International Journal of Plant & Soil Science

25(1): 1-12, 2018; Article no.IJPSS.44106
ISSN: 2320-7035

Micronutrients Status Assessment in Three Representative Locations in Ethiopia

A. Menna[1*]

[1]*Debre Zeit Research Center, Ethiopian Institute of Agricultural Research (EIAR), P.O.Box-2003, Addis Ababa, Ethiopia.*

Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/IJPSS/2018/44106
Editor(s):
(1) Dr. Alejandro Hurtado Salazar, Professor, Departamento de Produccion Agropecuaria, Universidad de Caldas, Colombia.
Reviewers:
(1) A. K. Ibrahim, Federal University of Kashere, Nigeria.
(2) Nyong Princely Awazi, University of Dschang, Cameroon.
(3) Addam Kiari Saidou, National Institute of Agricultural Research of Niger, Niger.
Complete Peer review History: http://www.sciencedomain.org/review-history/26788

Original Research Article

Received 08 July 2018
Accepted 25 September 2018
Published 23 October 2018

ABSTRACT

Though needed in very small quantities, micronutrients are as important as primary and/or secondary nutrients in yield-formation and in enhancing crop-quality. Twenty four field experiments (18 sulfur response; and six sulfur rate determination), therefore, were conducted to evaluate the micronutrients fertility of soils in three locations in central Ethiopia, during 2013-16. In doing so, 54 surface soil samples (24 before planting; and 30 after wheat harvest) were analysed using standard laboratory (Lab) methods. Some soil and crop yield variables were subjected to SAS statistical analysis. The results showed that iron, zinc, boron and molybdenum were low; whereas cupper and manganese were adequate in most studied soils. Among others, lack of nutrient recycling was the major cause for the observed micronutrients deficiency. Soil factors such as pH, organic carbon, $CaCO_3$ and parent material also have contributed to the low fertility of micronutrients vis-à-vis their contents in soils. Therefore, strategies involving soil enhancement by seed treatment or the use of organic amendments of different sources can be adopted to sustain optimum crop-yields and quality. Hence, in addition to the previous recommendations on sulfur, the deficient micronutrients need to be included in the balanced fertiliser formulas, if soil-test, plant-tissue analysis and/or crop-responses data are available. It is well recognised that, micronutrients application to soils is not economical in large scale productions, possibly due to the different losses in relation to their small

Corresponding author: E-mail: assefams@yahoo.com;

quantities to be applied. Furthermore, the deficiencies of elements like zinc and iron can be acute when alkaline soils like that of East-Shewa are brought under irrigation. Because of such problems, and adverse reactions, the use of special protective complexes (chelates), and direct application of the micronutrients to plant-foliage via foliar sprays or fertigation may be recommended. In some cases, food enhancement of the deficient micronutrients can also be adopted.

Keywords: Micronutrients; plant available; deficient; sufficient; toxic levels.

1. INTRODUCTION

For the last two decades, an increasing use of mineral fertilisers of different sources has led to yield increases in Ethiopian crop production systems. Modern cultivation methods; better control of plant diseases, pests and weeds and; increase in the irrigated area etc are all factors responsible for the general increase in crop-yields in recent years. Coupled with this, major emphasis was given to nutrients, mainly nitrogen (N), phosphorus (P) and potassium (K). For a long time, it was felt that under the existing farming systems, the levels of micronutrients were adequate and that their deficiency was not serious. Although micronutrients are as essential as primary/secondary elements in crops production, until recently little data are available on those elements in soils and crops. Interestingly, most micronutrients are routinely analysed in Ethiopian, soil-plant analytical Labs, but their fertiliser materials are not regularly applied to soils through common fertilisers. Furthermore, despite more than three decades of investigations on micronutrients, their role in soil–plant–animal systems of Ethiopia has not yet been studied systematically.

Although, some early reports recognised the problem of micronutrients deficiency [1,2,3], there are many reasons why the micronutrients didn't receive adequate attention in Ethiopian agriculture. Firstly, the smallholding agriculture has been based on exploiting soil's natural reserve, mainly micronutrients released as soil organic matter (SOM) decomposes and/or other parent materials mineralise. Secondly, there is a lack of responses to soil-applied micronutrients in cereal fields. Thirdly, in some cases, there are very narrow gaps between their levels that are being deficient, sufficient and/or toxic to plants. These, together with the large number of trace elements; their occurrences in different complex chemical forms in soils; their complicated functions in biological processes; and difficulties in identifying deficiency or toxicity symptoms if not severe; make their corrections often laborious and time-consuming, and in the cases of toxicity even risky. The micronutrient deficiencies, even with minor symptoms can lower crop-yields or quality; and low production in animals. From this, it is apparent that hidden trace elements deficiencies are far more widespread in crop lands than are generally estimated. Micronutrients enhance crop-yields, nutritional quality, resilience to drought and pest/diseases. These positive effects can range from 10-70%, and occur with or without NPK fertilisation [4]. Hence, the research questions for this study are, (a) Is the micronutrients deficiency wide-spread in annual crop-lands in Ethiopia? (b) If so, what are the causes for their deficiency?

In view of the above background, therefore, the objectives of this work were: (i) To assess the status of micronutrients in annual crop-lands, and (ii) To assess some of the root causes for the micronutrients deficiency in soils.

2. MATERIALS AND METHODS

2.1 Experimental Treatments and Design

Twenty four, on-farm experiments were conducted in three representative locations, namely Arsi (Ar), E/Shewa (ES) and W/Shewa or O/Liuu (OL) zones. For assessing micronutrients status, 54 soils samples (0-20 cm soil-depth) were collected in two cropping seasons. Twenty four soil samples, each representing an experiment were taken before planting; whereas 30 soil samples were taken after crop-harvest. The eighteen soil samples that were taken before planting represent 18 sulfur response experiments conducted during 2013-14. Similarly, the other six samples that were taken before planting, each represent six sulfur rate determination experiments conducted during 2015-16 in the same three locations. In 2015-16, the selected three site-fields, namely GS-2, Ke-2 and NS-2 were based on previous season's wheat responses to applied S. These site-fields were responsive to applied N, S and P as related to the soil-test values. Whereas WG/Do-2, Bk-2 and BT-2 were selected randomly without pre soil-testing, but on areas approximately 0.5 to 1.5

miles away from the previous season's S responsive sites, namely Do-1, Bk-1 and BT-1 respectively. The purpose of selecting the sites was to further evaluate wheat responses to applied S. In both seasons, a randomized complete block design (RCBD) was used, and it was replicated three times. From each field, surface soil samples were taken from 10-spots per block and bulked, and further composted to make one sample per experiment.

The third set, 30 soil samples, that were taken after harvest in 2015-16, each represents a treatment. The five treatment levels per experiment are indicated as: check(CK), or (N_0,P_0,S_0); (N_{69},P_0,S_0); (N_{69},P_0,S_5); (N_{69},P_0,S_{10}); and (N_{69},P_0,P_{20}). The subscripts represent NPS levels respectively in kg/ha. These soil samples were taken from only N and NS treated plots to estimate trends of micronutrients' depletion after harvest. At this stage, the soils were sampled from 10-spots (from each block); and bulked, and further composted together to represent one sample per experimental unit.

The nutrients applied in 2013-14, were 2-levels of S (0 and 20) kg/ha; 2-levels of P (0 and 20) kg/ha; and 2-levels N (0 and 69) kg/ha. But, in 2015-16, 4-levels of S (0, 5, 10 and 20) kg/ha; 2-levels of N (0 and 69) kg/ha; and 2-levels of P (0 and 20) kg/ha were applied. Sulfur was applied as gypsum ($CaSO_4.2H_2O$), nitrogen as urea, and phosphorus as triple-superphosphate (TSP). Nitrogen and P were applied as recommended for wheat production in the areas. Nitrogen was split-applied, whereas, the entire sources of SP were drilled within rows and incorporated into soils before seeding.

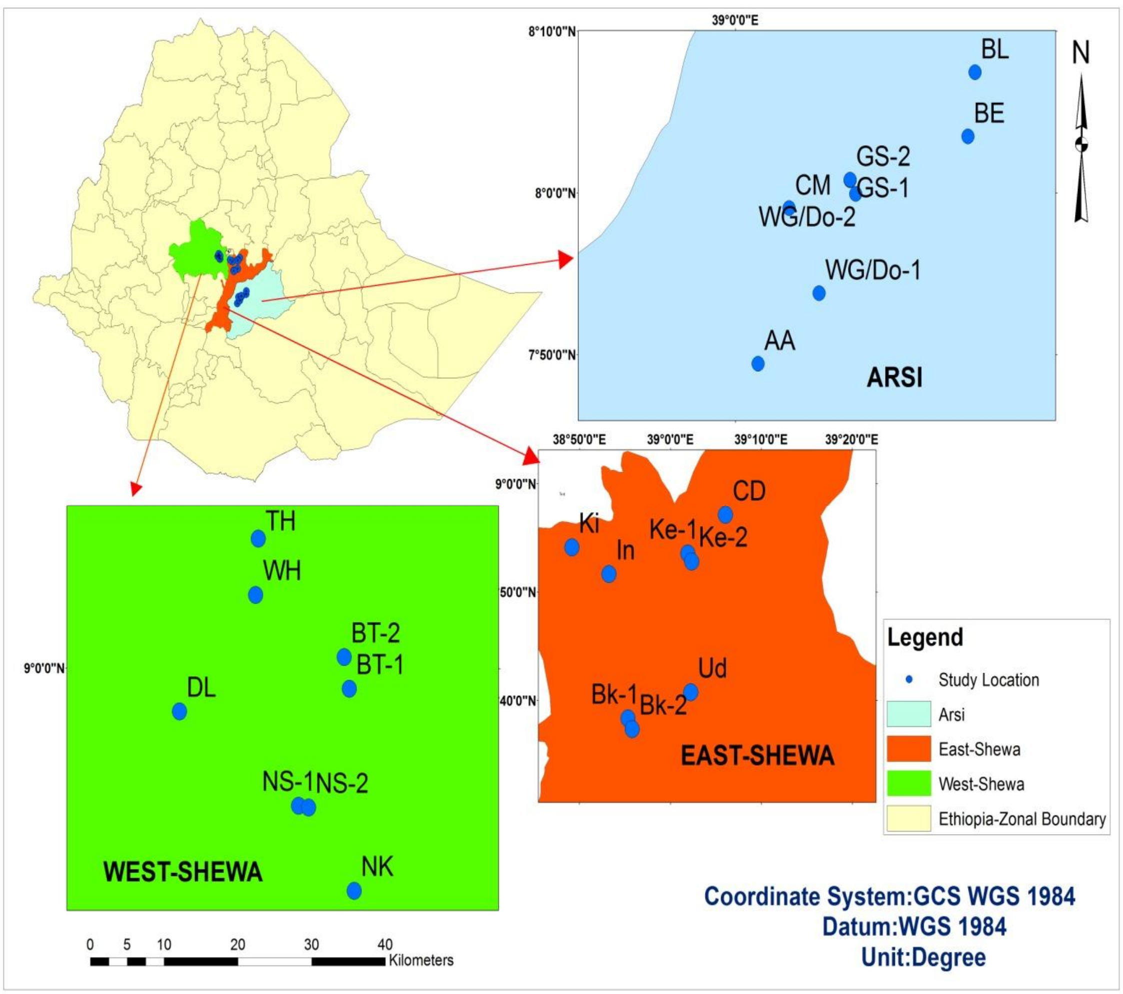

Fig. 1. Locations map showing study site-fields in Arsi, East-Shewa and West-Shewa

Table 1. The analytical methods used for the studied soils

Parameters	Unit	Extraction/Analytical method by	References
pH	Ratios	Potentiometrically,1:2.5;Soil:Water	[5]
EC	mS/cm	1:5 soil:water suspension	[6]
Exch. bases (Na^{+1}, K^{+1})	cmol(+)/kg	1*M*.NH4OAc-solution, pH=7.00	[7]
Exch. bases (Ca^{+2}, Mg^{+2})	cmol(+)/kg	1*M*.NH4OAc-solution, pH=7.00	[5]
CEC	cmol(+)/kg	1*M*.NH4OAc-solution, pH=7.00	[5]
BS	%	Calculated from Exch.bases	[5]
TN	%	Kjeldahl Digestion	[8]
OC	%	Walkley-Black as described in	[9]
Av.P	mg/kg	Bray-I,(pH<7.00)	[10]
Av.P	mg/kg	Olsen,(pH>7.00)	[11]
SO_4-S	mg/kg	Calcium Ortho-Phosphate, Turbidi-metric	[7]
Soil-texture	%	Hydrometer	[12]
Copper	mg/kg	(DTPA/-AAS)	[13]
Manganese	mg/kg	(DTPA/-AAS)	[13]
Iron	mg/kg	(DTPA/-AAS)	[13]
Zinc	mg/kg	(DTPA/-AAS)	[13]
Boron	mg/kg	Hot-water-soluble	[14]
Molybdenum	mg/kg	Acid-NH_4-Oxalate, pH3.3 extractable	[15 and 16]

DTPA = Diethylene-tetramine-penta-acetic; AAS = Atomic-absorption-spectrometry

In both seasons, a wheat cultivar known as 'Kekeba' was used as a test-crop. In the RCB design, each replicate was sub-divided into 3m by 5 m plots, and there were four experimental units per block in 2013-14; and nine in the 2015-16 cropping-seasons. There were 12-rows of plants per plot. The agronomic spacing used was, 25 cm between rows and 5 cm between wheat plants. There were two border rows and one was used for tissue sampling. The agronomic data and seed samples were collected from a 4 m by 1.5 m center rows. The seed samples collected at harvest, and tissue samples collected at wheat booting, from each plot were analysed for nutrients' N and S contents.

In each location, the 24 selected farmers' fields were geo-referenced using Global Positioning System (GPS), assisted by Google earth (2011) and were classified by elevation, size and soil-type when known and mapped. The sites were characterised and used for conducting S-response and rate determination experiments in wheat. The specific locations and sites are mapped (Fig. 1).

2.2 Soil Sample Preparation and Analysis

All soil samples were air-dried immediately in dust free dry-rooms to avoid SO_4-S^- formation from OM in the transit, and ground and sieved to pass 1-mm sieve. The variables analysed were cupper (Cu), manganese (Mn), iron (Fe), zinc (Zn), boron (B), molybdenum (Mo), pH, organic carbon (OC), electrical conductivity (EC), total nitrogen (TN), available phosphorous (PO_4-P), sulfate sulfur (SO_4-S), exchangeable bases, cation exchange capacity (CEC), base saturation (BS) and texture in the wet- soil chemistry Labs using the procedures outlined in Table 1.

2.3 Statistical Analysis

Data on yield and yield components were analysed using SAS [17]. The ANOVA was done using PROC-MIXED generalized linear model (GLM) for SAS to evaluate differences between the variables. When the differences between treatments were significant, least significant difference (LSD) was used to separate means at 0.1%, 1% and 5% probability levels. For some variables correlation or regression analysis was done using the PROC-REG [17] protocol.

3. RESULTS AND DISCUSSION

In spite of the positive impacts in fertilisers use, more and more micronutrients are being removed annually from the natural soils' reserve than are being applied as mineral fertilisers. Some removed nutrients are replaced from crop-residues and farmyard manure etc, but on the average the nutrients' balances remained negative. Tables (2a and 2b) depict data on available micronutrients for the soil samples taken before planting. The following sub-sections discuss their available contents vis-à-vis critical thresholds.

Table 2a. Contents of micronutrients in the soils of Arsi, E/Shewa and W/Shewa zones (2013-14)

Zone	District	Farmer field	Soil Type	Soil Tex.	Altitude (m)	OC (%)	BS (%)	pH (1:2.5, soil:H_2O)	Av. P (mg/kg)	SO_4-S (mg/kg)	Nodules of $CaCO_3$	Cu (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Zn (mg/kg)	B (mg/kg)	Mo (mg/kg)
Ar	Ti	AA	CV	SCL	2297.02	1.11	63.20	5.95	5.12	6.94	no	2.38	41.67	4.80	0.91	0.31	0.05
Ar	Ti	Do	RNi	C	2418.32	2.04	42.48	5.30	1.84	10.44	no	1.38	59.67	6.40	1.01	0.44	0.04
Ar	Ti	GS	CV	SC	2151.10	1.17	68.24	6.12	3.73	7.77	no	1.65	43.33	3.50	0.63	0.43	0.03
Ar	Ti	CM	Ni	C	1768.98	2.75	71.83	6.94	1.11	22.13	no	0.75	38.33	3.40	0.82	1.22	0.06
Ar	Hi	BE	CV	C	2359.95	2.77	64.03	6.19	1.95	21.50	no	2.38	43.33	5.00	0.76	0.99	0.06
Ar	Hi	BL	Ni	SC	2186.37	1.07	69.19	6.98	3.29	4.32	no	1.47	36.67	3.10	0.52	0.38	0.04
ES	Gi	CD	PV	C	2426.53	0.90	96.64	7.91	7.67	15.37	yes	1.29	5.00	1.60	0.34	0.24	0.59
ES	Ad	Ke	PV	C	2224.37	1.06	96.47	8.14	7.55	5.78	yes	1.47	6.70	1.80	0.33	0.23	1.08
ES	Ad	Ud	PV	C	1873.86	1.23	90.80	7.14	9.53	12.37	yes	2.38	5.67	2.00	0.32	0.42	0.11
ES	Ad	Bk	PV	SC	1874.16	1.31	93.39	7.33	10.82	1.30	yes	2.11	5.00	1.90	0.26	0.35	0.04
ES	Ak	In	CV	C	2211.30	1.35	92.65	7.15	10.99	6.62	yes	1.47	10.00	1.70	0.26	0.24	0.10
ES	Ak	Ki	PV	C	2204.00	1.39	95.23	8.02	8.17	8.27	yes	1.56	6.70	1.90	0.19	0.41	1.12
OL	We	NK	CV	C	2123.74	1.41	66.98	6.71	0.22	11.89	no	1.93	46.67	5.10	0.58	0.48	0.05
OL	We	NS	RNI	C	2229.54	1.47	45.73	5.65	0.39	5.64	no	2.29	50.00	7.10	0.91	0.41	0.07
OL	We	BT	RNi	CL	2252.64	1.69	41.60	5.07	1.89	3.82	no	1.75	60.00	8.20	1.25	0.25	0.06
OL	We	DL	RNi	CL	2173.60	1.71	52.91	5.86	0.28	10.83	no	3.11	63.33	7.60	0.88	0.44	0.05
OL	We	WH	RNi	C	2335.63	2.99	49.63	5.52	1.34	23.02	no	3.47	50.00	9.10	1.12	1.57	0.06
OL	We	TH	RNi	C	2349.62	1.31	50.25	5.62	1.45	24.18	no	4.11	53.33	5.10	1.17	0.43	0.07

Key: Soil Types (CV =Chromic Vertisol, RNi = Red Nitisol, PV =Pellic Vertisol); and Soil Texture (SCL =Sandy clay loam, C =Clay, SC =Sandy clay, and CL =Clay loam); and Av.P (pH >7.0, Olsen; and pH <7.0, Bray-1 method). Study areas[(Ar =Arsi, ES =E/Shewa =East-Shewa, OL =O/Liyuu=Oromia-Liyuu or West-Shewa)]; Districts[(Ti =Tiyo, Hi =Hitossa, Ad =Ada'a, and We =Welmera)]; Farmer fields (WG/Do-1-2 =Wonji-Gora/Dosha, GS-1-2 =Gora-Silingo, Ke-1-2 =Keteba, Be-1-2 =Bekejo, NS-1-2 =Nano-Suba, BT-1-2 =Berfeta-Tokofa, AA =Abosara-Alko, CM =Chefe-Misoma, BE =Boneya-Edo, BL =Boru-Lencha, CD =Chefe-Donsa, Ud =Ude, In =Insilale, Ki =Kilinto, NK =Nano-Kersa, DL =Dawa-Lafto, WH =Wajitu-Harbu and TH =Tulu-Harbu)

Table 2b. Contents of micronutrients in the soils of Arsi, E/Shewa and W/Shewa zones (2015-16)

Zone	District	Farmer field	Soil type	Soil Tex.	Altitude (m)	OC (%)	BS (%)	pH (1:2.5, soil:H_2O)	Av.P (mg/kg)	SO_4-S (mg/kg)	Nodules of $CaCO_3$	Cu (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Zn (mg/kg)	B (mg/kg)	Mo (mg/kg)
Ar	Ti	WG	PV	C	2418.32	2.71	70.22	6.36	2.01	31.98	no	2.56	61.67	4.10	0.87	1.60	0.06
Ar	Ti	GS	Ni	CL	2151.10	2.18	65.24	6.24	3.01	12.11	no	2.47	41.67	4.60	0.93	0.38	0.05
ES	Ad	Ke	PV	C	2224.37	1.15	93.31	8.00	9.02	6.77	yes	1.47	6.70	2.10	0.36	0.34	1.06
ES	Ad	Bk	PV	SC	1874.16	1.17	83.19	7.15	12.01	4.03	yes	3.20	5.50	2.20	0.49	0.21	0.05
OL	We	NS	RNi	C	2229.54	0.96	55.16	5.85	0.89	4.58	no	2.38	55.00	6.90	0.98	0.44	0.05
OL	We	BT	PV	C	2252.64	2.03	37.45	4.85	0.50	35.83	no	3.11	65.00	8.20	1.21	0.41	0.04

Table 3. Contents of micronutrients in the soils of Arsi, E/Shewa and W/Shewa zones (2015-16)

Zone	District	Farmer field	Soil type	Soil Tex.	Altitude (m)	BS (%)	pH(1:2.5, soil:H_2O)	Nodules of $CaCO_3$	Treatment, NPS (kg/ha)	Cu (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Zn (mg/kg)	B (mg/kg)	Mo (mg/kg)
Ar	Ti	WG	PV	C	2418.32	67.31	6.17	No	CK(0,0,0)	2.00	58.67	3.40	0.64	1.41	0.05
Ar	Ti	WG	PV	C	2418.32	68.28	6.10	No	69,0,0	1.44	50.00	3.10	0.50	1.22	0.05
Ar	Ti	WG	PV	C	2418.32	77.53	6.40	No	69,0,5	1.45	53.67	2.90	0.44	1.11	0.04
Ar	Ti	WG	PV	C	2418.32	88.05	6.57	No	69,0,10	1.37	54.33	2.80	0.58	1.33	0.03
Ar	Ti	WG	PV	C	2418.32	86.77	6.60	No	69,0,20	1.47	55.00	3.10	0.45	1.22	0.04
Ar	Ti	GS	Ni	CL	2151.1	63.06	6.06	No	CK(0,0,0)	1.64	37.67	3.80	0.81	0.31	0.04
Ar	Ti	GS	Ni	CL	2151.1	60.94	6.11	No	69,0,0	1.26	35.00	3.60	0.58	0.26	0.04
Ar	Ti	GS	Ni	CL	2151.1	68.90	6.39	No	69,0,5	1.53	33.33	3.30	0.51	0.24	0.04
Ar	Ti	GS	Ni	CL	2151.1	70.05	6.58	No	69,0,10	1.36	36.67	3.50	0.58	0.25	0.03
Ar	Ti	GS	Ni	CL	2151.1	71.69	6.88	No	69,0,20	1.73	30.00	3.20	0.49	0.26	0.04
ES	Ad	Ke	PV	C	2224.37	92.85	7.60	Yes	CK(0,0,0)	0.55	4.53	1.50	0.21	0.26	1.00
ES	Ad	Ke	PV	C	2224.37	91.62	7.71	Yes	69,0,0	0.44	2.20	0.80	0.08	0.22	1.00
ES	Ad	Ke	PV	C	2224.37	95.08	8.09	Yes	69,0,5	0.45	2.41	0.90	0.04	0.21	0.98
ES	Ad	Ke	PV	C	2224.37	100.04	8.10	Yes	69,0,10	0.55	3.01	1.10	0.07	0.21	0.97
ES	Ad	Ke	PV	C	2224.37	99.77	8.19	Yes	69,0,20	0.47	3.77	1.00	0.09	0.20	1.00
ES	Ad	Be	PV	SC	1874.16	82.25	6.70	Yes	CK(0,0,0)	2.55	3.67	1.60	0.26	0.14	0.06
ES	Ad	Be	PV	SC	1874.16	83.10	6.81	Yes	69,0,0	2.25	0.33	1.00	0.06	0.10	0.04
ES	Ad	Be	PV	SC	1874.16	98.31	7.25	Yes	69,0,5	2.06	1.30	1.10	0.03	0.10	0.02
ES	Ad	Be	PV	SC	1874.16	97.89	7.32	Yes	69,0,10	2.25	0.33	0.90	0.09	0.10	0.04
ES	Ad	Be	PV	SC	1874.16	99.95	7.39	Yes	69,0,20	2.06	1.20	1.00	0.06	0.10	0.03
WS	We	NS	RNi	C	2229.54	53.31	5.50	No	CK(0,0,0)	1.64	51.33	6.10	0.82	0.36	0.05
WS	We	NS	RNi	C	2229.54	54.45	5.65	No	69,0,0	1.15	50.50	5.50	0.64	0.31	0.03
WS	We	NS	RNi	C	2229.54	57.55	5.85	No	69,0,5	1.15	46.00	5.20	0.58	0.32	0.03
WS	We	NS	RNi	C	2229.54	58.78	5.90	No	69,0,10	1.34	42.87	5.60	0.51	0.31	0.03
WS	We	NS	RNi	C	2229.54	57.09	6.20	No	69,0,20	1.43	43.97	5.10	0.61	0.32	0.02
WS	We	BT	PV	C	2252.64	36.26	4.60	No	CK(0,0,0)	2.36	61.33	7.50	1.19	0.34	0.04
WS	We	BT	PV	C	2252.64	36.00	4.70	No	69,0,0	2.15	50.00	7.20	1.01	0.29	0.03
WS	We	BT	PV	C	2252.64	39.50	5.79	No	69,0,5	2.25	54.33	6.20	0.72	0.29	0.02
WS	We	BT	PV	C	2252.64	40.70	5.99	No	69,0,10	2.25	56.67	6.30	0.94	0.28	0.03
WS	We	BT	PV	C	2252.64	42.18	6.39	No	69,0,20	2.15	60.00	5.20	0.91	0.30	0.02

3.1 Copper

The average concentration of cupper in the earth's crust is 28 mg/kg [18]. Plant available copper in the two cropping seasons ranged from 0.75 to 4.11 mg/kg (Tables 2a and 2b). Its mean value was 2.17 mg/kg, with a standard deviation (Std-Dev) of 0.807. A 0.2 mg/kg was reported as a critical level (CL) for Cu-deficiency [13,19,20,21]. Based on this, therefore, none of the studied field-sites were found to be deficient in available Cu. In accordance, Sillanpää [2] reported a normal range, with no excess levels of Cu in Arsi and Shewa provinces. Similarly, from few soil samples analysed in ES, [22] reported adequate levels of Cu in all samples (but, using 0.5 mg/kg as a CL). In a study restricted to ES, in a few Vertisol samples [23], also reported a similar result. However, in contrary to the results, [3], reported, 51.6% of the Vertisol samples in Ethiopia to be deficient in Cu.

But, for soil samples collected after wheat harvest, the contents of available Cu, ranged from 0.44 to 2.55 mg/kg with a mean value 1.56 mg/kg, and a Std-Dev of 0.624 (Table 3). At this stage, the contents of Cu were reduced equivocally in the values ranging between 0.2 to 0.5 mg/kg as compared to that before planting. The fall in the values of available Cu might be due to the plants (wheat and weed) uptake combined with different losses. Even after crop harvest, the contents of available Cu were above the CL, which affirms the sufficiency of Cu in all samples. However, with the current trends of increasing levels of nutrient mining, Cu deficiency might be expected in the near future.

3.2 Manganese

Manganese concentration in the earth's crust is 1000 mg/kg [18]. The contents of available Mn in the soils ranged from 5.0 to 65.0 mg/kg with a mean value 35.87 mg/kg, and a Std-Dev of 22.60 (Tables 2a and 2b). The CLs for Mn-deficiency in soils were reported to be 1.0 mg/kg [13]; and 5.7 mg/kg [21]. Based on [13], therefore, all soils were adequate in Mn for sustaining crop production. In accordance, in a study restricted to few soil samples from ES [22,23] found adequate levels of available Mn (>1.0 mg/kg) in all samples.

Based on the CL suggested by Patel et al. [21], however, sites like C/Donsa; and Bekejo were found to be deficient in Mn (11.11% of the sites). Sites like Keteba, Ude, Kilinto were marginal or equilibrating this CL (about 12.50% of the sites). The rest were sufficient in available Mn. More generally, according to Sillanpää [2], a substantial percentage of Ethiopian soils form Sidamo, Arsi and Shewa provinces was high in Mn.

But, based on the critical thresholds for Mn-toxicity, 55 mg/kg [21], few sites like W/Gora; and B/Tokofa (Table 2b) were contaminated with excess levels of Mn. In these field-plots foliar symptoms of leaf chlorosis in wheat were also observed, which might be due to Mn-toxicity. In fact, those field-plots received high levels of PS treatments. In agreement, [24] reported, Mn-toxicity in plants that are fertilised with acid-forming fertilisers (high rates of superphosphate or NO_3^- as N-source); or plants that are low in silicon, or deficient in calcium, iron, magnesium or P as antagonistic effects. The soils of WG and BT are strongly acidic Vertisols (pH$\leq$ 5.0), and highly waterlogged. As a result, Mn-toxicity is expected. However, liming can reduce the toxicity levels.

Huang et al. [25] also reported the likelihoods of Mn-toxicity in plants grown in waterlogged soils, rich in OM or grown under high temperature or high light intensity due to its limited absorption or translocation. According to, Kirk et al. [26], the mechanisms of Mn-toxicity in waterlogged soils may include soil pH, redox-potential, CEC and microbial activity. With redox-potential declining after water-logging, the transition metals such as Mn^{4+} and Fe^{3+} are utilised as alternative electron acceptors when oxygen is depleted, resulting in an increased concentrations of soluble Mn^{2+} and Fe^{2+}, which may exceed plant requirements and cause toxicity. According to Thiagalingam [27], Mn-deficiencies are common also in sandy, organic-soils, high-pH calcareous soils, and plants with high demand of Mn.

But, for the soil samples taken after crop harvest (Table 3), the contents of Mn ranged from 0.33 to 61.33 mg/kg with a mean value 32.80 mg/kg and a Std-Dev of 23.26. In general, from the results it is learnt that, the availability of elements in soils is affected by multiple of interacting factors. As a result, for full understanding of Mn-toxicity, multidisciplinary approaches that make comparative studies among different genotypes of the same species might be needed.

3.3 Iron

Iron comprises about 5% of the earth's crust and is the fourth most abundant metal in the lithosphere [18]. Most of the soils iron is found in primary minerals, clays, oxides and hydroxides. The plant available Fe was ranged from 1.6 to 9.1 mg/kg with a mean value 4.48 mg/kg, and a Std-Dev of 2.414 (Tables 2a and 2b). Considering 4.5 mg/kg as a CL for Fe-deficiency [13], therefore, about 50% of the sites were found to be deficient in Fe, and only one site was marginal, 4.80 mg/kg. About, 45.83% of the fields were adequate in available Fe.

Considering 6.0 mg/kg as a CL [21], however, 54% of the field-sites were found to be deficient in Fe; and 25.20% were marginal. Only 20.83% of the sites were adequate in Fe. In general, the results are in accordance with that reported by Sillanpää [2]. According to the author, Ethiopian soils are insufficient in Fe. However, the results are somehow contrary to that reported by Enwezor et al. [28]. Based on their report, the available Fe is generally high in tropical soils, with only some localised areas to be deficient in Fe. Also, in some previous studies in Ethiopia, Fe-deficiency was not reported, except by Teklu et al. [29]. In their study, about 20% of Vitric Andisols in the Rift-Valley were reported to be deficient in Fe. Also Hillette et al. [22] reported adequate levels of available Fe (> 5.0 mg/kg) from few soils they sampled in ES. In fact, most soils in ES are alkaline, and this is in contrary to the general result by Thiagalingam [27]. According to this author, Fe-deficiency is common in calcareous-soils, arid-soils and soils cropped with high Fe-demanding plants (fruits, maize, soybeans…), which might be due to the fact that, the high levels of bicarbonate and phosphates lower Fe-availability due to its precipitations.

For the soils sampled after harvest (Table 3), the values fell between 0.80 to 7.50 mg/kg, with a mean value 3.45 mg/kg, and a Std-Dev of 2.104. Taking 4.5 mg/kg as a CL, therefore, all soil samples from Ar and ES, fell in a deficient range, whereas, all soil samples from WS, 33%, were found to be adequate in Fe. But, taking 6.0 mg/kg as a CL, only two soil samples from BT site were found to be adequate in Fe, and another two samples were marginal, 6.20 and 6.30 mg/kg. This may indicate that, with the current trends of an increasing crop production and continuous mining of Fe from soils, the deficiency of Fe would be more severe in the near future. According to Bassirani et al. [30], the deficiency of micronutrients is mainly caused by intensive cultivation of improved crop varieties those take-up nutrients more readily from soils. In general, from the present study, relatively high-pH calcareous and sandy soils were found to be more deficient in Fe, and the reverse was true for soils with low pH.

3.4 Zinc

Zinc content of the lithosphere is 67 mg/kg [18]. It has a strong affinity to combine with sulfide-ores and occurs most frequently as sphalerite. The plant available Zn in soils (Tables 2a and 2b) ranged from 0.19 to 1.25 mg/kg with a mean value 0.71 mg/kg, and a Std-Dev of 0.338. Taking 1.0 mg/kg as a CL for its deficiency [13], therefore, about 79.2% of the sites were deficient in Zn. Some 20.83% were marginally above the CL. In this study, no adequate levels of Zn were observed. In the study limited to few Vertisol samples from ES, [22,23] also found 70-98% of sites to be deficient in Zn (<1.5 mg/kg). The present result is also in accordance with the finding by Asgelil et al. [3]. The authors reported, 78.40% of the Vertisol samples collected from Ethiopia to be deficient in Zn. Generally, Zn has low mobility in soils and has a tendency to be adsorbed on clay-sized particles, which might be the cause for its observed deficiency.

But, after crop harvest, 93.33% of the soils fell either in a deficient or severely deficient range in available Zn (Table 3). A few soil samples, sufficient/marginal in Zn were found only in strongly acidic-soils of WS and/or Arsi zone. Generally, the micronutrients zinc, copper, iron, and manganese were reported to be readily available in acid-soils, but much less soluble at pH > 7.0 [31]. Therefore, in such alkaline-soils (e.g., like that in ES); plant growth can be limited by the problems of these elements. Indeed, the low levels of OC in the studied soils can also be the cause for their deficiency. Especially, their deficiencies can be acute when alkaline-soils are brought under irrigation. According to, Weil and Brady [31], because of such problems and adverse reactions, their corrections may need special protective-complexes, called chelates and the direct application of these micronutrients via foliar sprays or fertigation.

3.5 Boron

Boron concentration in soils is 20–200 mg/kg [32]. But, its available content varies from soil to soil. The available B in the studied soils (Tables 2a and 2b) ranged from 0.21 to 1.60 mg/kg, with a mean value 0.53 mg/kg, and a Std-Dev of 0.397. Based on the CLs for B-deficiency reported by Malewar [33], 0.50–0.52 mg/kg, therefore, 83.33% of the sites fall in B deficient categories. Only 16.67% were regarded as adequate in B. In a study restricted to few soil samples in ES, [22] reported the low levels of plant available B in all samples. Sillanpää [2] also made similar, but a more general report. According to the author, the average B contents of Ethiopian soils and pot-grown wheat were lower than the respective international averages.

In the present study, a strong association between available-B and SOC was observed (Table 4), which is in accordance with that report by Elrashidi and O'connor [34], and Waqar et al. [35]. According to, the authors, B-deficiency is widespread in alkaline-calcareous, coarse-textured soils with low levels of OM.

In the second season, for soil samples collected after crop harvest, the contents of available B (Table 3), were reduced to 0.10–1.41 mg/kg, with a mean value 0.41 mg/kg, and a Std-Dev of 0.394. Taking, 0.50–0.52 mg/kg as CLs, therefore, only five soil samples out of 30 were above these CLs, and the rest were found to fall-down to severe B-deficiency, owing to its uptake by plants, combined with the different losses.

3.6 Molybdenum

Molybdenum in soils usually occurs in extremely small quantities < 1.0 mg/kg [18]. The available Mo in the soils (Tables 2a and 2b) ranged from 0.03 to 1.12 mg/kg, with a mean value 0.21 mg/kg, and a Std-Dev of 0.357. Based on the CL, 0.10 mg/kg for Mo-deficiency reported by Patel et al. [21], therefore, 75% of the studied sites were regarded as deficient in Mo. Two sites (Ude and Insilale) were in equilibrium with this CL. Only 16.67% of the sites were found to be sufficient in Mo. In a study limited to few soil samples in ES, [22], found all samples to be low in plant available Mo. But, according to Sillanpää [2], low Mo values were rather more common in Sidamo, though were also found in Shoa, Wollega and Arsi provinces, usually in acidic and heavy-textured soils.

Table 4. Correlation between soil micronutrients and related variables

Variables	Cu	Mn	Fe	Zn	B	Mo
SO_4-S(mg/kg)	0.38878	0.44361	0.31691	0.45654	0.64934	-0.19663
	0.0604	0.0299	0.1313	0.0249	0.0006	0.3571
Av.P(mg/kg)	-0.23123	-0.92389	-0.80632	-0.80886	-0.41734	0.43783
	0.2770	<.0001	<.0001	<.0001	0.0425	0.0324
OC(%)	0.17611	0.48322	0.44649	0.48854	0.83923	-0.32208
	0.4104	0.0168	0.0287	0.0154	<.0001	0.1248
BS(%)	-0.44194	-0.93101	-0.93391	-0.94193	-0.21306	0.60396
	0.0306	<.0001	<.0001	<.0001	0.3175	0.0018
pH(1:2.5,	-0.49945	-0.89559	-0.89861	-0.92422	-0.21008	0.70381
soil:H_2O)	0.0130	<.0001	<.0001	<.0001	0.3245	0.0001
TN(%)	0.25682	0.74610	0.56344	0.69031	0.50131	-0.57833
	0.2257	<.0001	0.0041	0.0002	0.0126	0.0031
Cu(mg/kg)		0.36816	0.47305	0.49331	0.17133	-0.38212
		0.0767	0.0196	0.0143	0.4234	0.0654
Mn(mg/kg)	0.36816		0.86746	0.90121	0.37202	-0.59045
	0.0767		<.0001	<.0001	0.0734	0.0024
Fe(mg/kg)	0.47305	0.86746		0.88940	0.28231	-0.48504
	0.0196	<.0001		<.0001	0.1814	0.0163
Zn(mg/kg)	0.49331	0.90121	0.88940		0.32155	-0.55262
	0.0143	<.0001	<.0001		0.1255	0.0051
B(mg/kg)	0.17133	0.37202	0.28231	0.32155		-0.23309
	0.4234	0.0734	0.1814	0.1255		0.2730
Mo(mg/kg)	-0.38212	-0.59045	-0.48504	-0.55262	-0.23309	
	0.0654	0.0024	0.0163	0.0051	0.2730	

For the soil samples collected after harvest (Table 3), Mo contents fell to 0.02–1.00 mg/kg, with a mean value 0.19 mg/kg, and a Std-Dev of 0.362. Taking 0.10 mg/kg as a CL, therefore, only five samples from Keteba were above this CL. All the rest were reduced to severe Mo-deficiency. Indeed, the reduction was more in N and/or NS treated field-plots than the untreated checks. This might indicate, synergistically more uptake of Mo by the plants (wheat and weed), when combined either with N or NS, than the untreated checks.

4. CONCLUSIONS AND RECOMMENDATIONS

In the present study, the micronutrients iron, zinc, boron and molybdenum were deficient in the studied three locations; whereas copper and manganese were adequate or excessive in some field-plots. One-sided development in fertilising soils with only primary nutrients and the consequent increase in crop-yields, loss of micronutrients through weathering and leaching, the decreasing use of organic resources etc are among the contributing factors for the observed deficiency of trace elements in soils. Therefore, in addition to the previous recommendations on sulfur, the micronutrients: Fe, Zn, B and Mo need to be included in the balanced-fertiliser-formulas, if soil-test, plant-tissue analysis and/or crop-response data are available. Micronutrients application to soils is recognised to be uneconomical in large scale productions, owing to the different lose vis-à-vis their small quantities to be applied. Therefore, strategies involving soil enhancement of the micronutrients by seed treatment, foliar-sprays through fertigation or the use of organic amendments (including chelating) need to be adopted to sustain crop yields/quality. In some cases, food enhancement of the micronutrients can also be adopted. However, as CLs or thresholds depend on many factors (soil-plant-environmental...), nationwide micronutrients calibration-studies involving soil-test and crops'-response for specific soils and crops is also needed. Micronutrients indexing studies involving the different extraction methods or solutions may also be needed. Finally, it is also advisable to conduct controlled experiments for screening and evaluating crop genotypes for the deficient micronutrients use efficiencies.

ACKNOWLEDGEMENTS

Sokoine University of Agriculture (SUA/AGRA-SHP and its Lab), Tanzania; CASCAPE (funding by the Gov't of The Netherlands); EIAR (Kulumsa, Debre Zeit, and Holleta Res CTRs) are acknowledged for the many in-kind and financial supports.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Sillanpää M. Trace elements in soils and agriculture. The FAO Soils Bulletin-17. Rome, Italy; 1979.
2. Sillanpää M. Micronutrients and the nutrient status of soils: A global study. The FAO Soils Bulletin-48. Rome, Italy; 1982.
3. Asgelil D, Taye B, Yesuf A. The status of micro-nutrients in Nitisols, Vertisols, Cambisols and Fluvisols in major maize, wheat, teff and citrus growing areas of Ethiopia. In: Proc. of Agric. Res. 2007;77-96.
4. Christian O. Dimkpa, Prem S. Bindraban. Fortification of micronutrients for efficient agronomic production: A review. Agron. for Sust. Dev't, Springer Verlag/EDP. 2016;36(1):7.
5. Van Reeuwijk LP, (Ed.). Procedure for soil analysis, 6th (Ed.), Tchnical Paper- 9. ISRIC, Wageningen, The Netherlands. 1993;24-37.
6. Klute A, (Ed.). Methods of soil analysis, Part-I, Physical and Mineralogical Methods, 2nd (Ed.) Agronomy Journal, Madison, Wisconsin. ASA-SSSA. 1986;9.
7. Rowell DL. Soil science methods and applications. Department of Soil Science, University of Reading, Longman Group UK. 1994;205.
8. Okalebo JR, Gathua KW, Woomer P. Laboratory methods for soil and plant analysis. A working manual 2nd(ed). TSB-CIAT and SACRED-Africa, Nairobi, Kenya. 2002;128.
9. Nelson DW, Sommers LE. Total carbon, organic carbon and organic matter. In: Methods of Soil Analysis, Part-3, Chemical Methods, (Ed). DL Sparks, Madison, WI: ASA-SSSA. 1996;961-1010.
10. Bray HR, Kurtz LT. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 1945;59:39-46.

11. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA, Circular-939, US. Government Printing Office, Washington DC; 1954.
12. Bouyoucos G. Hydrometer method improved for making particle size analysis of soils. Agronomy Journal. 1962;54:464-465.
13. Lindsay WL, Norvell WA. Development of a DTPA soil-test for zinc, iron, manganese and copper. Soil Sci. Soc. of Am. Journal. 1978;42:421-428.
14. Berger KC, Truog E. Boron determination in soils and plants using the quinalizarin reaction. Industrial and Engineering Chemistry. Analytical (Ed.). 1939;11:540-545.
15. Grigg JL. Determination of the available molybdenum in soils. The New Zealand Journal of Science and Technology, Australia. 1953;34:405–415.
16. Lombin G. Micronutrient soil tests for semi-arid savanna of Nigeria: Boron and molybdenum. Soil Science and Plant Nutrition. 1985;31(1):1–11.
17. SAS Institute Inc. SAS/STAT users guide. Version-8 (Ed). Cary, NC: SAS Software; 2002.
18. Rudnick RL, Gao S. The composition of the continental crust. In: Holland, HD and Turekian, KK, Eds., Treatise on Geochemistry, the Crust, Elsevier-Pergamon, Oxford. 2003;3:1-64.
19. Mustapha S, Voncir N, Abdullahamid NA. Status of some available micronutrients in the haplicusters of Akko Local Government Area Gombe State Nigeria. International Journal of Soil Science. 2011;6:267-274.
20. Adamu GK, Aliyu AK, Jabbi AM. Fertility assessment of soils under rice cultivation in Kadawa, GarunMallam Local Government Kano State. Natural and Applied Sciences. 2014;5(1):22223-9553.
21. Patel KS, Chikhlekar S, Ramteke S, Sahu BL, Dahariya NS, Sharma R. Micronutrient status in soil of Central India. American Journal of Plant Sciences. 2015;6:3025-3037.
22. Hillette Hailu, Tekalign Mamo, Riikka Keskinen, Erik Karltun, Heluf Gebrekidan, Taye Bekele. Soil fertility status and wheat nutrient content in Vertisol cropping-systems of central highlands of Ethiopia. Agriculture and Food Security. 2015;4:19.
23. Yifru Abera, Mesfin Kebede. Assessment on the status of some micronutrients in vertisols of the Central Highlands of Ethiopia. IRJASSS. 2013;3(5):2251-0044.
24. Touria El-Jaoual, Douglas A. Cox. Manganese-toxicity in plants. Journal of Plant Nutrition. 2008;21:2-1998.
25. Huang X, Fan Y, Shabala L, Rengel Z, Shabala S, Zhou MX. A major QTL controlling the tolerance to manganese toxicity in barley (*Hordeum vulgare L.*). Molecular Breeding. 2018;38:16.
26. Kirk G, Solivas J, Alberto M. Effects of flooding and redox conditions on solute diffusion in soil. European Journal of Soil Science. 2003;54(3):617–624.
27. Thiagalingam K. Soil and plant sample collection, preparation and interpretation of chemical analysis. A training manual and guide. Australian Contribution to a NAR System in PNG(ACNARS), Adelaide, Australia. 2002;49.
28. Enwezor WO, Udo EJ, Ayotade KA, Adepetu JA, Chude VO. A review of soil and fertilizer use in Nigeria. In: FPDD, Literature reviews on soil fertility investigations in Nigeria (V-5). Federal Ministry of Agriculture and Natural Resources, Lagos, Nigeria. 1990;281.
29. Teklu B, Amnat S, Yongyuth O, Sarobol ED. Status of Mn, Fe, Cu, Zn, B and Mo in Rift-Valley soils of Ethiopia, Lab assessment. Kasetsart J. Nat. Sci. 2007;41:84–95.
30. Bassirani N, Abolhassani M, Galavi M. Distribution of available micronutrients as related to soil characteristics of Hisar, Haryana (India). African JAR. 2011;6(18):4239-4242.
31. Weil RR, Brady NC. The nature and properties of soils, 15th (Ed). Pearson Education, Inc., Upper Saddle River, New Jersey, USA. 2017;679-736.
32. Mengel K, Kirkby EA. Principles of plant nutrition. 4th (Ed). International Potash Institute, Worblaufen-Bern, Switzerland; 1987.
33. Malewar GU. Comparison of soil boron critical levels established by graphical and statistical approach in cauliflower (*Brassica Olercicea L.*). Agro-pedology, Department of Agricultural Chemistry and Soil Sci.,

Marathwada Agricultural University, Parbhani 431 402, India. 1999;9:119-124.
34. Elrashidi MA, O'Connor GA. Boron-sorption and desorption in soils. Soil Sci. Soc. Am. J. 1982;46:27-31.
35. Waqar Ahmad, Munir H. Zia, Sukhdev S, Malhi, Abid Niaz, Saifullah. Boron deficiency in soils and crops: A review. Crop Plant, In: Dr Aakash Goyal (Ed.); 2012. ISBN: 978-953-51-0527-5, InTech.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/26788