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Effects of Salinity on Yield and Yield Components of tef [*Eragrostis tef* (Zucc.) Trotter] Accessions and Varieties

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Abstract: This study aimed to screen fifteen low land tef genotypes (10 accessions and 5 varieties) with respect to yield and yield components at 0dS/m (control), 2, 4, 8 and 16 dS/m salinity levels and data analysis was carried out using SAS package (SAS version 8.2, 2001). The two ways ANOVA showed significant variation with respect to Main Panicle Length (MPL), Peduncle Length (PDL), number of spikelets per main panicle (SP/MP), number of Primary Panicle Branch per Main Panicle (PPB/MP), Main Panicle Dry Weight (MPDW) and Grain Yield per Main Panicle (GY/MP) at $p<0.001$ for both accessions/varieties and treatment. On the other hand, accession/variety*treatment interaction effect was significant for MPDW ($p<0.001$) and SP/MP ($p<0.01$). This implies that all the accessions and varieties respond to salinity stress differently with respect to these two characters. However, the accession/variety*treatment interaction for the rest characters was insignificant reflecting that the entire varieties and accessions react to salinity stress similarly. Accession 236514, varieties DZ-Cr-358 and DZ-01-1681 were salt sensitive genotypes whereas accession 237186 and variety DZ-cr-37 were salt tolerant genotypes of all. Generally, the study revealed the presence of broad intraspecific genetic variation in tef accessions and varieties for salt tolerance but more in the former. Irrespective of salinity being a growing problem in Ethiopia in general and the Awash valley in particular, only little has been done on crops salt tolerance. Therefore, to alleviate the already existing and the inevitable incoming salinity problem, there should be similar and profound studies on tef and other crops.

Key words: Grain yield, panicle, peduncle, salinity, spikelet number, yield components

INTRODUCTION

Salt-affected soils are distributed throughout the world and no continent is free from the problem (Brady and Weil, 2002). Salinization of soil is one of the major factors limiting crop production particularly in arid and semi-arid regions of the world (Ahmed, 2009). Globally, a total land area of 831 million hectares is salt affected. African countries like Kenya (8.2 Mha), Nigeria (5.6 Mha), Sudan (4.8 Mha), Tunisia (1.8 Mha), Tanzania (1.7 Mha) and Ghana (0.79 Mha) are salt affected to various degrees (FAO, 2000). Salt stress is known to perturb a multitude of physiological processes (Noreen and Ashraf, 2008). It exerts its undesirable effects through osmotic inhibition and ionic toxicity (Munns *et al*., 2006). Increased salinity caused a significant reduction in germination percentage, germination rate, and root and shoots length and fresh root and shoots weights (Jamil *et al*., 2006).

In Ethiopia salt-affected soils are prevalent in the Rift Valley and the lowlands. The Awash Valley in general and the lower plains in particular are dominated by salt-affected soils (Gebreselssie, 1993). A significant abandonment of banana plantation and a dramatic spread to the adjacent cotton plantation of Melka Sadi Farm was reported (Abeaz, 1995). Moreover, of the 4000ha irrigated land of the above farm 57% has been salt-affected (Taddese and Bekele, 1996). Similarly, the occurrence of salinity problem in Melka Werer Research Farm was reported (Haider *et al*., 1988). Another study also depicted that of the entire Abaya State Farm, 30% has already been salt-affected (Tsige *et al*., 2000).

This problem is expected to be severe in years to come. Because under the prevailing situation of the country; there is a tendency to introduce and implement large-scale irrigation agriculture so as to increase productivity (Mamo *et al*., 1996). In the absence of efficient ways of irrigation water management, salt-build up is an inevitable problem. To alleviate the problem, we need to look for a solution (Gebre and Georgis, 1988). It can be done either using physical or biological practice (Gupta and Mihas, 1993; Marler and Mickelbart, 1993). Since environmental management (physical approach) is not economically feasible (El-Khashab *et al*., 1997) there

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is a need to concentrate on the biological approach or crop management (Ashraf and McNeilly, 1988; Ashraf *et al*., 2008; Ashraf, 2009). Nevertheless, to proceed with this approach, affirming the presence of genetically based variation for salt-tolerance in a particular crop is a prerequisite (Verma and Yadava, 1986; Marler and Mickelbart, 1993; Mahmood *et al*., 2009).

Thus in doing so, one has to focus on crops that have been cultivated for a long period of time in a country, and are able to provide reliable yield under unreliable agro-climatic conditions and make ranking first against area coverage, demand and market value. Tef [*Eragrostis tef* (Zucc) Trotter] is one of such crops, which has been cultivated in the country as a cereal crop for quite long (Purseglove, 1972). Furthermore, tef can be adapted to a broader range of agro-climatic environments. It can grow in altitudes ranging from sea level to 2800 m above sea level under different moisture, soil, temperature and rainfall regimes. It can tolerate anoxic situations better than maize, wheat and sorghum. It has ease of storage, tolerance to weevils and other pests. The straw is preferred to any other cereal straws and can fetch premium price (Ketema, 1993). According to Hailemelak *et al*. (1965), it contains higher amount of a number of minerals than wheat, barley or grain sorghum. As compared to other cereals, the largest cultivated land area is covered by tef. Moreover, the area used for tef production is increasing from time to time (Tefera and Ketema, 2000). For example, it covered 1,818, 375 (in 2001/02) and 1,989,068 (2003/04) ha of land which is 28.5 and 28.4% of the area covered respectively by the whole cereals in each production year (CSA, 2004). Generally, tef is a reliable cereal under unreliable climate. That is why, in many areas where recurrent moisture stress occurs, tef production replaces the production of maize and sorghum (Ketema, 1993).

Therefore, this article attempted to screen 15 genotypes (10 accessions and 5 varieties) of tef [*Eragrostis tef* (Zucc.)Trotter] with respect to yield and yield components.

MATERIALS AND METHODS

This study was conducted from March 2004 to June 2005 at Melkasa Agricultural Research Center (MARC), Ethiopia. The experimental soil was taken from Melkasa Agricultural Research Center (MARC) at a depth of 0-20 cm and analyzed profoundly at the National Soil Testing Center (NSTC), Addis Ababa, Ethiopia. It was loam with 2.4% $CaCO_3$, 16.3% total nitrogen, 1.596% organic matter and a pH (1:2.5 soil water ratio) of 9.1. It has adequate phosphorus supply (21.28) and the exchangeable K, Na, Ca and Mg were 3.41, 0.46, 44.31 and 19.97 meq/100 g soil respectively. Its electrical conductivity, 0.235 dS/m was low. It has a bulk density of l.11 g/cm^3 and 45% of water saturation, and at field capacity it has moisture content of 31.35% while the permanent welting point was 17.31%.

The amount of NaCl to be added per 4kg dry soil was calculated using the formula:

$$\text{Gram salt per 100 g dry soil} = \frac{0.064\ \text{dS/m} \times \text{water saturation\%}}{100\%}$$

(Mamo *et al*., 1996)

Based on this formula 2.314, 4.628, 9.257, and 18.514 g NaCl were dissolved in 250 mL distilled water to get 2, 4, 8 and 16 dS/m salinity levels, respectively. The experiment was conducted in a mesh house having a total area of 100 m^2 using plastic pots. The pots were filled with 4 kg dry soil, placed on dishes for collecting leachate (if any) and arranged in a randomized complete block design (RCBD) with four replications. The mesh house was covered with polyethylene plastic sheet to avoid the entrance of salts and other particles through wind and rain. The average temperature, relative humidity, sunshine, and evaporation of the area were 22.08ºC, 47.33%, 8.45 h/day and 7.48 mm, respectively.

Supplemental nitrogen as ammonium nitrate (NH_4NO_3) was applied to the pots at a rate of 57.14 mg/pot in a solution form so as to ensure that nitrogen is not a limiting factor to the growth of tef. The NaCl treatments were applied in such a way that 50% before seeding and the remaining 50% in two splits 10 and 15 days after seeding. This is to avoid osmotic shock. Twenty tef seeds were seeded per pot and at three leaf stage; they were thinned to 10 per pot. Distilled water was applied as often as necessary. The leachate was collected on the dishes and returned to the pot. In the meantime, main panicle length (MPL), peduncle length (PDL), number of spikelets per main panicle (SP/MP), number of primary panicle branch per main panicle (PPB/MP), main panicle dry weight (MPDW) and grain yield per main panicle (GY/MP) were recorded.

Data analysis: Data analysis was carried out using SAS package (SAS version 8.2, 2001) and SPSS version 12. Since most accessions and varieties were salt sensitive at 16 dS/m, information from this salinity level has not been included in data analysis.

RESULTS AND DISCUSSION

Main Panicle Length (MPL): The ANOVA for both accessions/varieties and treatments with respect to Main Panicle Length (MPL) was found to be significant ($p<0.001$). However, it was insignificant for treatment*accession/variety interaction ($p>0.05$). Main Panicle Length (MPL) was not remarkably influenced by

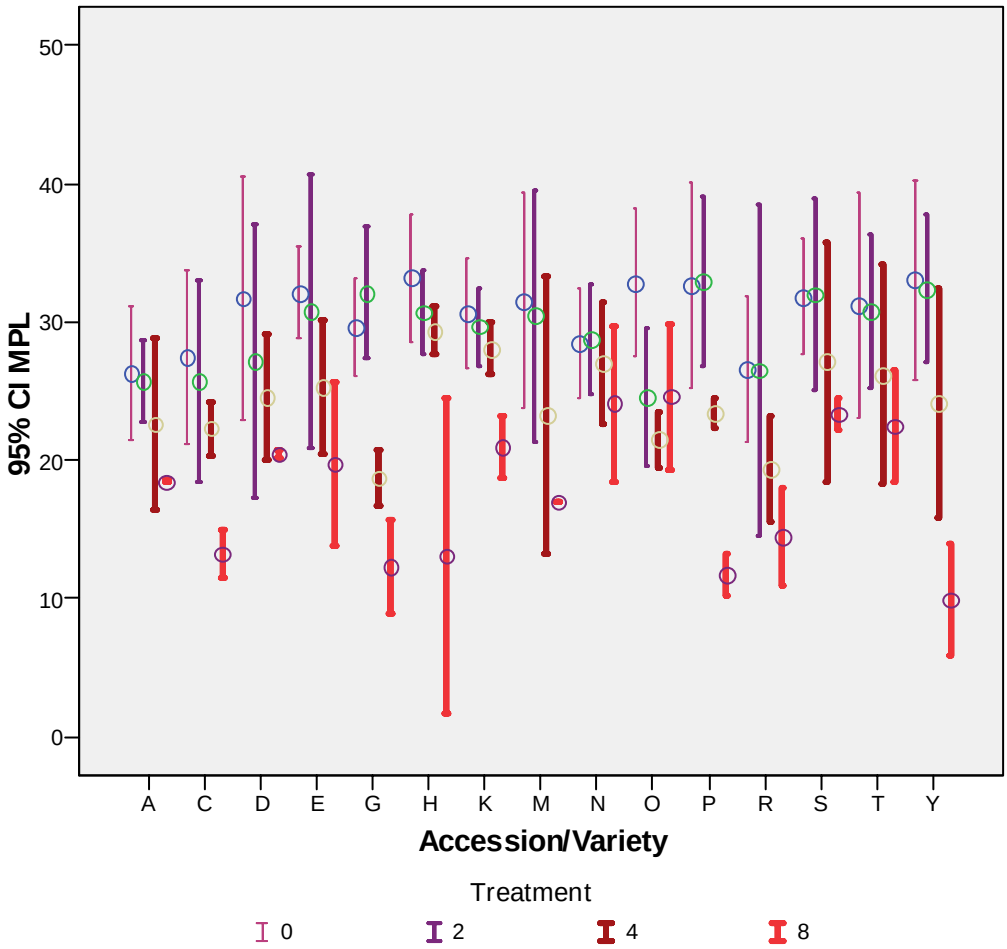

Fig. 1: Effects of salinity on main panicle length (MPL) of tef [*Eragrostis tef* (Zucc.) Trotter)] accessions and varieties. Key to accessions: A = 231217, C = 212611, E = 229747, G = 236514, H = 236512, M = 55017, N = 237186, O = 237131, R = 212928 and S = 205217; Key to varieties: D = DZ-01-196, K = DZ-Cr-37, P = DZ-01-1281, T = DZ-01-168 and Y = DZ-Cr-358)

2 dS/m rather it was stimulated in accession 236514; nevertheless, it was affected significantly at 4 and 8 dS/m but more profoundly at the latter treatment level. Consequently, at this treatment level there was a reduction of 15.4-64.3% in accessions and 27.9-70.1% in varieties as compared to the control. This is in agreement with early reports in sorghum (Azhar and McNeilly, 1989) and wheat (Grieve *et al*., 1992; Maas and Grieve, 1990). Accessions 236514, 236512 and 212611 and varieties DZ-Cr-358 and DZ-01-1281 were comparatively more salt affected than other genotypes. But accessions 237186, 237131 and 205217 and varieties DZ-01-1681 and DZ-Cr-37 were less affected ones (Fig. 1). Moreover, variety DZ-Cr-358 and accession 237186 were the most salt sensitive and salt tolerant of all genotypes studied respectively.

Peduncle Length per plant (PDL): The two ways ANOVA for both accessions/varieties and treatments with respect to peduncle length per plant (PDL) was found to be significant ($p<0.001$). However, it was insignificant for treatment*accession/variety interaction ($p>0.05$). Peduncle length (PDL) was stimulated at 2 dS/m in accessions 232517, 236514 and 237131 and variety DZ-01-1681. Similarly, as the case in MPL, even if it was affected at 4 and 8 dS/m, the reduction was remarkable at the latter treatment level. Thus at 8 dS/m salinity level, a reduction of 19.3-76.4 and 19.1-52.5% in accessions and varieties was obtained in comparison with the control respectively. Accessions 55017, 236512, 212928, 212611 and 229747 and varieties DZ-01-1281 and DZ-Cr-358 were more influenced than other genotypes. But accession 237186 and varieties DZ-Cr-37 and DZ-01-1681 were

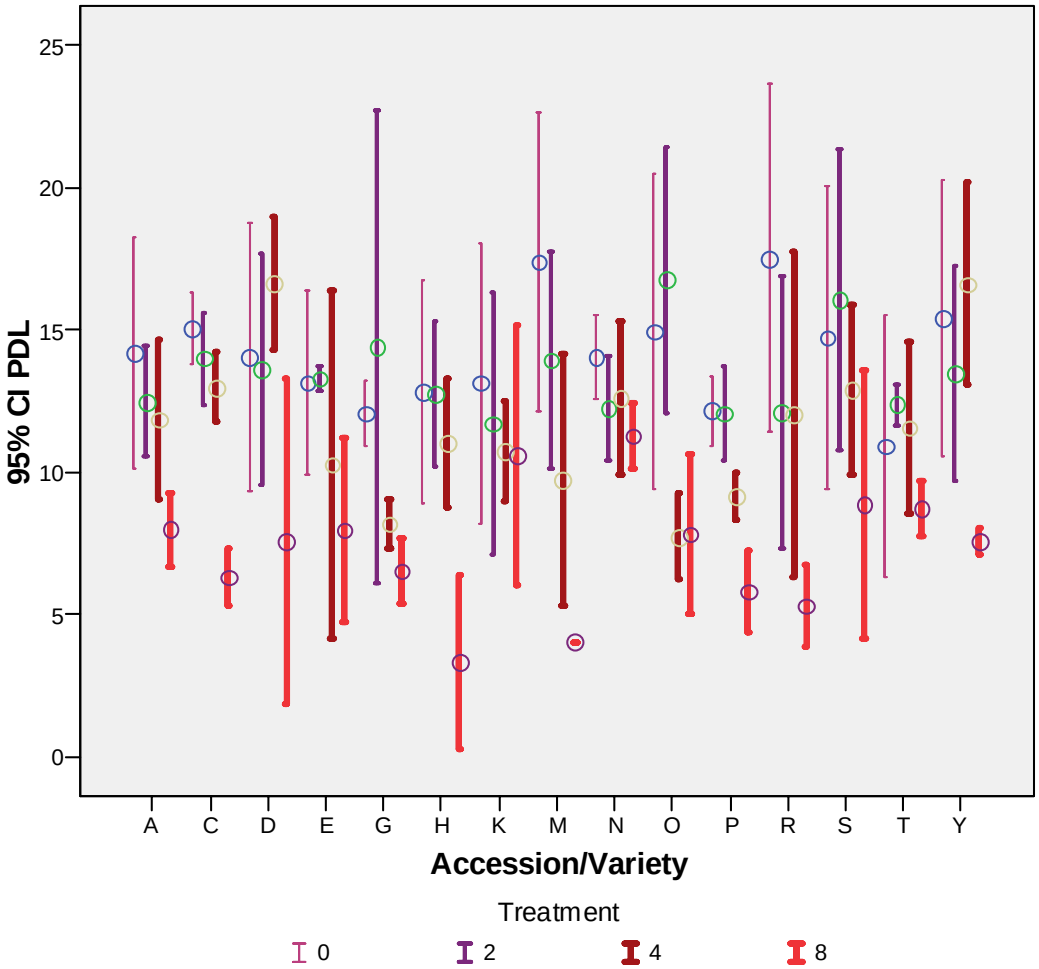

Fig. 2: Effects of salinity on peduncle length (PDL) of tef [*Eragrostis tef* (Zucc.) Trotter)] accessions and varieties. Key to accessions: A = 231217, C = 212611, E = 229747, G = 236514, H = 236512, M = 55017, N = 237186, O = 237131, R = 212928 and S = 205217; Key to varieties: D = DZ-01-196, K = DZ-Cr-37, P = DZ-01-1281, T = DZ-01-168 and Y = DZ-Cr-358)

least affected genotypes. Furthermore, accession 55017 was the most salt sensitive whereas variety DZ-Cr-37 and accession 237186 were the most salt tolerant of all genotypes under investigation (Fig. 2). It was possible to differentiate accessions into sensitive, intermediate and tolerant categories using this character, but only into intermediate and tolerant in the case of varieties. This implies the presence of broad gene pool in accessions for PDL unlike varieties and at the same time it signifies the relatively lower susceptibility of varieties to salt stress with regard to PDL.

Number of Primary Panicle Branch per Main Panicle (PPB/MP): The two ways ANOVA for both accessions/varieties and treatments with regard to number of primary panicle branch per main panicle (PPB/MP) was found to be significant ($p<0.001$). However, it was insignificant for treatment*accession/variety interaction ($p>0.05$). As of the rest characters, Primary Panicle Branch per Main Panicle (PPB/MP) was stimulated at 2 dS/m in accessions 202517, 229747, 231217 and 236514 and varieties DZ-01-1281 and DZ-01-1681 as compared to the control. It was influenced (reduced) at 4 dS/m and become pronounced at 8 dS/m salinity level. Consequently, a reduction of 6.8-76.5% in accessions and 11.7-60.2% in varieties was noticed at 8 dS/m in comparison with the control. Accessions 236514, 236512 and 55017 were influenced but accessions 237131, 237186, 205217, variety DZ-Cr-37 accession 229747, variety DZ-01-1681 and accession 231217 were the least affected genotypes respectively (Fig. 3). As the case in peduncle length, the varieties were not well differentiated into sensitive, tolerant and intermediate genotypes. Rather they fall only in the latter two categories and the

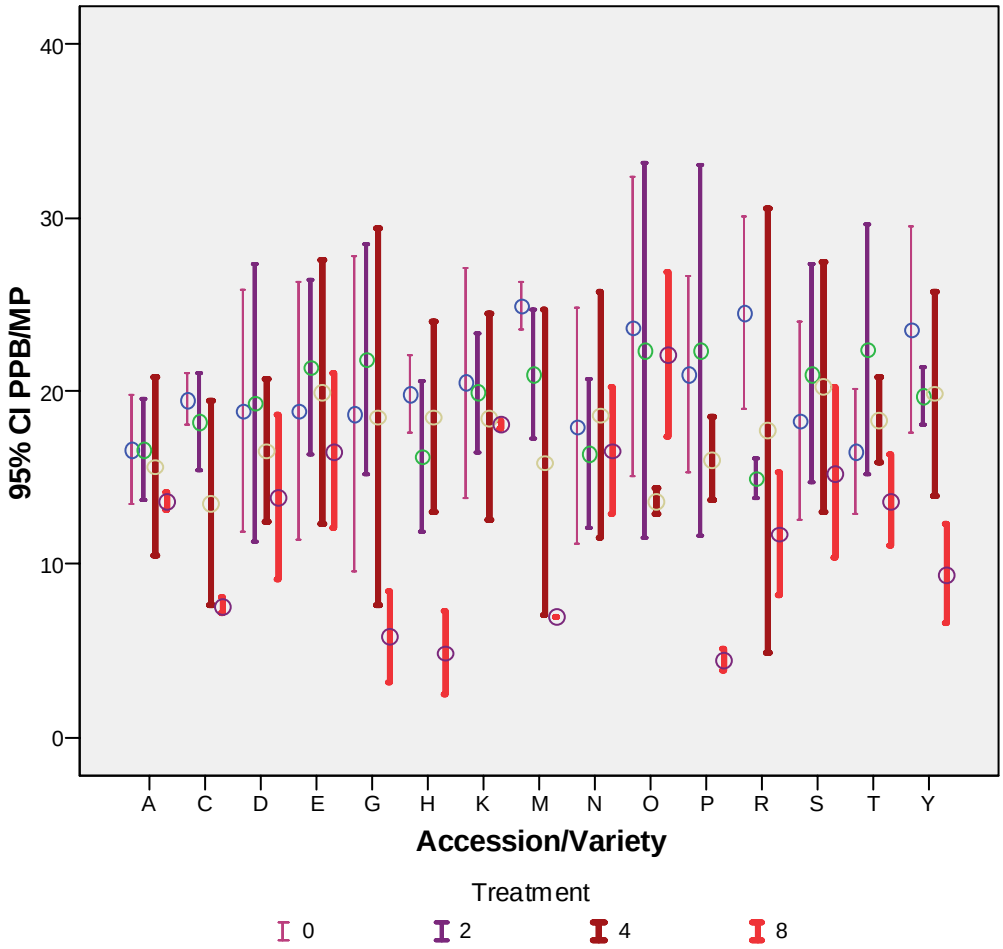

Fig. 3: Effects of salinity on the number of primary panicle branches per main panicle (PPB/MP) of tef [*Eragrostis tef* (Zucc.) Trotter] accessions and varieties. Key to accessions: A = 231217, C = 212611, E = 229747, G = 236514, H = 236512, M = 55017, N = 237186, O = 237131, R = 212928 and S = 205217; Key to varieties: D = DZ-01-196, K = DZ-Cr-37, P = DZ-01-1281, T = DZ-01-168 and Y = DZ-Cr-358)

intraspecifc variation was small unlike the case in accessions. Therefore, either this plant character is not good in screening tef varieties for salt tolerance or they don't have the genetic pool for the character vis-à-vis salt stress.

Number of Spikelcts per Main Panicle (SP/MP): The two ways ANOVA for both accessions/varieties and treatments with respect to number of spikelets per main panicle (SP/MP) was found to be significant ($p<0.001$). Furthermore, it was also significant for treatment*accession/variety interaction ($p<0.01$). Number of spikelets per main panicle (SP/MP) was stimulated at 2 dS/m in accession 229747; nevertheless, it was significantly affected at 4 and 8 dS/m and more profoundly at the latter treatment level. Consequently, this salinity level caused a reduction of SP/MP from 13.2-82.3% in accessions and 31.7-72.4% in varieties in comparison with the control. Similar results were reported in wheat (Dixit and Chen, 2010; Lesch *et al*., 1992; Maas and Grieve, 1990; Maas *et al*., 1996), rice (Grattan *et al*., 2002) and barely (Ahmad *et al*., 2003). Accessions 55017, 236512 and 236514 and variety DZ-Cr-358 were more affected and hence salt sensitive respectively. On the other hand, accessions 237186 and 202517 were salt tolerant. But no variety appeared tolerant (Fig. 4). With regard to SP/MP, accessions were equipped with broad degree of tolerance unlike varieties. Thus this plant character is efficient to screen accessions for salt tolerance.

Main Panicle Dry Weight (MPDW): The two ways ANOVA for both accessions/varieties and treatments with respect to Main Panicle Dry Weight (MPDW) was found

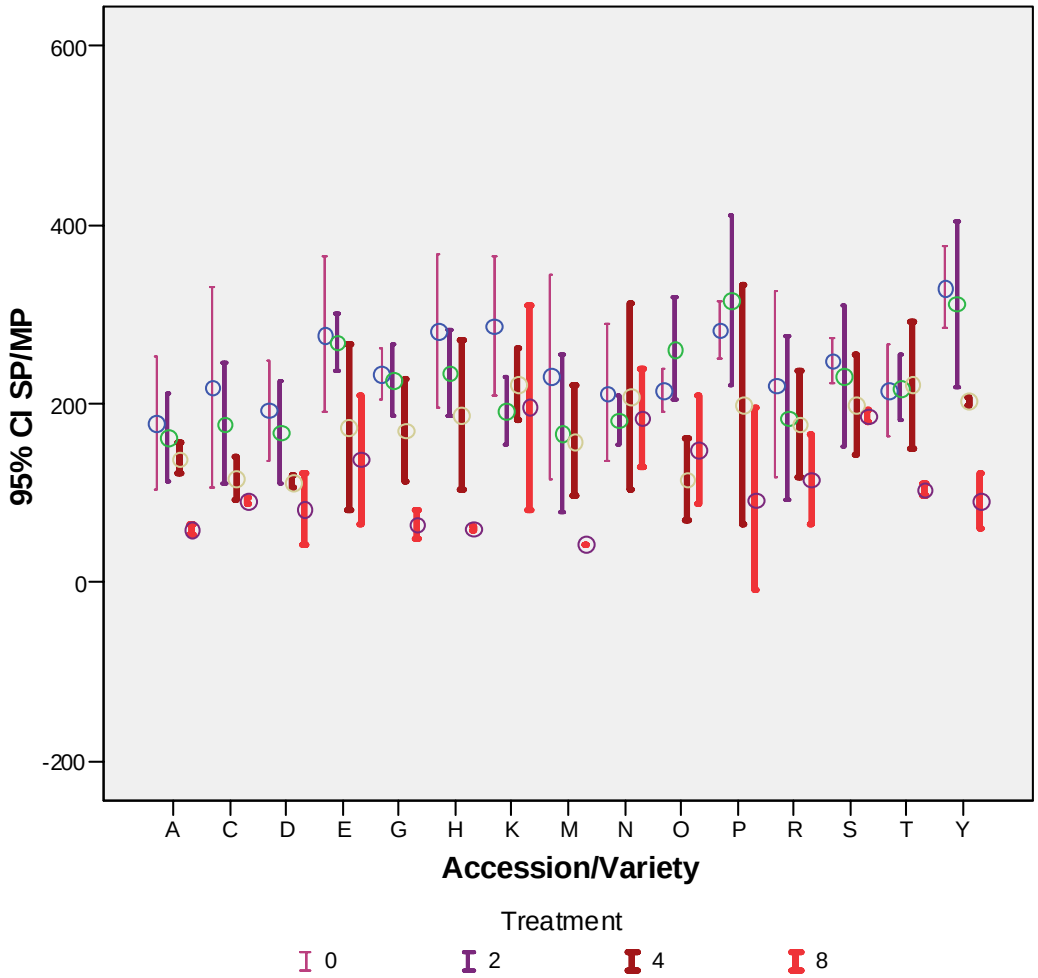

Fig. 4: Effects of salinity on number of spikelets per main panicle (SP/MP) of tef [*Eragrostis tef* (Zucc.) Trotter)] accessions and varieties. Key to accessions: A = 231217, C = 212611, E = 229747, G = 236514, H = 236512, M = 55017, N = 237186, O = 237131, R = 212928 and S = 205217; Key to varieties: D = DZ-01-196, K = DZ-Cr-37, P = DZ-01-1281, T = DZ-01-168 and Y = DZ-Cr-358)

to be significant ($p<0.001$). Moreover, it was also significant for treatment*accession/variety interaction ($p<0.001$). Main Panicle Dry Weight (MPDW) was stimulated in accessions 229747, 237131 and variety DZ-01-1281 at 2 dS/m as compared to the control. As the case in SP/MP it was affected at both 4dS/m and 8 dS/m but remarkably at the latter. Consequently, at this treatment level a reduction of 8.6-86.5% in accessions and 25.8-83.9% in varieties was noticed as compared to the control. This result is in agreement with reports in rye (Francois *et al*., 1989; Yildirim and Bahar, 2010). Notwithstanding, it is in contrast with report in triticale (Francois *et al*., 1988) where individual spike weight remained unaffected under salt treatment.

Accession 236514, variety DZ-01-1281, accession 236512, accession 212611 and variety DZ-01-1681 were salt sensitive respectively. On the other hand, accession 237186 and variety DZ-Cr-37 were salt tolerant genotypes. Furthermore, accessions 236514 and 237186 were the most salt sensitive and salt tolerant of all the genotypes investigated respectively. Unlike other yield attributes, MPDW differentiated both accessions and varieties into sensitive, intermediate and tolerant categories effectively (Fig. 5).

Grain Yield per Main Panicle (GY/MP): The two ways ANOVA for treatment*accession/variety interaction found to be insignificant ($p>0.05$). Nevertheless, it was significant for both accessions/varieties and treatments with respect to grain yield per main panicle (GY/MP) was found to be significant ($p<0.001$). In this study, yield was measured as grain yield per main panicle (GY/MP). It was

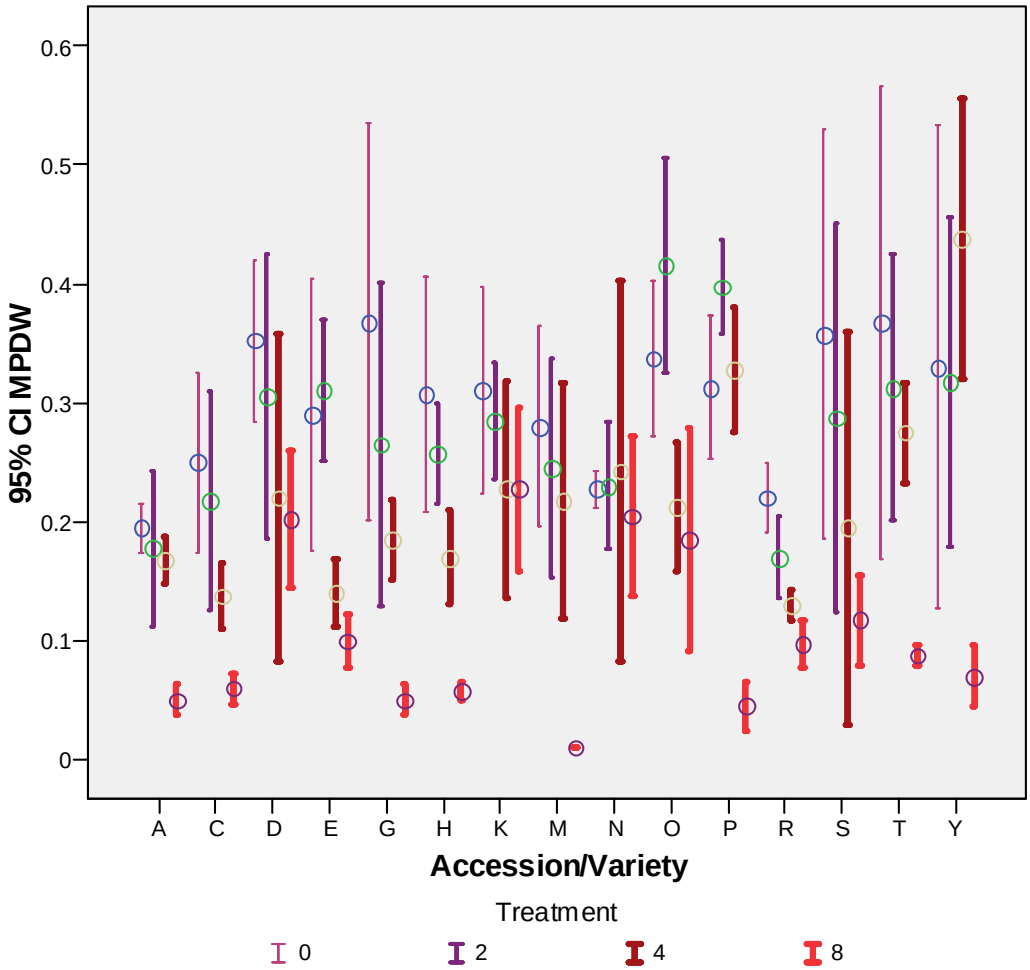

Fig. 5: Effects of salinity on main panicle dry weight (MPDW) of tef [*Eragrostis tef* (Zucc.) Trotter)] accessions and varieties. Key to accessions: A = 231217, C = 212611, E = 229747, G = 236514, H = 236512, M = 55017, N = 237186, O = 237131, R = 212928 and S = 205217; Key to varieties: D = DZ-01-196, K = DZ-Cr-37, P = DZ-01-1281, T = DZ-01-168 and Y = DZ-Cr-358)

stimulated at 2 dS/m in accessions 229747 and 237131 and variety DZ-Cr-37 and also at 4 dS/m in varieties DZ-Cr-358 and DZ-01-1281. This character was significantly reduced at 8dS/m especially in salt sensitive and salt intermediate varieties and accessions. Hence at 8 dS/m a reduction of GY/MP 33.3-93.3% in accessions and 31.6-89.5% in varieties was recorded in comparison with the control. This result comply with recent report in wheat (Bybordi, 2010; Dixit and Chen, 2010; Yildirim and Bahar, 2010).

Generally, disturbance of fertilization or blockage of assimilates translocation to seeds after fertilization would be a reason for reduced grain yield (Raptan *et al*., 2001). This in turn, may emanate mainly from osmotic effects of the salt and to a lesser extent from specific ion effects (Cerda *et al*., 1982). Moreover, reductions in Main Panicle Dry Weight (MPDW) and the number of spikelts per main panicle (SP/MP) contributed much for grain yield reduction per main panicle (GY/MP). Similarly, reductions in main spike weight in rye (Francois *et al*., 1992) and in spikelets number per main panicle in wheat (Grieve *et al*., 1992) had caused reduction in grain yield per spike.

Panicle length and primary panicle branches per main panicle (PPB/MP) also determined grains yield per main panicle through their influence on spikelet number per main panicle (SP/MP). Delayed days to maturity was also the reason for reduced grains yield per main panicle (Ahmed, 2009). Because as time of stress exposure increased, there would be entrance of more salt ions in to the plant (Dudeck *et al*., 1983) and this could affect different physiological processes; namely, nitrogen fixation (Jena and Rao, 1988), Water Use Efficiency (WUE) (Boland *et al*., 1993), mineral nutrient relations

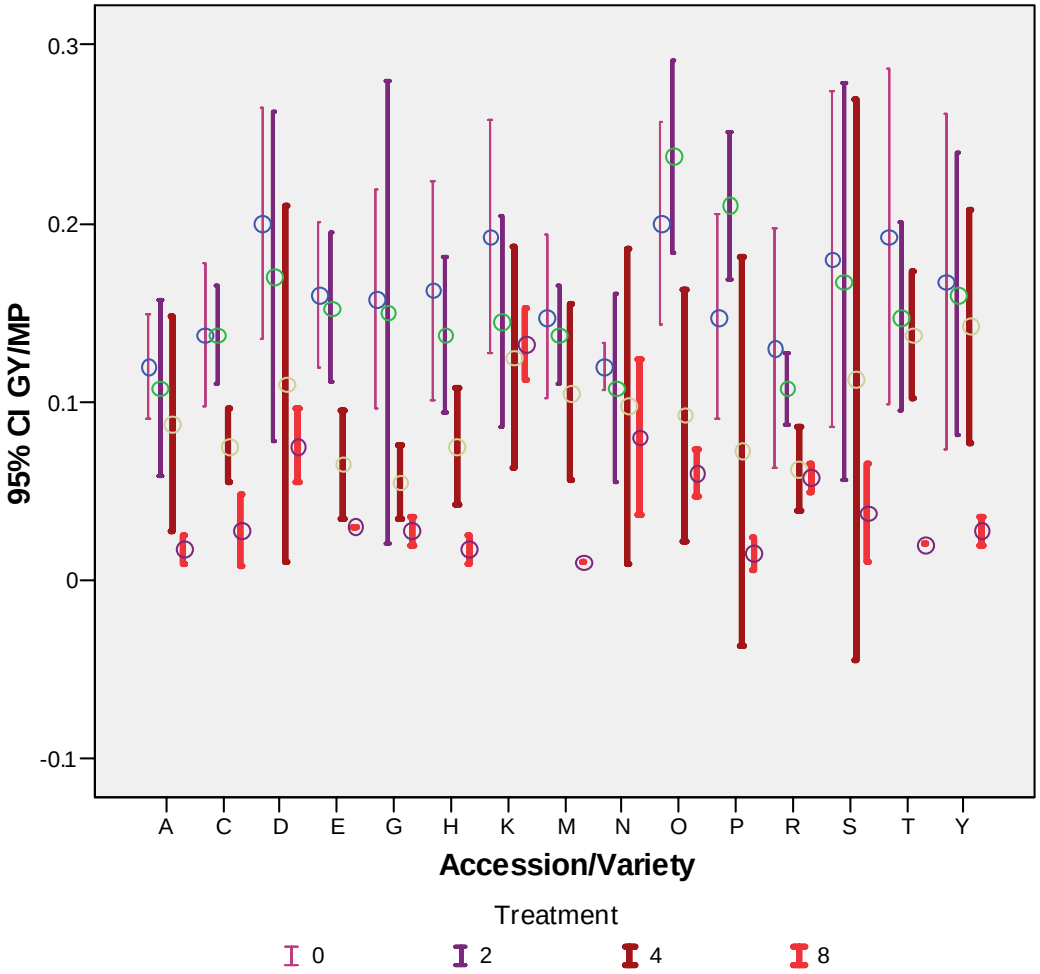

Fig. 6: Effects of salinity on grain yield per main panicle (GY/MP) of tef [*Eragrostis tef* (Zucc.) Trotter)] accessions and varieties. Key to accessions: A = 231217, C = 212611, E = 229747, G = 236514, H = 236512, M = 55017, N = 237186, O = 237131, R = 212928 and S = 205217; Key to varieties: D = DZ-01-196, K = DZ-Cr-37, P = DZ-01-1281, T = DZ-01-168 and Y = DZ-Cr-358)

(Hagemeyer, 1997) transpiration and chlorophyll content (Jin-Woong and Choong-Soo, 1998), membrane permeability (Kubran *et al*., 1998), respiration (Chen *et al*., 1999), leaf turgor pressure (Pardossi *et al*., 1999) and photosynthesis (Wang *et al*., 1999). The cumulative effect of all these impairments would result in deteriorated growth and grain yield. Furthermore, tolerant genotypes could tolerate these disturbances by storing organic solutes in the cytoplasm in the expense of growth because such osmotic adjustment is metabolically active. Thus eventually, this would lead to minimized grain yield (Rogers *et al*., 1993).

Moreover, accession 55017, variety DZ-01-1681, accession 236512, variety DZ-01-281, accession 231217, variety DZ-Cr-358, accessions 229747, 236514, 212611, 202517 were salt sensitive respectively. Accession 212928 that was unable to germinate and grow on two blocks found to be intermediate in terms of grain yield per main panicle. This implies that plant survival is not a reason for grain yield reduction. It is in conformity with early reports in kenaf (Francois *et al*., 1992). Accession 237186 and variety DZ-Cr-37 were relatively the most salt tolerant of all the genotypes investigated (Fig. 6). The yield in both genotypes was satisfying where more than 30% reduction was recorded as compared to the control. The reduction might be due to the fact that they could have used osmotic adjustment by storing organic solutes that is metabolically active and happened in the expense of growth (Läuchili, 1984).

Even if, their yield was not promising, these two genotypes displayed extremely significant variation of 60 and 55.1% from their salt sensitive accession and variety. This extremely significant difference between tolerant and sensitive accessions and varieties in their grain yield

indicated that variation in germination, vegetative growth, days to heading, grain filling and maturity as well as dry matter production responses to salinity were carried over to the mature plant effectively. Contrary to this, Hunt (1965) found that relative yield of tolerant intermediate wheatgrass genotypes (63.1%) was not remarkably different from the non-tolerant ones (61.9%). Hence, he concluded that the main reason was the lacks of response carry over, from seedling stage to mature plant.

As realized from these figures, salinity is a threat to tef production; especially, for country like Ethiopia, where *Eragrostis tef* is the source of staple food ('injera') and covering most proportion of cultivated lands in the country. Thus it is really a hovering problem to Ethiopia.

In accessions at low and moderate salinity levels, the highest yield was obtained from genotypes that secured maximum yield at the highest salt concentration (8 dS/m). It is in agreement with previous report in *Trifolium repens* (Rogers *et al*., 1993). Nevertheless, in varieties those genotypes that attained the highest grain yield at the control also secured highest grain yield at the highest salt concentration in general. This character also differentiated both accessions and varieties into sensitive, intermediate, and tolerant categories even more efficiently than MPDW.

CONCLUSION

At 2 dS/m some accessions and varieties showed enhanced growth with respect to most yield and yield component characters; however, at 16 dS/m all accessions and varieties found to be salt sensitive with regard to all the yield and yield component parameters. Accession 236514, varieties DZ-Cr-358 and DZ-01-1681 were salt sensitive whereas accession 237186 and variety DZ-Cr-37 salt tolerant genotypes. Grain yield per main panicle (GY/MP) was the most salt affected character as compared to the rest yield and yield component characters. In general, accessions showed broad gene pool for salt tolerance in comparison with varieties with respect to yield and yield component characters. Irrespective of salinity being a growing problem in Ethiopia in general and the Awash valley in particular, only little has been done on crops salt tolerance. Therefore, to alleviate the already existing and the incoming salinity problem, there should be similar and profound studies on tef and other crops.

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