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Effect of Zinc Containing Fertilizers on Yield and Grain Quality of Tef [(*Eragrostis Tef* (Zucc.) Trotter] in some Soils of Tigray Region, Ethiopia

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የዚንክ ንጥረ ነገር ለአዝርእት እድገትና ለሰዉ ምግብነት በጣም ጠቃሚ ነዉ፡፡ ይሁን እንጂ በትግራይ ክልል አፈር ውስጥ የዚንክ እጥረት በስፋት እንዳለ በጥናት ተረጋግጠዋል፡፡ ይህ መነሻ በማድረግ የዚንክን ማዳበርያ በጤፍ ምረታማነትና የዚንክን ይዘት ያለዉ ለመዳሰስ ከአስር የዚንክ እጥረት ያላቸዉ ቦታዎች አፈር በመሰብሰብ አምስት የዚንክ መጠን በሶስት ድግግሞሽ በኮምፕሊትሊ ራንደማይዝድ ዲዛይን በቤተ ጥናት ግሪንሃዉስ ተዘርቶ ተሰርተዋል፡፡ የዚንክ መጠኖች 0 ዚንክ፣ ጠ100 ኪ.ግ NPSZn ማዳበርያ የሚገኝ ዚንክ በሄክታር፣ 100 ኪ.ግ NPSZn ማዳበርያ + 2 ኪ.ግ ዚንክ በሄክታር፣ 100 ኪ.ግ NPSZn ማዳበርያ + 4 ኪ.ግ ዚንክ በሄክታር እና 100 ኪ.ግ NPSZn ማዳበርያ + 8 ኪ.ግ ዚንክ በሄክታር ናቸዉ፡፡ ተጨማሪ 4 ኪ.ግ ዚንክ በሄክታር በአፈር በመጨመር የጤፍ ጠቅላላ ምርት በ 36% ፣ ምርት በ 27% እንዲሁም የጤፍ የዚንክን ይዘት በ 15% አድርገዋል፡፡ ሆኖም ከ 2 ኪ.ግ ተጨማሪ ዚንክ በሄክታር ጋር ሲወዳደር የጎላ ልዩነት አላሳየም፡፡ ይህን የሚያመለክተዉ ከ 2 እስከ 4 ኪ.ግ ዚንክ በሄክታር ተጨማሪ ጠ100 ኪ.ግ NPSZn ማዳበርያ ከሚገኝ ዚንክ መጨመር ያስፈልጋል፡፡ በተቃራኒ ጠ100 ኪ.ግ NPSZn ማዳበርያ ከሚገኝ ዚንክ በላይ መጨመር የጤፍ ዚንክ ይዘት ከዚንክ መጨመር ተመሳሳይነት አለዉ፡፡ ዚንክ ካልተጨመረበት ጋር ሲወዳደር ከፍተኛዉ ዚንክ መጠን የጤፍ ዚንክ ይዘትን በአማካይ ከ 18.04 ወደ 23.4 ሚ.ግ በ ኪ.ግ አሳድገዋል፡፡ ጠቅላላ ጥናቱ የሚያመለክተዉ ዚንክ ወደ አፈር መጨመር ለጤፍ ምርትና ምርታማነት ማሳደግ በጎ ተፅእኖ ቢኖሮዉም ለሰዉ ምግብነት የሚፈለገውን ያህል አስተዋፅኦ አላደረገም፡፡ ሰለዚህ በአፈር ዚንክ መጨመር እና የተለያዩ የአዝርእት እንክብካቤ ስራዎች በማጣመር ለጤፍ ምረታማነትና ዚንክ ይዘት ሊጨምሩ ይችላሉ፡፡

Abstract

Zinc is an essential micronutrient for crop growth and human diet. Its deficiency is widespread in soils of Tigray Region. To evaluate the effects of Zn fertilizers on yield and quality of tef in ten Zn deficient soils of Tigray, greenhouse experiment composed of five treatments in a completely randomized design with three replications were conducted. Treatments were 0 Zn, Zn in 100 kg NPSZn ha^{-1}, (100 kg NPSZn + 2 kg Zn) ha^{-1}, (100 kg NPSZn + 4 kg Zn) ha^{-1} and (100 kg NPSZn + 8 kg Zn) ha^{-1}. Although the increases were not statistically different from the treatment with 2 kg ha^{-1} Zn, biomass and grain yields and grain Zn concentration of tef increased significantly by 36, 27 and 15% over the control with additional Zn of 4 kg ha^{-1}. This indicates that additional 2 to 4 kg Zn ha^{-1} might be needed beyond the Zn content in the 100 kg NPSZn compound fertilizer. In the contrary, grain Zn concentration increased linearly with Zn application rates beyond 100 kg NPSZn application. Compared with no application, Zn fertilizer at the highest rate increased grain Zn concentration from 18.04 to 23.4 mg kg^{-1} on average. The findings suggest that soil applied Zn is important to maintain sufficient yield, but has a modest biological impact on human health. Integrating soil Zn application with other agronomic practices might improve both yield and grain Zn of tef.

Introduction

Tef is among the major cereals grown in Ethiopia including the Tigray Region. The grain of tef comprises the major dietary and nutrient sources for Ethiopians (Tareke *et al.,* 2013), while its straw provides the major source of dry season fodder for livestock (Seyoum and Zinash, 1989; Alemu, 2013). Demands for tef are increasing locally because of an increase in Ethiopian population and internationally because of its increased global popularity (Tareke *et al.,* 2013; Crymes, 2015). To fulfill the growing demands locally and globally, increasing production and quality of tef are paramount importance.

The national average tef grain yield of 1575 kg ha^{-1}(1426 kg ha^{-1} in Tigray Region) is low compared to other cereals (CSA, 2015). Low soil fertility is the major constraint that contributes to the low productivity of tef (Bereket *et al.,* 2011; Getachew *et al.,* 2014; Tesfa *et al.,* 2013; Wakene and Yifru, 2013). Nitrogen (N) and phosphorus (P) were the only nutrients applied to cereals in Ethiopia in the form of Urea and Di-ammonium phosphate (DAP) since their introduction in 1967 (FAO, 1995). Accordingly, most of the fertilizer studies on cereals in the past also focused on N and P fertilizers. However, crop production demands more nutrients. Recent developments showed that application of K (IPI, 2014; Mulugeta *et al.,* 2015), S (Kiros and Singh, 2006), Zn (Bereket *et al.,* 2011), Zn and Cu containing DAP (Tareke *et al.,* 2013) increased grain and straw yields of cereals. The above fertilizer studies other than N and P might indicate the need for balanced fertilization to improve the productivity and quality of cereals.

The soil fertility map of agricultural lands has been developed by EthioSIS to identify nutrients that may limit crop productivity and to develop balanced fertilization in Ethiopia (MoA and ATA, 2014). Accordingly, widespread Zn deficiency in soils of Tigray Region was reported (MoA and ATA, 2014), which could be attributed to relatively higher soil pH, soil degradation, nutrient mining and depletion. Zinc deficiency is also a global problem in human nutrition associated with cereal-based diets, while low soil Zn often limits crop production and crop grain quality (Kayode, 2006; Cakmak and Kutman, 2017).

There are several management practices to alleviate Zn deficiency in crops and humans. Among others, the use of fertilizers containing Zn. There is an interest from the government of Ethiopia for use of Zn containing fertilizers such as NPSZn to increase crop yields. Farmers in Ethiopia have started using fertilizers containing Zn. In Tigray Region, farmers are encouraged through the extension system to apply fertilizer containing Zn at a rate of 100 kg ha^{-1} replacing Di-ammonium phosphate (DAP) for all crops. The Zn content in NPSZn fertilizer is 2.5 kg, which is lower than the average soil application rate of 10 kg Zn ha^{-1} (4.5-

34 kg Zn ha^{-1}) for different crops (Alloway, 2009). Additional Zn might be needed to improve productivity and quality of cereals including tef.

Management strategies to improve Zn in human nutrition are either to nourish diets rich in vegetable and meat or improve the concentration of Zn in grain crops using agronomic management practices (Hotz and Brown, 2004). The recommended target of Zn concentration in crop grains for human nutrition is 40-60 mg kg^{-1} (Graham *et al.,* 2007). Fertilizers containing Zn might also improve the concentration of Zn in tef grain. So far, there are limited studies investigating the effects of fertilizers containing Zn and their effects on yields and grain Zn concentration (quality) of tef. Therefore, this study was conducted to evaluate the effects of Zn containing fertilizer on yield and grain Zn concentration (quality) of tef in some Zn deficient soils of Tigray Region.

Materials and Methods

Greenhouse pot experiments were carried out at Mekelle Agricultural Research Center in 2017 during the months between February and April. Surface soil samples (0-20 cm depth) were collected from ten Zn deficient soils of Tigray Region, Northern Ethiopia (Table 1). The soils were collected from six districts, from Cambisols, Chromic Cambisols, Vertic Cambisols, Regosols and Luvisols; and from SM2-5 (Tepid to cool sub moist mountains and plateau) and SM1-3 (Hot to warm sub-moist lowland plains) agro-ecological zones. The soil samples were collected in a diagonal pattern from each selected site using an auger and mixed to obtain a composite bulk soil for the pot experiments and for analysis of selected soil chemical and physical properties.

The experiments had five treatments and three replications and conducted in the selected soils collected from ten sites arranged in a completely randomized design. The experiments had a total of 150 experimental units. The treatments were 1. 0 Zn, 2. Zn in 100 kg NPSZn ha^{-1}, 3. (Zn in100 kg NPSZn + 2 kg Zn) ha^{-1}, 4. (Zn in 100 kg NPSZn + 4 kg Zn) ha^{-1} and 5. (Zn in 100 kg NPSZn + 8 kg Zn) ha^{-1}. The additional Zn fertilizer was in the form of $ZnSO_4.7H_2O$. Hundred kilograms of NPSZn compound fertilizer contained 17.7 kg N, 35.3 kg P_2O_5, 6.5 kg S and 2.5 kg Zn.

Table 1. Experimental site characteristics

District	Sub-district	Site	Soil type	Latitude	Longitude	Altitude (m)	AEZ
Hawzien	Debrehiwot	Awade	Chromic Cambisols*	1542270	541972	2029	SM2-5
Hawzien	Megab	Megab	Cambisol*	1540266	540607	2049	SM2-5
Kilte-Awlealo	Genfel	Korir	Vertic Cambisols*	1520462	565044	1997	SM2-5
RayaAzebo	Chercher	Asayo	Leptic Regosol**	1382355	582992	1720	SM1-3
RayaAzebo	Kara	Kara	Vertic Cambisol**	1404445	570183	1661	SM1-3
RayaAzebo	Genete	Ganda Stola	Vertic Cambisol*	1410234	569656	1733	SM1-3
Alamata	Harle	Belay Tela	Luvisol**	1363737	565737	1501	SM1-3
Enderta	Dergajen	Chichat	Vertic Cambisols*	1492353	571743	2371	SM2-5
Enderta	Shibta	Dagiya	Vertic Cambisols*	1485843	550295	2129	SM2-5
Hintalo-Wajirat	Hiwane	Hiwane	Cambisol*	1450274	553912	2010	SM2-5

**FAO (1984); **Mitiku et al. (2007); AEZ: Agro-ecological zone; SM2-5: Tepid to cool sub moist mountains and plateau; SM1-3: Hot to warm sub-moist lowland -plains*

Plastic pots of 7.5 kg soil capacity with an upper diameter of 25 cm, bottom diameter of 17 cm and depth of 18 cm were filled with soil maintaining the field bulk density. Rowell (1994) reported an area base fertilizer application is preferred over soil mass base because weight base underestimate fertilizer application rate under pot experimentation. Area base has an advantage of supplying the needs of the crops in the pot (Rowell, 1994). This study used an area base fertilizer application. Nitrogen, P, K_2O and S were applied at the rate of 64, 20, 60 and 20 kg ha^{-1}, respectively, to each pot as basal by adjusting the nutrients in the Zn containing fertilizers. The forms of fertilizers for N, P, K and S were urea, TSP, KCl and gypsum, respectively. Phosphorus, K and S and the fertilizers containing Zn were applied during planting while the remaining N from urea fertilizer was applied during tillering. Tef variety *Quncho* (Dz-Cr-387) at a seed rate of 10 kg ha^{-1} mixed with equal amount of sand for ease of planting was sown to each pot. The pots were watered with deionizied water (pH = 6.74 and EC = 0.36 ds m^{-1}) based on crop water requirement by measuring with a graduated cylinder. The pots were randomized frequently within each block. The tef plants were grown under natural day length and light intensity. During the experiment, the average daily temperature in the green house was 27^{o}C during the day and 13^{o}C during the night.

The soils used for the pot experiments 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 determination of organic carbon content and total nitrogen, 0.5 mm sieve was used. Soil texture was determined by hydrometer determination according to Day (1965); and dry bulk density by using the gravimetric method according to Hesse (1971). Soil pH was measured in a soil/water ratio of 1:2.5 using glass electrode (Jackson, 1967).

Organic carbon content was determined following the modified Walkley and Black method (Jackson, 1967), and total nitrogen according to Bremner and Mulvaney (1982). Cation exchange capacity (CEC) was analyzed by replacing exchangeable cations with sodium acetate (NaOAc), removal of excess sodium (Na) by alcohol, exchanging Na by ammonium acetate (NH_4OAc), and determining the Na concentration by flame photometry (Chapman, 1965); calcium carbonate ($CaCO_3$) equivalent by neutralization with hydrochloric acid (HCl) (Allison and Moodie, 1965). Available phosphorous was determined according to Olsen *et al.* (1954) and Mehlich (1984). Available Zn was determined using DTPA-Zn (Lindsay and Norvell, 1978) and Mehlich-Zn (Mehlich, 1984), and total Zn 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).

Measurements were taken on plant height and panicle length at maturity using measuring tape. Aboveground biomass were sun-air dried to the barest minimum for 15 days in a paper bag before weighing. The shoots were threshed and cleaned and grain yield was weighed at 12.5% moisture content.

Tef grain samples were collected for analysis of Zn after threshing. The samples were cleaned of any contamination and ground with a stainless grinder. The samples were digetsed using a wet digetion method (di-acids HNO_3-$HClO_4$ at 2:1 ratio) to obtain full recovery of Zn (Estefan *et al.*, 2013). The aliquots of the digest were determined for Zn using Fast Sequential Flame Atomic Spectrometry (Varian AA 240FS) at an accredited laboratory of Ezana Analytical Laboratory, Mekelle, Ethiopia.

The data were subjected to analysis of variance using GenStat 14th edition (VSN, 2011). Means were compared with Least Significant Difference (LSD) test at the 5% level of probability.

Results and Discussion

Experimental soil characteristics

Properties of soils used for the pot experiment are depicted in Table 2. Soil pH varied from neutral to strongly alkaline (Tekalign, 1991). The soil organic carbon (< 1.5%) and total nitrogen (< 0.1%) contents were low at all sites according to the rating by Tekalign (1991). The soil phosphorus status ranged from very low (Olsen-P < 5 mg kg^{-1} soil or Mehlich-III P < 15 mg kg^{-1} soil) to high (Olsen-P > 10 mg kg^{-1} soil or Mehlich-III P < 30 mg kg^{-1} soil) (Olsen, 1954; MoA and ATA, 2014). Total soil Zn content ranged from 6.1 to 36.7 mg kg^{-1} soil. All soils were low in Zn concentration (DTPA-Zn < 0.6 mg kg^{-1} soil) (Lindsay and Norvell, 1978). When extracted with Mehlich-III, nine out of the ten sites were low in soil Zn (< 1.50 mg kg^{-1} soil) according to the rating by MoA and ATA (2014). The results indicate that the Zn fertilizer application is required to avoid probable yield loss. DTPA extracted Zn showed a statistically significant relationship (R^2 = 0.817; $p < 0.001$) with Mehlich-III Zn is showing either of the extracatant can be used under the conditions of this study. The CEC of the soils of the study sites varied from low (5-15 meq 100 g^{-1} soil) to very high (> 40 meq 100 g^{-1} soil) (London, 1991). Lower CEC value in the soils of Awade and Megab could be due to a high sand plus silt and relatively lower organic carbon contents of the soils. Calcium carbonate equivalent ranged from 3.30 to 15.57 %. The soil textural class varied from sandy loam to clay loam with dry bulk density range of 1.31 to 1.50 g cm^{-1}. The relatively higher bulk density might be attributed to the low organic carbon content of the soils.

Effects on plant height and panicle length of tef

There was no significant interaction effect of Zn fertilizer and soil for either panicle length or plant height of tef (Table 3). The main effect of Zn fertilizer increased significantly panicle length and plant height of tef. Application of 100 kg NPSZn ha^{-1} + 4 kg Zn ha^{-1} significantly increased panicle length and plant height of tef over the control. However, the recorded increases were not statistically significant compared to the preceding Zn rate.

The lowest and highest panicle length and plant height of tef were recorded from plants grown in Megab and Kara soils, respectively (Table 3). Low soil organic carbon, total nitrogen, clay content, both available and total Zn and other related poor physical and biological soil properties might have contributed for the lowest growth of tef at Megab soil (Table 2). There are no peculiar soil characteristics other than low sand content (Table 2) that can explain for better growth of tef at Kara soil.

Response of tef yield to zinc fertilization

There was a significant interaction effect of Zn fertilization and soil for biomass yield of tef (Table 4). At Ganda Stola soil, the highest biomass yield (53.67 g pot^{-1}) of tef was recorded from the application of 100 kg NPSZn ha^{-1} + 4 kg Zn ha^{-1} and the lowest (19.33 g pot^{-1}) was obtained from the control at Megab soil. Ganda Stola soil had the highest CEC and relatively low calcium carbonate equivalent (Table 2) which might have contributed for the Zn ion to be retained in the exchange site and made it easily available to the tef plants during the growing period. Karimian and Moafpouryan (1995) reported calcium carbonate and CEC were among the soil factors that affect Zn adsorption. Relatively low soil fertility (Table 2) and poor tef growth (Table 3) might have contributed for the low biomass yield of tef at Megab soil.

The main effect of Zn fertilizer increased significantly biomass yield of tef (Table 4). The highest biomass yield of tef was recorded from the application of 100 kg

NPSZn ha^{-1} + 4 kg Zn ha^{-1}, with an increase of 27% over the control. However, the recorded increase was not significantly different from the preceding rate.

There was no significant interaction effect of Zn fertilizer and soil for grain yield and harvest index of tef (Table 3). On average Zn fertilizer increased significantly grain and harvest index of tef (Table 3). The highest grain yield and harvest index of tef were recorded from the application of 100 kg NPSZn ha^{-1} + 4 kg Zn ha^{-1} with recorded increases of 36% and 7.6%, respectively, over the control. However, the increases were not statistically different from the preceding rate. Therefore, the results showed that application of 2 to 4 kg Zn ha^{-1} may be needed for Zn deficient soils for improved productivity of tef in Tigray in addition to the recommended application rate of Zn in100 kg NPSZn ha^{-1}. Previous studies also indicated that application of Zn increased yields of wheat (Cakmak *et al.,* 1999; Rattan *et al.,* 2008), rice (Wissuwa *et al.,* 2007; Rattan *et al.,* 2008; Fageria, 2009), maize (Abunayewa and Mercer-Quarshie, 2004; Rattan *et al.,* 2008), sorghum (Traore, 2006; Rattan *et al.,* 2008) and tef on Vertisol (Bereket *et al.,* 2011).

Though the plants were grown under optimum moisture condition, there were variations in yields and harvest index of tef among the different soils (Table 3). The differences might be due to the variability in soil chemical and physical characteristics indicated in Table 2 and possibly other inherent biological as well as unrecorded soil properties.

Table 2. Surface (0-20 cm) soil properties of the experimental soils

Soil	pH_{water} (1:2.5)	$CaCO_3$ (%)	CEC meq 100 g^{-1} soil	OC (%)	Total-N (%)	Olsen- P	Mehlich III - P	DTPA- Zn	Mehlich III - Zn	Total-Zn	Sand	Silt	Clay	Bulk Density
						mg kg^{-1} soil					%			g cm^{-3}
Awade	6.82	3.30	5.11	0.59	0.052	4.77	13.61	0.236	0.393	8.9	42	42	16	1.38
Megab	7.40	7.55	6.52	0.29	0.010	5.95	28.63	0.059	0.148	6.1	84	8	8	1.45
Korir	8.08	6.79	32.03	1.10	0.060	7.31	20.19	0.536	1.581	23.5	48	28	24	1.32
Asayo	7.96	4.62	28.96	1.06	0.065	10.24	28.76	0.227	0.331	34.4	48	36	16	1.31
Kara	8.04	5.66	35.01	1.24	0.076	9.12	44.85	0.151	0.379	34.9	32	40	28	1.35
Ganda Stola	8.10	4.25	41.31	1.18	0.076	11.12	40.15	0.240	0.507	36.7	34	40	26	1.40
Belay Tela	7.87	6.13	24.87	0.68	0.067	5.82	42.20	0.096	0.287	25.1	46	38	16	1.50
Chichat	7.47	4.72	26.58	1.35	0.074	9.57	34.81	0.190	0.332	33.1	46	38	16	1.49
Dagiya	8.02	15.57	37.83	1.46	0.089	8.20	10.64	0.266	0.333	27.4	38	36	26	1.47
Hiwane	7.60	5.77	30.00	0.81	0.064	28.85	79.14	0.429	0.779	27.1	54	32	14	1.49
Minimum	6.82	3.30	5.11	0.29	0.010	4.77	10.64	0.059	0.148	6.1	32	8	8	1.31
Maximum	8.10	15.57	41.31	1.46	0.089	28.85	79.14	0.536	1.581	36.7	84	42	28	1.50
Mean	7.74	6.44	26.82	0.98	0.060	10.10	34.30	0.240	0.51	25.72	47.2	33.8	19.0	1.42

Table 3. Main effects of Zn containing fertilizers and soil on panicle length, plant height, grain yield and harvest index of tef

Treatment	Panicle length (cm)	Plant height (cm)	Grain yield (g pot^{-1})	Harvest index (%)
0	28.84c	80.85c	8.2c	25.67b
Zn in 100 kg ha^{-1} NPSZn	30.93ab	90.14b	10.49b	26.73ab
Zn in 100 kg NPSZn ha^{-1} + 2 kg Zn ha^{-1}	31.32ab	92.50a	10.97ab	27.48a
Zn in 100 kg NPSZn ha^{-1} + 4 kg Zn ha^{-1}	31.50a	92.87a	11.17a	27.63a
Zn in 100 kg NPSZn ha^{-1} + 8 kg Zn ha^{-1}	30.37b	89.45b	10.72ab	26.87a
P	<0.001	<0.001	<0.001	0.004
LSD (0.05)	0.98	2.17	0.487	1.08
Soil				
Awade	29.97bc	87.87cd	11.08bc	28.44b
Megab	26.40e	76.29f	8.14e	32.65a
Korir	28.79cd	83.48e	6.99f	28.12b
Asayo	27.79de	87.79d	11.25b	28.59b
Kara	35.52a	101.64a	10.16d	22.49f
Ganda Stola	31.33b	91.99b	13.13a	26.12d
Belay Tela	30.65b	93.48b	10.80bcd	26.86cd
Chichat	31.09b	90.65bc	10.40cd	24.34e
Dagiya	34.89a	92.68b	8.28e	23.2ef
Hiwane	28.28d	86.45de	12.93a	27.97bc
LSD (0.05)	1.388	3.07	0.690	1.527
P	<0.001	<0.001	<0.001	<0.001
Zinc x Soil	0.814	0.793	0.335	0.076
CV (%)	6.30	6.87	9.2	7.8

Concentration of zinc in tef grain

There was a significant interaction effect of Zn fertilization and soil for grain quality or Zn concentration of tef (Table 4). The highest grain Zn concentration (32.93 mg kg^{-1}) of tef was recorded in Awade soil from the application of 100 kg NPSZn ha^{-1} + 8 kg Zn ha^{-1} and the lowest (14.70 mg kg^{-1}) at Megab soil from the control. Zinc might be desorbed and could be available to the tef plants at Awade soil because of less Zn adsorption characteristics (Table 2). Megab soil is relatively poor in its fertility and available Zn content (Table 2) that might have contributed for the low Zn concentration in the tef grain. Zinc fertilizer beyond the Zn content in the 100 kg NPSZn ha^{-1} improved grain Zn concentration of tef over the control in eight out of the ten sites (Table 5). The absence of significant responses of tef grain Zn concentration to Zn fertilizer applications at Korir and Dagiya soils might be attributed to the high Zn adsorption characteristics (relatively high soil pH and calcium carbonate contents) of these soils (Table 2).

Table 4. Main and interaction effects of Zn containing fertilizers and soil on biomass yield (g pot^{-1}) of tef

Soil	Treatment					
	0	Zn in 100 kg NPS Zn ha^{-1}	Zn in 100 kg NPSZn ha^{-1} + 2 kg Zn ha^{-1}	Zn in 100 kg NPSZn ha^{-1} + 4 kg Zn ha^{-1}	Zn in 100 kg NPSZn ha^{-1} + 8 kg Zn ha^{-1}	Mean
Awade	31.33	40.67	41.00	41.33	40.67	39.00e
Megab	19.33	22.67	24.67	27.33	29.67	24.73g
Korir	20.67	25.67	25.67	25.67	26.33	24.80g
Asayo	31.00	41.00	41.00	42.00	42.33	39.47e
Kara	39.67	45.33	48.00	46.33	45.33	44.93c
Ganda Stola	42.33	51.67	52.00	53.67	52.33	50.40a
Belay Tela	33.00	40.67	41.00	41.67	42.67	39.80e
Chichat	37.67	44.00	44.33	44.33	42.67	42.60d
Dagiya	29.00	36.33	38.00	38.00	36.33	35.53f
Hiwane	38.67	48.00	49.00	50.33	45.33	46.27b
Mean	32.27c	39.60b	40.47ab	41.07a	40.37ab	
CV (%) = 4.4, Zn: $p < 0.001$ & LSD = 0.87; Soil: $p < 0.001$ & LSD = 1.23 and Zn x Soil: $p < 0.003$ & LSD = 2.75						

Despite statistically non significant, main effects of Zn fertilizer slightly decreased grain Zn concentration of tef due to the application of 100 kg NPSZn ha^{-1} over the control (Table 5). Immediate increases in grain production (Table 3) at this application rate might dilute the Zn concentration in the tef grain. In the contrary, grain Zn content increased linearly with Zn application rates beyond the application of 100 kg NPSZn ha^{-1}. Compared with no application, Zn fertilizer at the highest rate increased grain Zn concentration from 18.04 to 23.4 mg kg^{-1} on average. However, the Zn concentration is low compared to targeted Zn content for human consumption (Graham *et al.,* 2007). The findings suggest that soil applied Zn is important to maintain sufficient yield, but has modest biological impact on human health. Hence, integrating soil Zn application with other agronomic management practices, such as foliar zinc application, nitrogen fertilization, crop rotation and intercropping (Cakmak, 2008; Shivay *et al.,* 2008a, b), breeding and genetic biofortification (Bouis and Welch, 2010; Bouis *et al.,* 2013), mycorrhizal inoculation with an understanding of the rhizosphere (Subramanian *et al.,* 2013) might improve both yields and grain zinc concentration of tef.

Table 5. Main and interaction effects of application of Zn containing fertilizers and soil on grain Zn content (mg kg^{-1}) of tef

Soil	Treatment					
	0	Zn in 100 kg NPSZn ha^{-1}	Zn in 100 kg NPSZn ha^{-1} + 2 kg Zn ha^{-1}	Zn in 100 kg NPSZn ha^{-1} + 4 kg Zn ha^{-1}	Zn in 100 kg NPSZn ha^{-1} + 8 kg Zn ha^{-1}	Mean
Awade	29.06	27.79	28.20	29.00	32.93	29.40a
Megab	14.70	13.36	19.13	21.12	22.80	18.22d
Korir	20.99	21.68	21.01	21.14	21.51	21.26c
Asayo	15.74	14.20	17.95	18.30	19.29	17.09d
Kara	18.78	16.51	20.91	22.40	27.51	21.22c
Ganda Stola	10.36	10.38	13.19	15.76	18.65	13.67f
Belay Tela	15.48	13.41	15.65	18.90	21.42	16.97de
Chichat	13.68	14.59	15.71	16.31	18.04	15.67e
Dagiya	21.25	21.53	21.69	21.20	22.28	21.59bc
Hiwane	20.34	21.11	22.19	23.50	26.39	22.70b
Mean	18.04d	17.46d	19.56c	20.76c	23.08a	
CV (%) = 9.5, Zn: $p < 0.001$ & LSD = 0.958; Soil: $p < 0.001$ & LSD = 1.355 and Zn*Soil: $p < 0.001$ & LSD = 3.03						

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