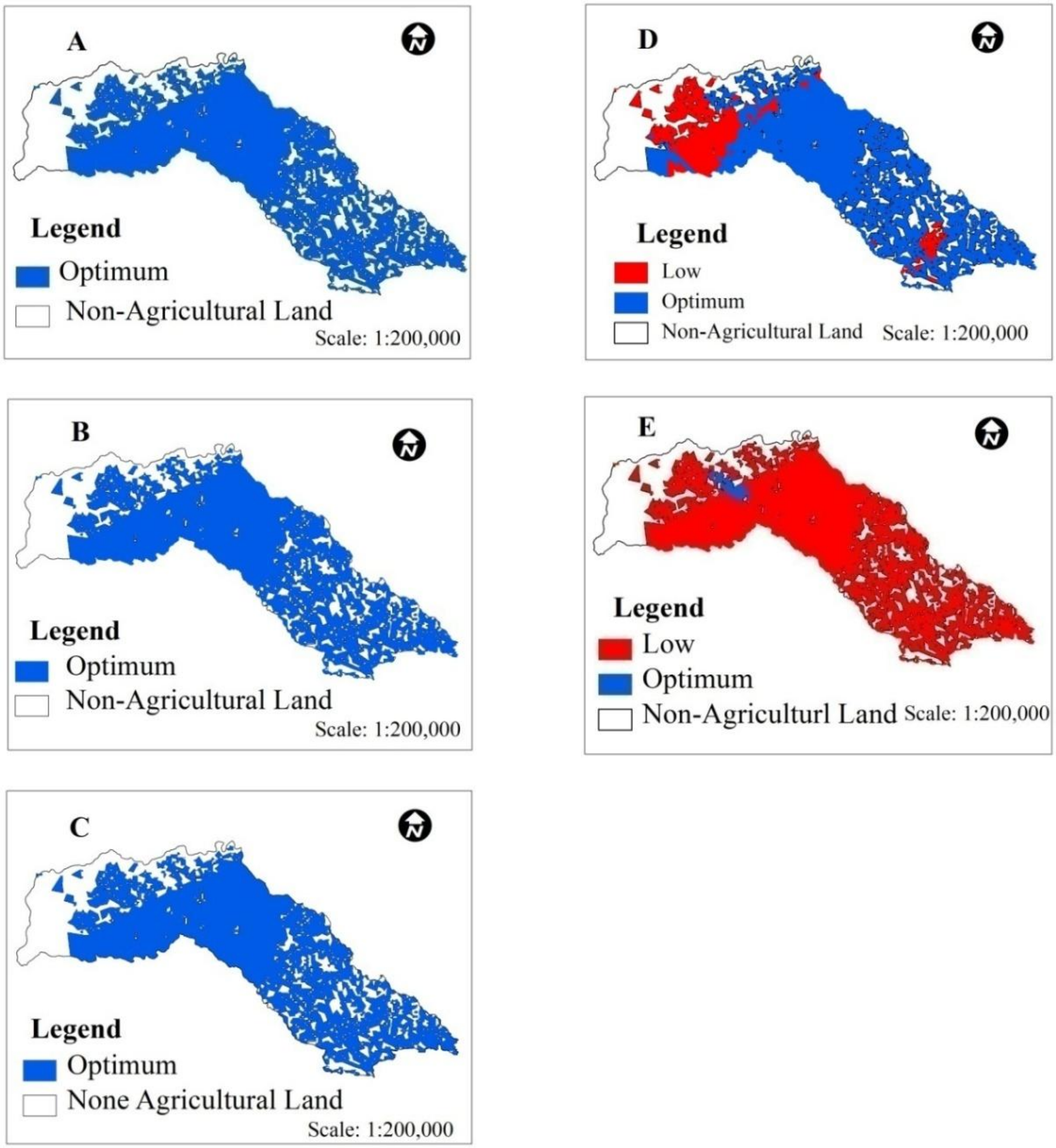

Figure 3. Spatial distribution of extractable Fe (A), Mn (B), Cu (C), Zn (D) and extractable B (E) in the agricultural soils of of the study area.

and all the samples collected in this study were in sufficiency range. As depicted in Figure 3A, the estimated data indicated that all agricultural soils of the study area are non-deficient in extractable iron. The content indicates that with values above critical limits for crops, iron deficiency is unlikely for any crop grown on these soils. The high concentration of extractable Fe in the area apparently was due to the lowpH of the soils, that Fe deficiency is very unlikely in acid soils; as it known to be soluble under relatively acid and reducing conditions (Ibrahim and Abubakar, 2013) Similarly, the concentration of extractable Mn content ranged from 31 to 290 ppm with mean and median values of 108.4 and 101 ppm, respectively (Table 2). According to the critical level of 25 ppm suggested by Karltun et al. (2013),the extractable Mn content of the studied soils is within the range of high in 100% agricultural soils of the area (Figure 3B). These values suggest that Mn content of the soils is high and cannot be a limiting factor for successful crop production in the area. This finding is in agreement with Haqueet al. (2000) who reported extractable Fe and Mn levels were usually adequate for Ethiopian soils; andHue et al. (2001) who concluded Mn toxicity is even more common than deficiency in humid tropics where most soils are highly weathered and leached. The most probable reason for the high content of extractable Mn in the soils could be the acidic nature of the soils in the study area. The mean and median value of extracted Cu of all the samples collected from the study area was 1.81 and 1.7 ppm, respectively and ranged from 0.62 to 4.75 ppm. Based on the critical limit of 0.9 ppm recommended by Karltun et al. (2013),100 % of all the soil samples were found to have sufficient level of extractable copper (Figure 3C), indicating that Cu deficiency is not likely for any crop production in this soil.

As shown in Table 2, the mean and median values of extractable Zn were 2.36 and 1.9 ppm, respectively and ranged from 0.6 to 10.4 ppm (Table 2). Based on the critical levels of 1.5 ppm suggested byKarltun et al. (2013), 80 % and 20 % of the agricultural soils of the District were above and below critical level, respectively (Figure 3D). This result shows that some parts of the study area are deficient in extractable Zn and would require Zn fertilization for a better crop production.

The deficiency of extractable Zn could be due to high clay of the soil, which has the capacity to fix in its colloidal surface. These results are in accordance with the findings of Alloway (2008) who revealed that Zn generally has low mobility in soils and a tendency of adsorption on clay-sized particles. The other reason for the low level of Zn in the area might be due to continuous harvesting of crop, organic matter oxidation, removal of the topsoil by sheet and rill erosion that is aggravated by tillage activities (Wakene, 2001).

The extractable B ranged from 0.27 to 0.98 ppm with the mean and median values of 0.57 and 0.53 ppm, respectively (Table 2). Based on critical limit suggested byKarltun et al. (2013), about 97 % of the soils in the study area have fallen below critical level (< 0.8), while the remaining 3% was above critical level (≥ 0.8 ppm) in extractable B content (Figure 3E). The major factors, which may cause B deficiency in soils, are low B content in the parent material, which decompose easily, soil type, pH and leaching(Tisdale et al*.,* 2003). This might be also indicated that low B contents in soils could be due to initial low B content in the soil parent material, loss through leaching and extremes of low pHBrady and Weil (2002). Low soil organic matter content, coarse/sandy texture, intensive cultivation and continuous nutrient uptake by crops without application to the soils as fertilizer, and the use of fertilizers poor in micronutrients are considered to be the major factors associated with the occurrence of B deficiency(Rashid et al., 2005, Niaz et al., 2007)**.** Generally, by comparing the extractable micronutrients (Fe, Mn, Cu, Zn and B), all the soils were found to be above critical level in extractable Fe, Mn and Cu, while they were found that 20 % and 80 % soil samples were below and above critical level extractable Zn content, respectively.

CONCLUSIONS AND RECOMMENDATION

Results from the present study indicated that the soils were generally clay in texture and strongly acidic to moderately acidic in 70 and 30%, respectively. Based on the critical levels suggested, the extractable Fe, Mn and Cu values were high and above the critical levels in 100 % soil samples collected from soils of the study area whereas, about 80 and 3% of soil samples were optimum in extractable Zn and B, respectively. From this study, it can be concluded that, almost all soils of the study areawere low in extractable B. As a conclusion, we remark that locally tested and adopted critical levels for all nutrients need to be developed in order to make sure that these findings were well ascertained. In addition, future research should focus on assessing the availability of these and other micronutrients by collecting large number of soil and plant samples and conducting field trials in the area.

Furthermore, it is fundamentally important to conduct a more comprehensive survey of soil fertility of the country, which will provide the opportunity to develop a national fertility map and improving Ethiopia’s soil fertility, which ensure crop productivity as well as other agricultural productivity.

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