ORIGINAL ARTICLES

Status of tissue Zinc and Iron contents of Teff [(*Eragrostis tef (Zucc.) Trotter*] and Bread Wheat (*Tritcum aestivum*) and their relationships with some Soil parameters in Tigray Region, Northern Ethiopia

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ABSTRACT

Leaf nutrient content is an important indicator of soil supply status. Soil and flag leaf samples were collected from three major agro-ecologies in Tigray, Ethiopia. Results revealed that regardless of agro-ecologies, Zn deficiency is widespread. Of the total soil, tef and wheat samples, 90%, 98% and 89% were deficient in Zn, respectively. While Fe was deficient in 5% soil samples and Fe concentration in the crops varied between agro-ecology. Soil pH, EC and sand content were the soil properties that could possibly predict tef leaf Zn, whereas soil organic carbon content could be used to predict bread wheat leaf Zn content. Similarly, total soil Fe and soil pH were the soil characteristic that possibly predict tef leaf Fe, whereas DTPA extractable-Fe and soil carbon content could be used to predict bread wheat leaf Fe. Further similar research should consider other multiple soil extractant method such as Mehlich-III.

Key words: Agro-ecology, Deficiencies, Micro nutrients, Survey

INTRODUCTION

Zinc and Fe are essential for the normal healthy growth and reproduction of crop plants. They are among the elements that are referred to as 'essential trace elements' or micronutrients, because they are only required in relatively small concentrations by the plant tissues (5 - 100 mg kg–1) (Alloway, 2004). Zinc is constituent of several enzymes with roles in carbohydrate and protein synthesis; maintaining the integrity of membranes, regulating auxin synthesis and in pollen formation (Srivastava and Gupta, 1996) while iron is a constituent of cytochromes and metallo enzymes in addition to its roles in photosynthesis, symbiotic N fixation, N metabolism, and redox reactions (Srivastava and Gupta, 1996). The inadequacy of bio-available Zn and Fe in the soil system and the factors affecting their plant bio-available in the soil reduce crop yields and the quality of crop products (Alloway, 2004; Hansen et al., 2006).

Soil total Zn content in agricultural soils of world ranged from 10 to 300 mg kg^{-1} with mean value of 50 mg Zn kg^{-1} (Kiekens, 1995). The most commonly quoted bio-available or DTPA extractable critical limit for Zn in tropical soils is 1 mg kg^{-1} (Alloway, 2004). The most quoted indicator of Zn critical limit of deficiency of leaf samples for cereals is 20 mg kg^{-1} (Manson, 1998). The main soil factors that control plant bio-availability of Zn are total Zn content of the soil, soil pH, salinity, calcite ($CaCO_3$), organic carbon content, concentration of ligands forming organo-Zn complex, clay content, cation exchange capacity, concentration of macro-nutrients (especially P), soil moisture regimes, root and rhizosphere effects and concentration of other trace elements (Catlett *et al.*, 2002; Cakmak, 2008; Alloway, 2009). However, Tisdale *et al.* (1993) concluded that P induced Zn deficiency caused by formation of insoluble Zn phosphates in soil that had been reported by many authors should be discounted rather the authors concluded it could be due to P uptake of plants.

Next to aluminum, iron is the second most abundant metal in the earth's crust (Broadley *et al.*, 2012). It comprises about 50 g kg^{-1} (5%) of the earth's crust (Prasad and Power, 1996). Iron is an element relatively abundant in many cultivated soils with, on average, a total concentration of 20 to 40 g kg^{-1} (Cornell and Schwertmann, 2003). A range from 0.46 to 27.3 % was also reported for Indian soils (Kanwar and Randhawa, 1974). The most commonly quoted bio-available or DTPA extractable critical Fe is 4.5 mg kg^{-1} (Lindsay and Norvell, 1978). The average concentration of Fe in leaf samples considered insufficient for adequate growth of crops is less than 100 mg kg^{-1} (Manson, 1998). Soil factors associated with the expression of Fe deficiency include: soil pH, salinity, Fe composition, moisture, bulk density, soil organic matter content, concentration and form of interacting elements and compounds, and environmental conditions (Hansen *et al.*, 2004; Hansen *et al.*, 2006).

Tissue analysis especially leaf is based on the principle that the concentration of a nutrient within the plant is an integral value of all the factors that have interacted to affect it (Estefan *et al.*, 2013). It is an indicator of soil supply status, deficiency and adequacy of the specific nutrient to crops. When tissue analysis is supported by soil characteristics it gives a clear picture. However little is known on Zn and Fe contents on tef and bread wheat leaves in relationship with soil parameters in Ethiopia particularly in Tigray region where widespread soil Zn and Fe deficiencies in soils relatively higher in pH are reported (MoA and ATA, 2014).

Therefore, a study was conducted to assess the status of Zn and Fe in leaves of tef and bread wheat in relation to soil Zn and Fe contents and other soil properties in tef and bread wheat growing agro-ecologies of Tigray.

MATERIALS AND METHODS

Description of the Study Area

A survey was conducted in 2010 in Tigray Region, Northern Ethiopia. Tigray Region extends from 12° 13' to 14° 54' N latitude and from 36° 27' to 40° 18' E longitude.

The survey covered three major agro-ecological zones (namely cold moist highlands-M2, Tepid to cool sub moist mountains and plateau-SM2-5 and Hot to warm sub moist lowland plains- SM1-3) as described by Dangew (2003). The survey also included eleven districts and two crop types (tef and bread wheat) as indicated in Table 1.

Table 1. Major agro-ecological zones, districts, mean annual rainfall and leaf sample of crop collected for the study in 2010

Agro-ecological zone	District	Mean annual rainfall (mm)	Mean Min Temp °C	Mean Max Temp °C	Elevation (masl), range for the study	Sample Crop
Cold moist highlands-M2	Tsegede	2385	3.1	22.0	2359-2859	Tef and bread wheat
	Welkait	1257	11.4	29.0	1940-1958	Tef
Tepid to cool sub moist mountains and plateau-SM2-5	Tahtay Koraro	1149	10.8	29.9	1831-1954	Tef
	Laelay Michew	726	8.5	28.8	2061-2117	Tef
	Adwa	801	8.7	30.3	1890-2109	Tef and bread wheat
	Hawzien	530	7.5	29.6	2083-2196	Bread wheat
	Enderta	566	8.5	27.0	2110-2383	Bread wheat
	Hintalo-Wajrat	499	10.3	25.0	2010-2579	Bread wheat
	Ofla	990	3.5	24.0	2451-2572	Bread wheat
Hot to warm sub moist low land plains-SM1-3	Raya Azebo	550	13.0	32.0	1584-1750	Tef
	Raya Alamata	723	13.2	32.7	1469-1504	Tef

Plant and Soil Samples Collection and Processing

Farm fields surveyed in each district were randomly selected in consultations with district offices of agriculture and rural development to represent the respective districts. Irrespective of crop variety and soil types, flag leaf samples at flowering were collected from all the three agro-ecologies for tef (62 samples) while it was collected from only two (M2 and SM2-5) agro-ecologies for bread wheat (57 samples) for analysis of Zn and Fe contents. Wheat traditionally did not grow in the SM1-3 agro-ecology. To make one composite sample, leaf samples from 15-20 plants were collected with clean hands using polyethylene gloves, in order to avoid contamination.

The samples were cleaned for any contamination by washing with deionized water, oven dried at 70 °C for 24 hours to a constant weight. Samples were ground with a stainless grinder and stored in airtight plastic bags. Surface soil samples (0-20 cm) were also collected from the selected farms for analysis of selected soil parameters.

The soil samples were collected in a diagonal pattern from each selected field using an auger points (15-20) and mixed to obtain a composite bulk soil samples. The soils samples were air dried at room temperature, ground with porcelain pestle and mortar, passed through a 2-mm sieve, and used for the determination of physical and chemical properties. For determinations of organic carbon and total nitrogen, 0.5 mm sieve was used.

Plant and Soil Samples Analysis

The leaf samples were digetsed using a wet digetion method (di-acids HNO_3-$HClO_4$ at 2:1 ratio) to obtain full recovery of Zn and Fe (Estefan *et al*., 2013). The aliquot of the digest were determined for Zn and Fe using Fast Sequential Flame Atomic Spectrometry (Varian AA 240FS) at accredited laboratory of Ezana Analytical Laboratory, Mekelle, Ethiopia.

The soil samples were analyzed following the standard laboratory procedures. Soil texture was determined by hydrometer method (Day, 1965). Soil pH and electrical conductivity (EC) were measured in 1:2.5 soil to water suspensions (Jackson, 1967). Organic carbon content was determined by using modified Walkley and Black method (Jackson, 1967). Cation Exchange Capacity (CEC) by NaOAc extraction method by adjusting the pH to neutral (Chapman, 1965); $CaCO_3$ equivalent by neutralization with hydrochloric acid (Allison and Moodie, 1965); available P by Olsen method (Olsen et al. 1954); available K by NH_4OAc method (Chapman, 1965); available Zn and Fe by DTPA extraction method (Lindsay and Norvell, 1978); total Zn and Fe by digestions of the soil by H_2O_2 followed by di-acids HNO_3-$HClO_4$ at 2:1 ratio (Estefan *et al*., 2013) and total nitrogen by Kjeldhal method (Bremner and Mulvaney, 1982) were determined.

Data Analysis

Descriptive analysis was used to compile the data of the leaf Zn and Fe content by crop type and agro-ecology, and the soil parameters by agro-ecology using SPSS software Version 20 for windows (International Business Machine (IBM), 2011). Correlation analysis between the leaf nutrients (Zn and Fe) content of the crops (tef and bread wheat) and the selected soil parameters were also performed separately for each crop to evaluate the relative importance of the soil parameters to influence the nutrient content in the crops. Furthermore, stepwise regression models were constructed using the same software for each crop to identify the most influential soil variables that govern the leaf Zn and Fe contents of each of the crops. The reason for the use of stepwise linear regression model than the other linear models was because the model has an advantage of giving priority to independent variables with the smallest probability of F-value and maintained in the equation.

RESULTS AND DISCUSSION

Selected Chemical and Physical Properties of the Study Soils by Agro-Ecology

The pH of the soils considered in the status survey varied from very strongly acidic to moderately alkaline (Table 2) according to the rating of Jones (2003). It ranged from very strongly acidic to moderately medium acidic in the M2, from moderately medium acidic to moderately alkaline in SM2-5 and neutral to moderately alkaline in SM1-3 agro-ecologies. Calcium carbonate equivalent contents of the study soils were from 2.91 to 11.17 % which ranged from non calcareous (< 4%) to strongly calcareous (> 10%) according to the rating by Prasad *et al*. (1999).

The soils were non-calcareous to moderately calcareous in M2, non-calcareous to strongly calcareous in SM2-5 and moderately calcareous to strongly calcareous in SM1-3 agro-ecologies. The likely reason for the occurrence of moderately calcareous nature in the soils of M2 agro-ecology could be due to application of lime for acid soil management in that agro-ecology. The soils of all the study agro-ecologies were non-saline with an EC of < 2 dS m^{-1}.

The samples were collected from rain-fed farms which could be one of the possible reasons for non-saline nature of all the surveyed farms. The agro-ecology with relatively higher soil pH had also higher EC and calcium carbonate.

The cation exchange capacity of the soils varied from low (5-15 Cmol(+)kg^{-1} soil) to high (25 - 40 Cmol(+)kg^{-1} soil) in M2 agro-ecology with mean value in the medium range (Landon 1991). In the SM2-5 and SM1-3 agro-ecologies, CEC ranged from low to very high with mean values of high and very high (> 40 Cmol(+)kg^{-1} soil), respectively.

According to the rating by Tekalign (1991), the organic carbon content of the soil samples from M2 agro-ecology ranged from low (< 1.5%) to high (> 3%) with mean value in the range of medium (1.5 - 3%). The soil organic carbon content in the SM2-5 and SM1-3 agro-ecologies ranged from low to medium with mean values also in the low and medium ranges, respectively. Similarly, the total nitrogen of the soil samples ranged from low (< 0.05%) to very high (> 0.25%) in M2 agro-ecology, low to high (0.12- 0.25%) in SM2-5 and SM1-3 agro-ecologies with mean values in the ranges of high, medium and high, respectively.

The soil available P status (Table 2) ranged from very low (Olsen-P < 5 mg kg^{-1} soil) to high (Olsen-P > 10 mg kg^{-1} soil) (Olsen *et al.*, 1954) in all agro-ecologies with mean values medium in M2 and SM2-5 agro ecologies and high at SM1-3 agro-ecology. The mean optimum available P at SM1-3 agro-ecology may be attributed to P deposition from upland areas by erosion.

The soil available K (Ammonium Acetate-K) status (Table 2) ranged from low (78 - 117 mg kg^{-1} soil) to very high (> 468 mg kg^{-1} soil) (FAO, 2006) in M2 agro-ecology, very low to very high in SM2-5 agro-ecology and medium to very high in SM1-3 agro-ecology. However the mean soil potassium status was high, medium and high in M2, SM2-5 and SM1-3 agro-ecologies, respectively.

The soil sand, silt and clay contents of the different agro-ecologies are shown in Table 2. The contents had wider range in SM2-5 agro-ecology than M2 and SM1-3. This could be probably due to the wider districts coverage of SM2-5 agro-ecology.

Table 2. Mean and range of selected soil physical and chemical properties by agro-ecological zones (mean ± SE) in 2010. The values in the parenthesis indicate range.

	Agro-ecological Zone		
	Cold moist highlands-M2	Tepid to cool sub moist mountains and plateau-SM2-5	Hot to warm sub moist low land plains- SM1-3
No. of samples	25	79	16
pH-H_2O	4.9 ± 0.1 (4.18 – 5.74)	7.2 ± 0.08 (5.57- 8.23)	7.9 ± 0.06 (7.3 - 8.3)
EC, dS m^{-1}	0.04 ± 0.008 (0.01 - 0.14)	0.07 ± 0.005 (0.01 - 0.22)	0.2 ± 0.026 (0.07 – 0.37)
OC (%)	2.8 ± 0.16 (0.59 – 3.64)	0.93 ± 0.07 (0.14 - 2.23)	1.77 ± 0.11 (1.10 – 2.54)
Olsen-P (mg kg^{-1})	5.5 ± 1.08 (0.06 – 18.70)	7.4 ± 0.7 (0.10 - 39.14)	16 ± 5 (3.38 - 93.82)
NH_4OAc-K (mg kg^{-1})	269 ± 26 (86 - 493)	191 ± 15 (26 - 480)	454 ± 21 (143 - 487)
Total-N (%)	0.19 ± 0.02 (0.05 – 0.38)	0.094 ± 0.004 (0.03 - 0.20)	0.14 ± 0.01 (0.01 – 0.21)
CEC Cmol(+)kg^{-1} soil	24.4 ± 1.7 (7.6 -35.8)	36 ± 1.31 (9.8 - 64)	42 ± 2.4 (26 – 59.7)
$CaCO_3$ (%)	5.3 ± 0.3 (2.91 -7.38)	7.1 ± 0.2 (3.9 – 10.7)	8.2 ± 0.4 (4.85 – 11.17)
Sand (%)	49 ± 1.17 (37 - 61)	46 ± 2.23 (15 – 91)	33 ± 1.52 (25 -47)
Silt **(%)**	29 ± 1.08 (21 - 39)	30 ± 1.18 (3 – 49)	43 ± 1.38 (35 -53)
Clay (%)	22 ± 1.16 (12 -34)	24 ± 1.60 (4 -58)	24 ± 1.80 (12 - 36)

Total and DTPA Extractable Zinc and Iron by Agro-ecology

The means and ranges of total and available soil Zn and Fe contents are shown in Table 3. Mean total soil Zn and Fe concentrations in the different agro-ecological zones are within the range of average soil concentration of the world agricultural soils according to Kiekens (1995) for Zn and Cornell and Schwertmann (2003) and Kanwar and Randahawa (1974) for Fe. Total Zn and Fe contents varied from one agro-ecological zone to the other. Total soil Zn and Fe contents decreased in the order of M2 > SM2-5 > SM1-3 similar to the trends of mean annual rainfall (Table 1). Mean DTPA extractable (available) soil Fe followed the same trend with that of total soil Fe while available Zn followed in the order of SM1-3 > M2 > SM2-5. However soil Zn deficiency level < 1 mg kg^{-1} (Alloway, 2004) was recorded in all agro-ecologies under study. Out of the total soil samples (120) collected, 90% (108) were Zn deficient. Mean Fe contents indicated no deficiency in all agro-ecological zones under study. However, out of the total (120) samples collected, 5% (6) were deficient (< 4.5 mg kg^{-1}) in Fe according to Lindsay and Norvell (1978). The mean and range of DTPA extractable fractions of Zn and Fe obtained to their respective total fractions were (2%, 0.34 – 6.25) and (1.2%, 0.02- 7.95), respectively. Sharma *et al.* (2006) reported that DTPA extractable fractions were 0.34 to 0.74 % for Zn and 0.019% for Fe to their respective total fractions in the Indian soils. The mean fractions in this study were higher than that of Indian soils probably because of the differences in the method of analysis for the total contents of Zn and Fe. The differences could also be due to geological formation, soil type and agro-ecologies.

Table 3. Mean and range of total and DTPA extractable zinc and iron concentration in soils (mean ± SE) by agro-ecological zones in 2010. The values in the parenthesis indicate range.

AEZ	No of samples	Total		DTPA extractable (mg kg^{-1})	
		Zn (mg kg^{-1})	Fe (%)	Zn	Fe
M2	25	47.56 ± 3.2 (21 - 98)	4.4 ± 0.26 (1.39 - 8.22)	0.73 ± 0.103 (0.18 - 2.26)	110.6 ± 20 (14.8 - 324)
SM2-5	79	33.1 ± 1.5 (3.2 - 65)	2.4 ± 0.10 (0.43 – 5.33)	0.59 ± 0.03 (0.20 – 1.56)	19.7 ± 1.44 (3.48 - 68.18)
SM1-3	16	32.5 ± 1.04 (24.1 - 39.8)	2.24 ± 0.10 (1.46 - 2.93)	0.77 ± 0.04 (0.50 - 0.95)	8.31 ± 0.90 (5.15 - 18.72)

Tef and Bread Wheat Leaf Zinc and Iron Concentration by Agro-Ecology

Zinc and Fe concentrations of leaf samples of tef and bread wheat by agro-ecology are shown in Table 4. The mean Zn concentrations of tef and bread wheat in the studied agro-ecologies were below the critical limit (< 20 mg kg^{-1}) according to the rating of Manson (1998). Only one sample out of sixty two tef samples had concentrations above the critical limit. Similarly, two wheat samples out of eight samples in M2 agro-ecology and four out of forty nine in SM2-5 agro-ecology were not deficient in Zn (> 20 mg kg^{-1}).

The mean and range of Fe concentrations in the tef and bread wheat plants follow in the order of M2 > SM2-5 >SM1-3 and M2 > SM2-5 agro-ecologies, respectively (Table 4), probably due to the difference in the combined agro-ecological characteristics. Iron deficiency in tef and bread wheat plants were not observed in M2 agro-ecology. Out of the thirty tef samples in SM2-5 agro-ecology, three samples were found to be deficient (< 100 mg kg^{-1}) in Fe while in SM1-3 agro-ecology twelve out of the fifteen samples were deficient according to the rating of Manson (1998). Out of the forty nine wheat samples in SM2-5 agro-ecology, two samples were found to be non-deficient (> 100 mg kg^{-1}) in Fe.

The relative importance of Fe deficiency in tef and bread wheat in SM2-5 and SM1-3 might be related to the relative higher pH of the soils in these agro-ecologies (Table 2). Soil pH is considered as master variable for Fe deficiency (Lindsay and Schwab, 1982). Fageria *et al.* (1994) reported soils affected by Fe deficiency have pH higher than 6.0 while Kean *et al.* (2015) reported above 7.0 soil pH. Alloway (2008) also reported Fe is most available in acid soils. The results of the current study are in agreement with Fageria *et al.* (1994), Alloway (2008) and Kean *et al.* (2015).

Table 4. Mean and range of tef and bread wheat leaf zinc and iron concentrations (mean ± SE) by agro-ecological zones in 2010. The values in the parenthesis indicate range.

Crop type	Agro-ecology	Number of samples	Zn (mg kg^{-1})	Fe (mg kg^{-1})
Tef	M2	17	16.6 ± 0.45 (13 - 20)	395 ± 54 (170 - 868)
	SM2-5	30	12.7 ± 0.50 (8.5 - 22)	136 ± 6.7 (64 - 205)
	SM1-3	15	9.6 ± 0.95 (5 – 16.5)	70 ± 7.0 (29.5 - 110)
Bread wheat	M2	8	21.75 ± 3 (14.5 - 42)	317.7 ± 69 (134.5 - 653)
	SM2-5	49	12.77 ± 0.73 (2 - 26)	60 ± 3.2 (25 -120)

Relationship between Leaf Zinc and Iron Concentrations of Tef and Bread Wheat with Selected Soil Properties

Zinc concentration of tef leaf significantly and positively correlated with total soil Zn and sand and negatively correlated with pH, EC, CEC, calcium carbonate, available P and silt content while Zn concentration of bread wheat significantly and positively correlated with soil organic carbon content and negatively correlated with pH and CEC (Table 5).

The soil factors such as total soil Zn, pH, salinity, calcite ($CaCO_3$), organic carbon content, concentration of ligands forming organo-Zn complex, clay content, CEC, concentration of macro-nutrients (especially P) were reported to affect plant availability of Zn (Catlett *et al.*, 2002; Cakmak, 2008; Alloway, 2009). However soil pH, EC and sand content were the soil characteristic that were maintained in stepwise regression model possibly predict tef leaf Zn concentration (Table 7), whereas soil organic carbon content could be used to predict bread wheat leaf Zn concentration. The positive influence of sand content with Zn availability of tef might be related with the ease of Zn desorption in the soil system.

Iron concentration of tef was significantly and positively correlated with total soil Fe, soil organic carbon content and sand and negatively correlated with pH, EC, available P and silt content. Similarly, Fe concentration of bread wheat was significantly and positively correlated with total soil Fe, DTPA-Fe, organic carbon content, total N and available K and negatively correlated with pH and CEC (Table 6). Soil pH, EC, Fe composition, moisture, bulk density, soil organic matter content, concentration and form of interacting elements (such as potassium) and compounds, and environmental conditions were reported as factors for Fe deficiency problems in plant (Hansen *et al.*, 2004; Hansen *et al.*, 2006). However, total soil Fe and soil pH were the soil characteristic that were maintained in stepwise regression model that possibly predict tef leaf Fe concentration (Table 7), whereas DTPA extractable-Fe and soil organic carbon content predicted bread wheat leaf Fe concentration

Table 5. Correlation coefficient (r) between leaf Zn concentrations (in tef and bread wheat) and selected soil properties in Tigray, 2010.

Soil property	Tef	Bread wheat
Total soil Zn	0.299*	0.139
DTPA-Zn	0.005	0.099
pH-H_2O	-0.699**	-0.350**
EC	-0.621**	0.219
OC	0.169	0.517**
CEC	-0.321*	-0.447**
$CaCO_3$	-0.347*	-0.122
Total-N	0.157	0.172
Olsen-P	-0.448**	0.163
Sand	0.502**	-0.170
Silt	-0.507**	0.097
Clay	-0.212	0.205

** Significant at P≤0.01,* Significant at P≤0.05

Table 6. Correlation coefficient (r) between leaf Fe concentration (in tef and bread wheat) and selected soil properties in Tigray, 2010.

Soil property	Tef	Bread wheat
Total soil Fe	0.717**	0.428**
DTPA-Fe	0.163	0.723**
pH-H_2O	-0.617**	-0.641**
EC	-0.441**	-0.018
OC	0.309*	0.567**
CEC	-0.150	-0.449**
$CaCO_3$	-0.184	-0.232
Total-N	0.122	0.402**
Olsen-P	-0.289*	0.047
Amm. Acetate-K	-0.175	0.329*
Sand	0.287*	-0.105
Silt	-0.387*	0.091
Clay	-0.045	0.088

** Significant at P≤0.01,* Significant at P≤0.05

Table 7. Regression models between tef and bread wheat leaf zinc and iron concentration ($mg\ kg^{-1}$) with soil properties in Tigray, 2010.

Equations	R^2
Zinc	
Tef leaf Zn concentration = 19.70 – 1.14pH-H_2O – 15.43EC (dS/m) + 0.062Sand (%)	0.609**
Bread wheat leaf Zn concentration = 9.51 + 3.75OC (%)	0.267**
Iron	
Tef leaf Fe concentration = 246.4 + 64.98Total-Fe (%) – 39.36pH-H_2O	0.567**
Bread wheat leaf Fe concentration = 24.5 + 0.815DTPA-Fe ($mg\ kg^{-1}$) + 28.36OC (%)	0.560**

** Significant at P≤0.01,* Significant at P≤0.05

CONCLUSION

Widespread Zn deficiency in soils, tef and wheat tissues were recorded in all agro-ecological zones investigated in Tigray. Unlike Zn, Fe deficiency was limited in the soil while in the plant it depended on the agro-ecology. For instance, Fe deficiency in tef and bread wheat tissues was not observed in M2 agro-ecology where it had also relatively higher mean annual rainfall. In the present study, soil pH, EC and sand content predicted tef tissue Zn concentrations whereas soil organic carbon content did for wheat leaf Zn concentrations. Similarly, total soil Fe and soil pH predicted Fe concentration in tef leaf whereas DTPA extractable-Fe and soil organic carbon content predicted Fe concentration in bread wheat leaf. In conclusion, plant tissue along with soil analysis could provide substantial information in assessing Fe and Zn status of tef and wheat growing agro-ecologies of Tigray. Similar research is further suggested considering other soils multiple extraction methods such as Mehlich-III.

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REFERENCE

Allison, LE, and Moodie CD. 1965. Carbonate, pp. 1379-1396. In Black CA (Eds.) Methods of soil Analysis; Part 2, American Society of Agronomy, Madison, W I.

Alloway, BJ. 2004. Zinc in Soils and Crop Nutrition. In. Brussels: International Zinc Association. www.zinc-crops.org.

Alloway, BJ. 2008. Micronutrients and crop production: An introduction. In Dordrecht (eds.) Micronutrient deficiencies in global crop production, Springer, Amsterdam, The Netherlands.

Alloway, BJ 2009. Soil factor associated with zinc deficiency in crops and humans. Environ Geochem Health. 31:537-548.

Bremner, JM, and Mulvaney, CS. 1982. Total nitrogen. In Page AL, Miller RH and Keeney DR (eds.) In Methods of Soil Analysis, Part 2, Agronomy Society of America and Soil Science Society of America, Madison, WI, USA

Broadley, M, Brown, P, Cakmak, I, Rengel, Z and Zhao, F. 2012. Function of Nutrients: Micronutrients. Marschner's Mineral Nutrition of Higher Plants. doi: 10.1016/B978-0-12-384905-2.00007-8.

Cakmak, I. 2008. Enrichment of cereal grains with zinc: Agronomic or genetic biofortification. Plant and Soil. 302:1-17.

Catlett, KM, Heil, DM, Lindsay, WL, and Ebinger, MH. 2002. Soil chemical properties controlling Zn2+ activity in 18 Colorado soils. Soil Sci. Soc. Am. J. 66:1182-1189.

Chapman, HD. 1965. Cation Exchange Capacity. In Black CA (eds.) In Methods of Soil Analysis, Part II, p 891-901, American Society of Agronomy, Madison, WI, USA.

Cornell, RM, and Schwertmann, U. 2003. The iron oxides, 2nd ed. Weinheim: Wiley-VCH.

Dangew Esayas. 2003. Agro-ecological zonation map of Ethiopia: Strength, drawbacks and proposal to revise. Paper read at Proceeding of the Regional Agricultural Research Strategy Workshop; 13-15 April 2002, at Mekelle, Ethiopia.

Day, PR. 1965. Particle fractionation and particle-size analysis. In Black CA (eds.) In Method of Soil Analysis Part I, 545-567. American Society of Agronomy, Madison, WI, USA.

Estefan, G, Sommer, R and Ryan, J. 2013. Methods of soil, plant and water analysis. Beirut, Lebanon: International Center for Agricultural Research in the Dry Areas (ICARDA).

Fageria, NK, Guimarães, CM and Portes, TA. 1994. Iron deficiency in upland rice. Vol. 47. Lav. Arrozeira.

FAO, (Food and Agriculture Organization). 2006. Plant nutrition for food security: A guide for integrated nutrient management. FAO, Fertilizer and Plant Nutrition Bulletin no. 16. FAO, Rome

Hansen, NC, Hopkins, BG, Ellsworth, JW and Jolley VD. 2006. Iron nutrition in field crops. In Barton LL and Abadía J (eds.) In Iron Nutrition in Plants and Rhizospheric Microorganisms, Springer, The Netherlands.

Hansen, NC, Jolley, VD, Naeve, SL, and Goos, RJ. 2004. Iron deficiency of soybean in the North Central U.S. and associated soil properties. Soil Science and Plant Nutrition. 50: 983-987.

International Business Machine (IBM). 2011. IBM SPSS Statistics Version 20 release. USA.

Jackson, ML. 1967. Soil Chemical Analysis. New Delhi: Prentice Hall of India.

Jones, JB. 2003. Agronomic Handbook: Management of Crops, Soils, and Their Fertility. Boca Raton, FL, USA: CRC Press LLC.

Kanwar, JS and Randhawa, NS. 1974. Micronutrient research in soils and plants in India: A review. ICAR Tech. Bull. (Agric.). 50:1–60.

Kean, MA, Delgado, EB, Mensink, BP, and Bugter, MHJ. 2015. Iron chelating agents and their effects on the growth of Pseudokirchneriella subcapitata, Chlorella vulgaris, Phaeodactylum tricornutum and Spirulina platensis in comparison to Fe- EDTA. Journal of Algal Biomass Utilization. 6 (1):56-73.

Kiekens, L. 1995. Zinc. In Alloway B J (eds.) In Heavy metals in Soils. Blackie Academic and Professional, London.

Landon, JR. 1991. Booker Tropical Soil Manual: A hand book for soil survey and agricultural land evaluation in the Tropics and Subtropics. Essex, Longman Scientific and Technical, New York.

Lindsay, WL, and Norvell, WA. 1978. Development of DTPA soil test for zinc, iron, manganese and copper. Soil Sci. Soc. Am. J. 42:421-428.

Lindsay, WL, and Schwab, AP. 1982. The chemistry of iron in soils and its availability to plants. Journal of Plant Nutrition. 5:821-840.

Manson, RD. 1998. Principles of Plant analysis. In Karla YP in Handbook of Reference Method for Plant Analysis. CRS Press, Taylor & Francis Group, Boca Raton, Florida.

Ministry of Agriculture (MoA) and Agricultural Transformation Agency (ATA). 2014. Soil fertility status and fertilizer recommendation Atlas for Tigray Regional State, Ethiopia. Addis Ababa, Ethiopia.

Olsen, SR, Cole, CV, Watanabe, FS and Deal, LA. 1954. Estimation of Available Phosphorus in Soil by Extraction with Sodium Bicarbonate. Government Printing Office, USDA Circular 939. Washington, DC, USA.

Prasad, R, and Power, JF. 1996. Soil fertility management for sustainable agriculture. CRC Press LLC, Boca Raton, Florida.

Prasad, SN, Singh, ID and Mishra, BB. 1999. Characterization of some salt affected alluvial soils of South Bihar. Indian Journal of Agricultural Chemistry. 32:106-113.

Sharma, BD, Mukhopadhyay, SS, and Katyal, JC. 2006. Distribution of total and DTPA-extractable Zinc, Copper, Manganese, and Iron in Vertisols of India. Comm Soil Sci and Plant Analysis. 37:653-672.

Srivastava, PC, and Gupta, UC. 1996. Trace Elements in Crop Nutrition. NH: Science Publishers, Lebanon.

Tekalign Tadese. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. International Livestock Research Center for Africa, Addis Ababa, Ethiopia.

Tisdale, SL, Nelson WL, Beaton JD and Havlin JL. 1993. Soil Fertility and Fertilizers. 5th Edition. Macmillan Publishing Company,

USA.