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Research Article

The Status of Selected Essential Plant Micronutrients under Enset (*Ensete Ventricosum* (Welw.) Cheesman) Farming Systems in Sidama Region, Ethiopia

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Article Info

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Abstract

Information regarding micronutrients' status under enset farming system soils is rare. Thus, the objective of this study was to assess the status of micronutrients in soils under an enset farming system and their relationship with soil properties in Hula, Dale and Hawassa-Zuriya districts of Sidama region, Ethiopia. Soil samples were collected from Woinadega (warm subtropical climate) and 'Dega' (wet and cool temperate climate) agro-ecologies using stratified random sampling technique. The acidic reaction was high, medium and low in Hula, Dale and Hawassa-Zuriya districts, respectively. The lowest (2.0 mg/kg) Zinc, the highest (259 mg/kg) and the lowest (15 mg/kg) Manganese ($P<0.0001$) were recorded in Hawassa-Zuriya, Dale and Hawassa- Zuriyadistricts, respectively. The highest (0.0028) iron (214 mg/kg) and copper (2.0 mg/kg) were determined in a Hula district. Boron was low (0.5-0.8 mg/kg) in a Hula district while optimum (0.8-2 mg/kg) in Dale and Hawassa-Zuriya districts. Zinc was optimum in Hawassa-Zuriya while high in Dale and Hula districts. Manganese was very low (<60 mg/kg) in Hawassa-Zuriya district while optimum (100-300 mg/kg) in Dale and Hula districts. Iron (25-300 mg/kg) and Cu (0.9-2.0 mg/kg) were optimum in the districts. Positive correlations occurred between Boron, pH and CEC; Cu, Mn and CEC and SOM, and the micronutrients while pH and micronutrients such as Fe and Zn; and phosphorus and zinc correlated negatively. Agro-ecological and soil type variations influenced the size of essential plant micronutrients across the districts with the lowering effect from the low to high altitudes except for Boron. Hence, it is concluded that there should be soil micronutrients management to tackle the altitudinal variation effects that lowers their level in soils.

Keywords: enset, Ethiopia, soil nutrients, soil organic matter

1 Introduction

Enset (Ensete ventricosum (Welw.) Cheesman) is a part of sustainable production system and has been cultivated in Ethiopia since ancient times (Garedew et al. 2017). It is among the domesticated cultigens (Khoury et al.2016) and referred to as false banana.

Enset is commonly known as false banana because it differs from domesticated bananas in that the mature plant does not produce edible fruit (USDA Agricultural Research Service, 2015). It is most commonly grown in home- gardens, frequently intercropped with peas or beans,which is suitable to compensate the low protein level in enset foods (Abebe et al. 2010).

Micronutrients are elements (Fe, Mn, Zn, Cu, B, Mo and Cl) required by crops in small quantities and known to be essential for plant growth. Plants require them for protein and auxin production (Zn), as constituent of cytochrome oxidase (Cu), photosynthesis (Fe), germination of pollen grains and growth of pollen tubes, and formation of seed, cell walls, and protein (B), conversion of nitrates to ammonium within the plant and process of N fixation by legume nodules (Mo), in several enzymatic reactions, in the synthesis of chlorophyll, carbon assimilation and nitrogen metabolism (Mn) (Arokiyaraje et al. 2011).

Soil pH is a valuable soil property since it affects the wide range of soil chemical and biological processes, including nutrient availability and microbial activity (Neina 2019). In highly acidic soils, manganese, iron, copper and zinc can become more available while phosphorus and most micronutrients become less available in highly alkaline pH (Jensen, 2010). Soil organic matter plays an important role by improving physical and chemical properties of soils and/or by buffering nutrient supply (Viventsova et al. 2005). The CEC is a chemical property of a soil that describes soils' capacity to supply nutrient cations to the soil solution for plant uptake and it is highly associated with clay minerals and organic matter (OM) content of soil (Cornell University Cooperative Extension, 2007).

When there are large quantities of crop available micronutrients in soils, they harm crops because of their interaction with other nutrients (Yadav and Meena 2009). Hence, maximizing agricultural production needs, among others, a balanced use of micronutrients (Patel and Singh 2009). It also requires giving due attention to their relation with soil properties since it could help one to understand their function during the micronutrients application. In line with this, Wondwosen and Sheleme (2011) reported the importance of micronutrient application through balanced fertilization while giving due attention to soil factors such as organic matter content, adsorptive surface, soil pH, lime content, soil texture, topography and nutrient interactions in the soil (Eyob et al. 2015). In view of the above considerations, knowledge of the status of micronutrients and their relationship with some soil physic- chemical properties become very important to revise the fertilizer package to boost crop productivity.

According to the research report by Desta (1983), micronutrients deficiency was not serious problem in Ethiopian soils. As a result, sufficient efforts are not made to reveal what on the ground. It also brought about to come up with a conclusion that remarkable deficiency of micronutrients doesn't occur until recently. In spite of this assumption, most recent studies confirmed that certain soil micronutrients were deficient in soils of Ethiopia, which limits crop productivity. Supporting this, Teklu et al. (2007) reported the deficiencies of Mo, Cu, and Zn in Ethiopian Nitisols while Yifru and Mesifn (2013) was reporting the deficiency of Fe and Zn in almost all soil samples collected from the Vertisols of central Ethiopia. Regardless these facts, special attention had been given only to macronutrients such as N and P in Ethiopia and it seems to block further strive to see the relationship of soil properties with plant micronutrients in soils. Owing to these reports, an attempt to find out the status and the relationship between soil factors and micronutrients are scarce in Sidama, Ethiopia especially in the soils under enset farms.

Therefore, a clearer understanding of the micronutrients status and their relationships with other physico-chemical properties are required to enable effective management of micronutrient supply and use. Therefore, this study was aimed to assess the status of some micronutrients and their relationship with selected physico-chemical properties under enset farming system in Sidama region, Ethiopia.

2 Materials and Methods

2.1 Study Area

The study was conducted in Hawassa-Zuriya, Dale and Hula districts of Sidama region, Ethiopia (Figure 1) in 2020/21. Sidama region is located within 5°45'- 6°45'N latitude and 38°-39° E longitude, covering a total area of 6,538.17 sq km of which 97.71% is land and 2.29% is covered by water (SZPEDD 2004). It is bordered by Gedeo administrative zone in the south, Bilate River, which separates it from Wolayita zone in the west and Oromiya regional state in the north and southeast. The region lies in the area varying from low land (warm to hot) to highland (warm to cold). The regional capital, Hawassa, which is located in the northern tip of the region, has a distance of 275 km from Addis Ababa. The sampling sites are located between 038°20'7.8" - 038°32'36.5"E and 06°28'15.5" - 07°04'50.3"N. Altitudes vary from 1710 – 1732, 1720 - 1798 and 2684 – 2783 m.a.s.l in Hawassa-Zuriya, Dale and Hula districts, respectively. A total of nine 'kebeles' (peasant associations) were selected, of which 3 were from Hawassa-Zuria, 3 from Dale and 3 from Hula district.

2.2 Climate and soil management

The Hula district has temperature range of 10-18 °C. The rainfall pattern of the area is bimodal and receives 1100-1400 mm per annum. The long rainy season begins from July and ends in September and the short rainy season begins in March and ends in May (Gebre-Egizabher 2022). The mean annual temperature in Dale district ranges between 9.6°C and 29.2°C. The area has a bimodal rainfall pattern with the peaks ranging from April to May and August to October. The mean annual rainfall of the area is 1102 mm per year (Kewessa et al. 2015). The mean minimum and maximum monthly temperature of Hawassa-Zuriya district is 13.8 °C and 27.8 °C, respectively (NMA 2017). The mean annual total rainfall is 935 mm with main wet season from April to September. In the districts, application of high amount organic fertilizers (household refuses, farmyard manure and compost) is common with inconsiderable removal of enset's residue from the farm.

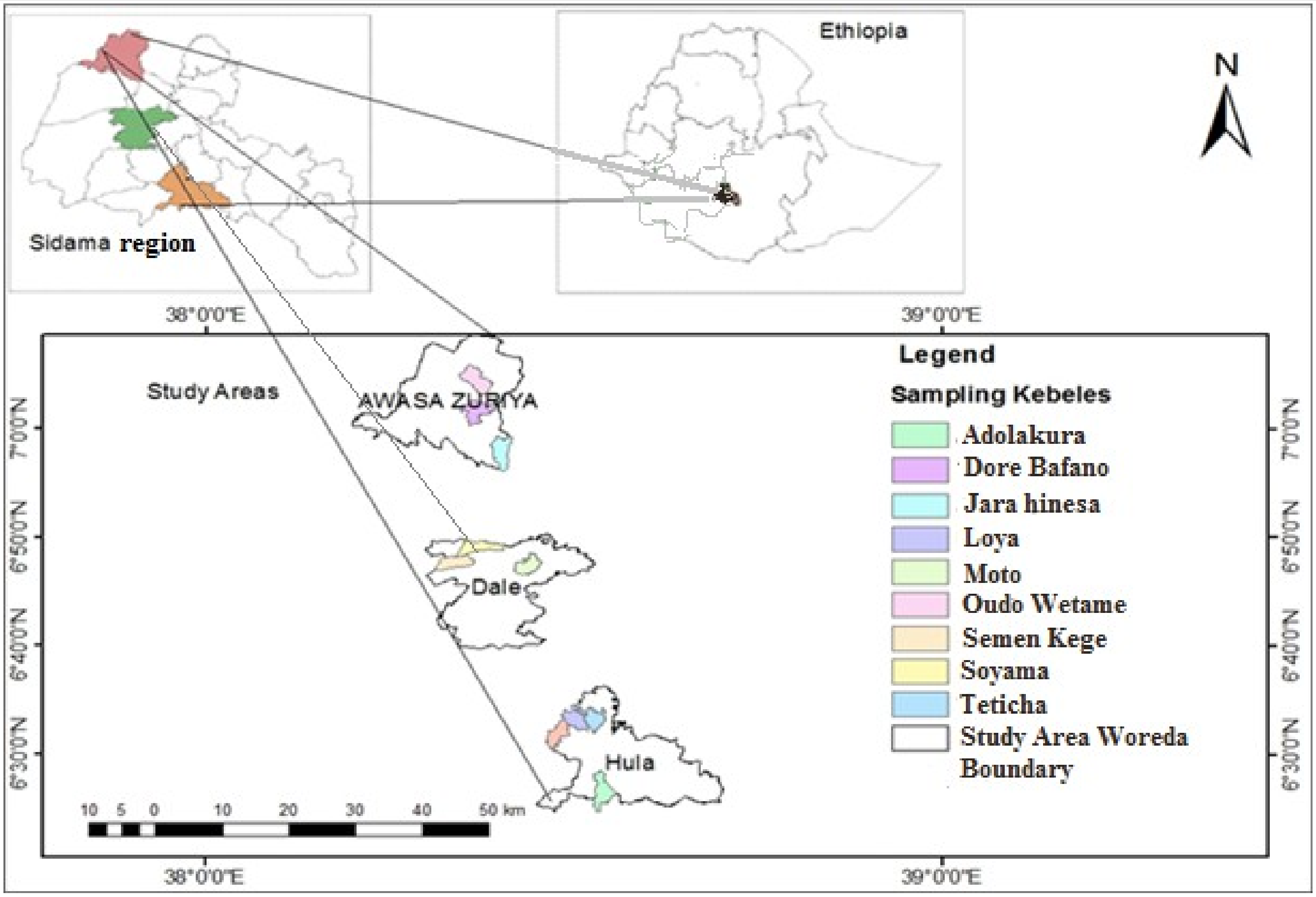

Figure 1: Map of study districts and soil sampling ‘kebeles’ in the study districts.

2.3 Soil Sampling

In the present study, sample districts from the region were randomly selected because nearly all areas in the region have good potential for enset production irrespective of productivity variation due to rainfall and altitude discrepancy. Following this, enset farms of the representative farmers in the ‘kebeles’ were selected using systematic sampling method and each field was divided into three strata 12 m long in the direction from home vicinity to far located fields based on enset’ growth variations. Since the study planned to explore the micronutrients status within the enset rooting depth, 50 cm depth for each core was bored randomly from each stratum using an auger and samples were collected in plastic pail. Core samples collected in plastic pail were then placed on a plastic sheet with an area of 3 m^2 and thoroughly mixed. Then, about 1 kg sample was taken and kept in a polyethylene plastic bag and labelled. Finally, eighty one composite soil sample (12 cores) was taken based on the method outlined by Rikard (2008) in November 2020 from the districts and kebeles (3 woredas*3 kebeles* 3 farmers field*3 strata) were collected in November 2020. Before laboratory analysis, samples were air-dried at room temperature, grounded using mortar and pestle, homogenized, and passed through a 2 mm sieve. Lastly, samples were stored in clean and dry area at room temperature until the time of use.

2.4 Physico-chemical analysis

Particle size analysis was performed using the Bouyoucous hydrometer method (Bouyoucos, 1951). Bulk density was determined by core method (Blacke 1965). The pH was determined in 1:2.5 soil-water suspensions using a glass electrode (Jackson 1973). Organic carbon was determined by wet oxidation method (Walkley and Black 1934). Soil organic matter (SOM) was estimated by multiplying the soil organic carbon by 1.72 (Baldock and Skjemstad 1999). Cation exchange capacity (CEC) was determined using ammonium acetate method (Sumner and Miller, 1996). Available phosphorus was determined using the Olsen method (Olsen and Sommers, 1982). Micronutrients were extracted using Mehlich III extractant (Mehlich 1984) and determined by inductively coupled plasma-atomic emission spectrometry (ICP-AES). The different values for the various soil fertility parameters were rated using the EthioSIS adopted critical levels (Ethiosis 2014). The soil samples were analyzed at Horticoop Ethiopia (Horticultural) PLC in Addis Ababa and at Hawassa College of Teacher Education.

2.4.1 Critical limits of micronutrients

The critical limits of micronutrients contents as proposed by EThioSIS (2014) for elements extracted with Mehilich 3

Table 1: Critical limits of soil micronutrients

Micronutrient	Concentration (mg kg^{-1})	Status	Micronutrient	Concentration (mg kg^{-1})	Status
Zn	¡1	Very low	Mn	¡60	Very low
	1-1.5	Critical level		60-100	Critical level
	1.5-10	Optimum		100-300	Optimum
	10-20	High		300-500	High
	¿20	Very high		¿500	Very high
Fe	-	Very low	Cu	¡0.5	Very low
	25	Critical level		0.5-1	Critical level
	25-300	Optimum		0.9-20	Optimum
	300-400	High		20-30	High
	¿400	Very high		¿30	Very high
B	¡0.5	Very low			
	0.5-0.8	Critical level			
	0.8-2	Optimum			
	2-4	High			
	¿4	Very high			

Source: EThioSiS (2014)

2.5 Statistical Analysis

Data analyses were performed with the statistical analysis system (SAS Institute, 2012). The soil data generated were subjected to analyses of variance (ANOVA) using the general linear model procedure. Tukey's Studentized Range (HSD) means comparison test was used to determine the differences among soil samples of different districts based on the measured micronutrients and other soil properties at p = 0.05. The simple correlation analyses of data were computed in relation to the micronutrients amount with physico-chemical properties of soil under study.

3 Results

3.1 Soil Physical Properties

Selected physical properties are summarized in Tables 1. The proportions of sand, silt and clay varied from 14 to 56, 16 to 45 and 17 to 50% for Hawassa-Zuriya, Dale and Hula districts, respectively. The results indicate that most of the soils contained relatively higher proportion of clay as compared to silt and sand, but among the districts, Hula had the highest sand contents (Table 1). Percentage of clay fraction in Dale and Hula districts was the highest (55.6%) while only 22.2% of the studied soils in Hawassa- Zuriya. Bulk densities (g/cm^3) of the soils of Hawassa-Zuriya, Dale and Hula districts varied from 0.71 to 0.94, 0.87 to 1.22 and 0.87 to 1.08, respectively. The mean bulk density of Hawassa-Zuriya was the lowest and statistically different (p =0.0022) from that of Dale and Hula districts.

3.2 Soil Chemical Properties

Selected chemical properties determined in the soils are summarized in Table 1. The soil pH values of Hawassa-Zuriya, Dale and Hula districts varied from 6.2 to 7.5, 6.3 to 7.6 and 4.7 to 5.4, respectively. According to EThioSiS rating (2014), the pH ranged from strongly acidic to moderately alkaline and all soil samples from Hula district were strongly acidic in reaction. Percent SOM ranged from 2.1 to 7.1% and was observed to increase with decreasing pH. The Cation exchange capacity ranged between 17.4 and 46.4 meq/100 soil g and the values were not significantly different across the districts. According to the CEC (meq/100 soil g) rating by Landon (1984): infertility (<4), minimum value (5-15), optimum (15- 25), high (25-40), very high (>40). Hence, the CEC values varied from optimum to very high. Available phosphorus content varied from 7.10 to 140.20, 1.10 to 7.32 and 0.23 to 8.40 mg/kg for Hawassa-Zuriya, Dale and Hula districts, respectively. The mean values of P was 45.20, 3.80, 3.04 mg/kg in Hawassa- Zuriya, Dale and Hula districts, respectively. There were significant differences (p =0.0083) in available phosphorus across sites (Table 1).

3.3 Soil Micronutrients

The level of micronutrients is shown in Table 3 below. Available zinc ranged from 4.5 to 32.7 mg/kg while the mean values were 2.0, 13.8 and 11.4 mg/kg in Hawassa-Zuriya, Dale and Hula districts, respectively. Crop available manganese in the soils ranged from 55.7 to 334.4 mg/kg and the mean values were 15.1, 197.3 and 259.4 mg/kg, respectively for Hawassa-Zuriya, Hula and Dale districts. Among the districts, the Dale district had the highest (259 mg/kg) Mn (p <0.0001) content while the lowest Mn was determined in Hawassa-Zuriya district. Crop available iron ranged from 79.5 to 290.0 mg/kg having the mean values of 128, 149 and 214 mg/kg for the soils of Hawassa- Zuriya, Dale and Hula districts, respectively. Significantly (p =0.0028) higher mean iron (214 mg/kg) was determined in the Hula district than the Dale and Hawassa-Zuriya districts. Copper ranged from 0.3 to 2.8 mg/kg and the mean values in the soils of Hawassa-Zuriya, Dale and Hula districts were 1.2, 1.5 and 2.0 mg/kg, respectively. The contents of copper in the Hawassa-Zuriya and Dale districts were statistically similar while the contents were statistically and significantly ($p < 0.0001$) different from Cu contents in the Hula soils. The highest mean copper was recorded in the Hula district. Boron ranged from 0.01 to 1.9 mg/kg while the mean values in the soils of Hawassa-Zuriya, Dale and Hula districts were 1.2, 0.9 and 0.5 mg/kg, respectively. Statistically different and higher B contents were determined in Dale district than the Hula and Hawassa-Zuriya districts.

4 Discussion

4.1 Soil Physical Properties

The wide variability of sand proportion among the districts might be due to the differences in soil mineralogy (Auge et al. 2017) and the extent to which silt and clay size particles are washed by the soil erosion. On the other hand, the high clay proportions recorded in Dale and Hula districts indicates that the soils are well covered by the canopy of enset crops and organic matter as these districts have more enset coverage than Hawassa-Zuriya district.

This result agrees with the finding of Chakoro and Mekuria (2015) who reported the effects of organic matter and crop canopy in reducing erosion and the resulting effect on soils' clay. The bulk density of Hawassa- Zuria soils was lower than those in Dale and Hula districts and it could be due to the lowest mean sand proportion in the soils of the district. This is in line with the report by Sakin et al. (2011) that negative correlation exists between the bulk density and the sand content of soils. On the other hand, bulk density values less than one indicated that the studied soils were of organic soils (Sakin and Deliboran 2011; Sakim 2012).

4.2 Soil Chemical Properties

The significant variations observed among the mean pH of the districts could be due to the differences in topographic position (Dessalegn et al. 2014), degree of removal of basic cations by crop harvest (Hartemink 2006; Sisay 2019) and prevailing micro- climate condition like rainfall intensity (Dessalegn et al. 2014). On the other hand, strong and moderate acidic reactions determined in soils of Hula district could be due to the heavy rains it experiences and the resulting accelerated leaching of the exchangeable bases. Cation exchange capacity (CEC) increased with increasing contents of clay and SOM. This was because of the negative sites which attracts positively charged ions (Kibreselassie and Suh-Yong 2020). Hence, the moderate to very high range of CEC indicated that soils are capable of keeping the micronutrients from leaching down a profile.

Significantly high variations of percent SOM in the studied soils among the districts could be due to agro ecological differences among the districts. This has been manifested by an increase in SOM with decreasing pH and with increasing elevation from Hawassa- Zuriya to Hula district (section 2.1). In line with this, Jeffrey et al. (2002) reported an increase of SOM and a decrease of pH with increasing elevation.

Phosphorus contents varied noticeably among the districts. These variations could be due to the different soil management practices, inherent soil fertility status and type and rate of organic fertilizers used in enset farming system (Fixen and Grove 1990). Besides, variation in parent material, degree of P-fixation, soil pH and slope gradient may also contribute to the difference in available P contents (Abate et al. 2016).

4.3 Status of Micronutrients in the Soils

Significant variations of zinc, boron and copper across the districts reveal that soils were different in chemical properties and the variation could be due to variations in the animal manure applied, the rain fall status and topography. The topography and rainfall effects are based on soil erosion processes and matter transport which flushes the top fertile soils. On the other hand, since manure reduces runoff, the loss of micronutrients is seldom as compared to soils containing low level of manure. This is in line with the report by Primus et al. (2017) that animal manure, rain fall amount, and topography affect the level of micronutrients in soils.

Within the districts, variance of zinc could be due to variations in SOM contents of the soils; i.e., an increase in zinc content with increasing SOM. Supporting this, a report by Brock et al. (2005) indicated an increase of zinc content as a function of the applied animal manure. This might be due to the chelation and mineralization effect of high organic matter level that increases the solubility of Zn. The finding is in line with Iratkar et al. (2014) who reported the high availability of zinc when SOM level increases. The statistically different and lower Zn contents were determined in Hawassa-Zuriya district than the Dale and Hula districts. This could be due to the calcareous nature of Hawassa-Zuriya soils that was indicated by pH (7.0) and low (2.9%) SOM. It can also be attributed to the adverse effect of high available phosphorus content (129.6 mg/kg) on zinc. This is supported by the finding of Rengel (2015) that an increase in soil pH negatively affects, especially above 6.5, the extractability and plant availability of soil Zn. The effect of high available phosphorus is in line with Yang et al. (2011) who reported that Zn extractability from soil is negatively related to phosphate. In the present study, the optimum status of Zn in soils of Hawassa-Zuriya district while high in Dale and Hula districts is convincing since enset protects the soil from erosion and degradation because of its canopy leaves, and high accumulation of applied manure as was also reported by Tamire and Argaw (2015). In accordance with EThioSiS (2014), the level of zinc was optimum in Hawassa-Zuriya district while high in the Dale and Hula districts.

The very high variations of Mn in Hawassa-Zuriya district could be due to the variations in parent materials of soils and the resulting mineralogy. Significantly different from those of other districts

Table 2: Descriptive statistics of selected soil properties under enset farming system in Sidama region.

District	Descriptive Statistics	Phosphorus (mg/kg)	pH (H_2O)	SOM (%)	Bulk density (g/cm^3)	CEC (cmol/kg)	Soil texture (%)		
							Sand	Clay	Silt
Hawassa-Zuriya (N = 27)	Mean	45.20^a	7.0^a	2.9^a	0.83^a	28.30	32.0	34.0	33.6^a
	StdDev	44.60	0.4	0.8	0.08	8.99	12.9	10.4	4.7
	Minimum	7.10	6.2	2.1	0.71	17.40	14.0	20.0	30.0
	Maximum	92.20	7.5	4.8	0.94	43.40	50.0	48.0	45.0
Dale (N = 27)	Mean	3.80^b	6.9^a	4.5^b	0.976^b	30.90	31.3	39.8	26.7^{ab}
	StdDev	2.00	0.4	1.0	0.10	6.03	7.9	6.8	6.6
	Minimum	1.10	6.3	3.4	0.87	27.10	19.0	30.0	19.0
	Maximum	7.32	7.6	6.6	1.22	46.40	44.0	50.0	38.0
Hula (N = 27)	Mean	3.04^b	5.1^b	5.4^b	0.95^b	32.00	37.9	36.4	24.8^b
	StdDev	3.00	0.3	1.0	0.06	5.30	11.4	11.3	6.9
	Minimum	0.23	4.7	4.4	0.87	26.0	26.0	17.0	16.0
	Maximum	8.40	5.4	7.1	1.08	42.6	56.0	46.0	40.0
Total (81)	Mean	17.30	6.6	4.3	0.92	30.4	33.7	36.7	28.3
	StdDev	31.92	0.9	1.4	0.10	6.90	10.9	9.60	7.0
	Minimum	2.10	4.7	2.1	0.71	17.4	14.0	17.0	16.0
	Maximum	92.20	7.6	7.1	1.22	46.4	56.0	50.0	45.0
	F value	7.84**	23.1****	16.4****	8**	0.66^{NS}	0.98^{NS}	0.8^{NS}	5*

N = number of total samples per district, **** = $p<0.0001$, *** = $p<0.001$, ** = $p<0.01$, * = $p<0.05$,
NS = non-significant, Means within a column having similar letters are not statistical significant at $p \leq 0.05$,
StdDev = standard deviation, F value = statistical F test

and the highest (259 mg/kg) content of Mn found in Dale district could be attributed to tropical weather condition of the district and the weathering of primary Mn containing ferromagnetism minerals that form secondary minerals such as pyrolusite (MnO2) (Schaefer et al 2017).

On the other hand, the lowest (15 mg/kg) Mn content of the Hawassa-Zuriya soils could be due to the statistically different and the lowest value of SOM (2.9%) determined compared to those of the other districts (Chabra et al. 1996). Moreover, it could also be due to the dry and well-aerated features of the soils since high concentrations of Mn occur in poorly drained and reduced environments (Rengel, 2015). In accordance with EthioSiS (2014), the mean Manganese level of Hawassa-Zuriya district soils was very low (<60 mg/kg) while optimum (100- 300 mg/kg) in the Dale and and Hula districts. The very low Mn is the indicative of the need for its fertility in the area.

The very high variations of Fe in Hawassa-Zuriya could be due to variations in soils' mineralogy. Significantly different and higher mean iron (214 mg/kg) determined in the Hula district could be due to the high acidic reaction (pH =5.1) in the district which increases the solubility of iron as was also reported by Kumar and Babel (2011). In the study, concentrations of Fe fall in optimum range (25-300 mg/kg) in all districts.

The within Hawassa-Zuriya and Dale district variations of Cu could be attributed to variations in mineralogy and parent materials of the soils. In the study, the highest mean copper in the Hula district soils could be due to the low pH (5.1) and high SOM (5.4%). This is supported by Iratkar et al. (2014) who reported the available copper increase with increasing contents of SOM. On the other hand, statistically similar and low Cu contents determined in Hawassa-Zuriya and the Dale district could be due to the comparatively high and statistically similar pH of soils in the districts. In the present study, concentrations of Cu fall in the optimum range (0.9-2.0 mg/kg) and this is convincing since enset protects the soil from erosion and degradation because of its canopy leaves, accumulation of decomposing SOM and application of manure as to the report by (Tamire and Argaw, 2015).

The very high variations of B could be attributed to variations in the landscape positions, management practices, soil type and mineralogy, and parent materials of the soils. The lower boron contents found in the soils of Hula district than in the soils of Hawassa-Zuriya could be due to acidic and sandy nature of the soils, and aggravated leaching of mobile borate ions by high rainfall from the root zone and vise-versa. This is in line with the finding of Oyinlola and Chude (2010), and Fekadu (2020) who reported the leaching of boron in acidic and sandy soils where heavy rain is common. According to EthioSiS (2014), B was low (0.5-0.8 mg/kg) in the soils of Hula district while optimum (0.8-2 mg/kg) in the soils of Dale and Hawassa-Zuriya districts. The low B contents in Hula district soils shows that Hula requires B fertility.

Table 3: Descriptive statistics of micronutrients in the soils under enset farming system in Sidama Region

District	Descriptive statistics	Zinc (mg/kg)	Manganese (mg/kg)	Iron	Copper	Boron
Awassa-Zuriya (N=27)	Mean	2.0^{b}	15^{c}	128^{b}	1.2^{b}	1.20^{a}
	StdDev	0.9	9	71	50.0	0.70
	Minimum	1.4	56	80	0.3	0.01
	Maximum	7.7	260	231	2.4	1.10
Dale (N=27)	Mean	13.8^{a}	259^{a}	149^{b}	1.5^{b}	0.90^{ab}
	StdDev	5.6	46	17	0.5	0.40
	Minimum	8.8	203.4	113	1.1	0.30
	Maximum	25.4	334.4	168	2.6	1.90
Hula (N=27)	Mean	11.4^{a}	197.3^{b}	214	2.0^{a}	0.50^{b}
	StdDev	4.3	40.1	41	0.6	0.40
	Minimum	4.5	125.7	153	0.9	0.10
	Maximum	17.6	243.0	290	2.8	1.20
Total (81)	Mean	9.1	157.3	164	46.7	0.80
	StdDev	6.5	111.1	60	70.4	0.60
	Minimum	4.5	55.7	80	0.3	0.01
	Maximum	32.7	334.4	290	2.8	1.90
	F value	20.5^{*****}	114.0^{*****}	7.6^{*}	65^{*****}	4.4^{*}

N=number of total samples per district, **** = $p<0.0001$, *** = $p<0.001$, * = $p<0.05$,
Means within a column having similar letters are not significant at $p\leq0.05$, StdDev = standard deviation,
F value = statistical F test.

4.4 Correlations among the Micronutrients and Selected Soil Properties

Results pertaining to the correlation studies between micronutrients and selected properties of soils showed positive and significant correlations. Boron correlated positively and significantly (r =0.3995, p< 0.039) with pH and CEC (r =0.4164, p<0.031) indicating that leaching loss of B is seldom when pH increases and it also revealed that the CEC of the soils is pH dependent and increases with increasing concentration of hydroxide ions in the soils (Dora, 2019). Significant and positive correlation existed between CEC and Mn (r =0.5350, p<0.004), and CEC and Cu (r =0.4263, p<0.027) showing that an increase in CEC increases the availability of these micronutrients due to more availability of exchange sites on soil colloids (Domingues et al., 2020). Positive correlations occurred between SOM and micronutrients (except for Zn) while statistically significant relationships existed between SOM and Mn (r =0.4271, p<0.026), and SOM and Cu (r =0.5920, p =0.0011). This is in line with the report by Kaleem et al. (2010) that the available Fe, Mn, Cu and Zn positively and significantly correlated with soil organic matter. These positive associations are convincing since SOM supplies soluble chelating agents which chelate the micronutrients, releases them slowly and increases their availability (Kumar and Babel, 2011). With regard to positive correlation between Cu and SOM, it could also be said that soils of the study area are not high in organic matter like soils of peat and mucks areas since these held Cu^{++} or Cu^{+++} more tightly and thereby cause the deficiency (Mathayo et al. 2016).

Statistically significant and negative correlation between pH and micronutrients such as Fe (r = -0.6683, p=0.0001) and insignificant negative correlation with Cu indicated that the solubility of these micronutrients decreases with increasing pH. Here, negative correlation of Fe with pH shows the iron reducing effect of the lowering pH, from non-available (non-toxic) Fe^{3+} into plant-available Fe^{2+} ions and vice versa (Rengel 2015). On the other hand, the decrease in plant available forms of micronutrients with increasing pH may result from poor solubility of the given chemical form of the nutrient (Takala 2019).

Although not statistically significant, positive association between clay and the micronutrients shows that the availability of micronutrients increases with increasing clay content. Supporting this, Doug (2004) reported that fine textured soils with higher amounts of clay are less likely to be low in plant available micronutrients. Statistically significant and negative correlation occurred between phosphorus and zinc (r = 0.6949, p<0.0001). This revealed that in the soils where available phosphorus is high, available Zn becomes low because of the ‘phosphorus induced zinc deficiency’ (Nguyen et al, 2019). Besides, statistically significant and positive correlation (r =0.6642, p =0.0002) existed between Zn and B indicates that compounds which constitute them solubilise in the same pH range. Furthermore, significant and positive association occurred between Mn and B (r =0.5574, p =0.0025), and Fe and Cu (r =0.4820, p =0.011) also show that compounds containing these pairs of micronutrients solubilise in the same pH range.

Statistically significant and negative correlation between pH and Altitudes (r = - 0.9329, p<0.0001) indicated that the hydrogen ion concentration in the soils increased with an increasing altitude while decreasing with a decreasing altitude. This means, pH decreases with increasing altitude and vice versa. This is in line with the report that higher precipitation increases the leaching of basic cations while increasing the hydrogen ions (Shazia et al. 2014). Positive association of SOM with altitudes (r =0.6527, p=0.0002) showed that the decomposition rate of SOM slowed as an altitude increases and decomposition hastened with a decreasing altitude. The result agrees with Charan et al. (2013) who reported an increase of SOM content when altitude increases. The positive correlation of Fe and Cu with altitudes showed the solubilising of iron and Cu chemical forms (compounds) by the low pH (soil reaction). Even though insignificant, the negative correlation of B with Altitudes showed the decreasing of B with an increasing altitude. This could be due to the leaching loss of B, in the forms of boric acid (H3BO3), which dominates in soil solutions below pH 7.0; by the heavy rains in high altitude areas (Quaggio et al. 2003).

5 Conclusion

The effect of mean soil pH on Zn, B and copper contents show that the micronutrients management must be on the basis of soils' pH management. The very low Mn content determined in Hawassa-Zuriya, which is probably due to the rapid decomposition of added manure, indicates the importance of manure management to raise the soil Mn level so as to come up with economically sound yield. The low B content determined in Hula implied the importance of boron management while giving due attention to the narrow range occurring between optimum and deficiency. From the correlation study, the positive relationship among pH, CEC and available B; the positive relationship among CEC, SOM, Mn and Cu show the importance of very slight increase in pH during lime application. This indicates the importance of SOM management in order to increase the Mn and Cu contents of the soils. On the other hand, significant and negative correlation existed among pH, Fe and Zn indicated the effect of decreasing pH on an availability of Fe and Zn. Hence, pH decreases as altitude increases, and the availability of these micronutrients becomes high as compared to low altitude areas. Thus this indicates the importance of Fe and Zn management in low altitude areas. Finally, it is concluded that people engaged in enset production/agricultural activities should apply phosphorus based on soil's zinc content.

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Table 4: Pearson cross-correlation matrix between micronutrients and selected soil properties and altitudes

	pH	SOM	CEC	Clay	P	Zn	Mn	Fe	Cu	B	Alt
pH	1	-0.5008	0.4829	-0.0195	0.3485	-0.7701***	0.0694	-0.6683***	-0.3576	0.3995	-0.9329****
SOM		1	0.4829	0.0626	-0.4585	-0.0234	0.4271	0.3513	0.5920	0.2304	0.6527****
CEC			1	0.1861	-0.3085	0.0315	0.5350	-0.0692	0.4263	0.4164	0.1729
Clay				1	0.0240	0.0512	0.3117	0.1916	0.0425	0.1472	-0.0225
P					1	-0.6949***	-0.5716	0.0979	-0.1629	0.1579	-0.3410
Zn						1	-0.0833	0.2911	0.1631	0.6642	-0.2123
Mn							1	-0.0907	0.3418	0.5574	0.0341
Fe								1	0.4820	-0.0427	0.6662***
Cu									1	0.3590	0.5331***
B										1	-0.2571
Alt											1

* Denotes significant at $p<0.05$, ** denotes significant at $p<0.01$, *** denotes significant at $p<0.001$,
**** denotes significant at $p<0.0001$,
Bd=Bulk density, p=phosphorus, Zn=zinc, Mn=manganese, Fe=iron, Cu=copper, B=boron, Alt=Altitude.

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