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Response of the Vegetative Growth of tef [*Eragrostis tef* (Zucc.)Trotter] Accessions and Varieties to Soil Salinity

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Abstract: This study aimed to screen fifteen low land tef genotypes (10 accessions and 5 varieties) during vegetative growth at 0 dS/m (control), 2, 4, 8 and 16 dS/m. Data analysis was carried out using SAS package (SAS version 8.2, 2001) and SPSS version 12. The two ways ANOVA showed significant variation for both accessions/varieties ($p<0.01$) and treatment ($p<0.001$) with respect to Plant Height During Heading (PHDH), Plant Height at Harvest (PHAH), Culm Length Per plant (CLE), Culm Diameter per plant (CDI) and Root Length per plant (RLE). On the other hand, the ANOVAforaccession/variety*treatment interaction was significant for CLE and RLE ($p<0.001$) and PHDH ($p<0.01$). This implies that all the accessions and varieties respond to salinity stress differently with respect to these three vegetative growth characters. However, the ANOVA for the accession/variety*treatment interaction for the rest characters was insignificant reflecting that the entire varieties and accessions react to salinity stress similarly. Accessions 205217, 55017, 231217 and variety DZ-Cr-358 were salt sensitive genotypes whereas accessions 237186, 212928 and variety DZ-Cr-37 were salt tolerant genotypes of all. Plant Height During Heading (PHDH) and Culm Diameter per plant (CDI) were the most and the least salt affected vegetative growth characters respectively. Generally, the study revealed the presence of broad intraspecific genetic variation in tef accessions and varieties for salt tolerance but more in the former.

Key words: Culm diameter, flag leaf, harvest, plant height, root length, salinity

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) 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 4000 ha 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 Minhas, 1993; Marler and Mickelbart, 1993). Since environmental management (physical approach) is not economically feasible (El-Khashab *et al.*, 1997) there is a need to concentrate on the biological approach or crop management (Ashraf and McNeilly, 1988; Ashraf *et al.*,

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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) hectares of land which is 28.5 and 28.4 percent 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 study attempted to screen fifteen genotypes (10 accessions and 5 varieties) of tef [*Eragrostis tef* (Zucc.) Trotter] during vegetative growth.

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 MARC at a depth of 0-20 cm and analyzed profoundly at the National Soil Testing Center (NSTC). 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 gm soil. 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 22.08^{0}C, 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 (if any). Distilled water was applied as often as necessary. The leachate was collected on the dishes and returned to the pot. In the meantime, Flag Leaf Length (FLL), Plant Height During Heading (PHDH), Plant Height at Harvest (PHAH), Culm Length per plant (CLE), Culm Diameter per plant (CDI) were measured. At maturity, plants were harvested by cutting at the soil surface using a cutter. The roots were uprooted after the soil has been dissolved completely. Roots were washed and rinsed several times and then Root Length per plant (RLE) was measured.

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

Plant Height During Heading (PHDH): The two ways ANOVA found to be significant with respect to Plant Height During Heading (PHDH) for both accessions/varieties (p<0.01) and treatments (p<0.001). Moreover, it was also significant for treatment*accession/variety interaction (p<0.01). As compared to the control, average PHDH was stimulated at 2 dS/m in accession 237186. It has been influenced at each treatment level but significant reduction was recorded at 8dS/m. A reduction of 18.9-75.9% in accessions and 39-74.7 % in varieties was evident. Accessions 205217, 55017 and 236512 and variety DZ-01-1281 were the most salt affected whereas accessions 237131 and 237186 were the least salt affected genotypes at 8 dS/m salinity level. Furthermore, accessions 205217 and 237186 were the most salt sensitive and salt tolerant accessions of all genotypes respectively (Fig. 1). Most varieties appeared intermediate in their salt tolerance and no variety managed to be salt tolerant with respect to PHDH..

Plant Height at Harvest (PHAH): The two ways ANOVA found to be significant with respect to Plant Height at Harvest (PHAH) for both accessions/varieties ($p<0.01$) and treatments ($p<0.001$). However, it was insignificant for treatment*accession/variety interaction ($p>0.05$). Plant Height at Harvest (PHAH) was affected by each and every treatment level especially in sensitive and moderate accessions and varieties. Furthermore, the effect was more pronounced at 8dS/m and at this treatment level a reduction of 18.6-69% in accessions and 29.8-56.5% in varieties was recorded. In comparison with the rest, accession 55017 was the most salt affected genotype but accessions 237186 and 237131 were the least salt affected ones. Accession 237186 was the most salt tolerant of all accessions and varieties taken into consideration. No variety happened sensitive or tolerant, all were intermediate.

In terms of PHDH and PHAH, both the most and the least salt affected genotypes occurred in accessions. This reflects that accessions were endowed with a broad range of salt tolerance unlike varieties provided that the latter

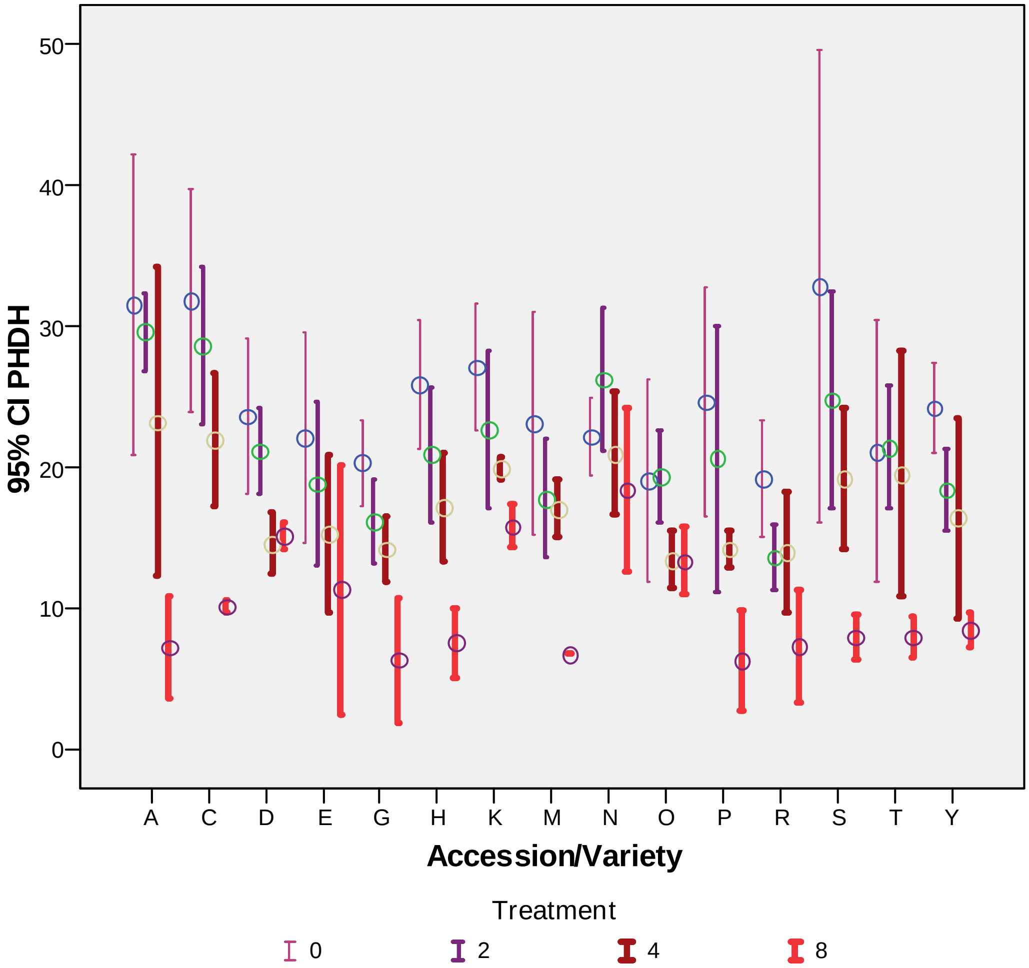

Fig. 1: Effects of salinity on Plant Height During Heading (PHDH) of tef [*Eragrostis tef* (Zucc.) Trotter)] accessions and varieties, Key to accessions: A = 231217, C = 212611, E = 229747, G = 236514, H = 236512, M = 55017, N = 237186, O = 237131, R = 212928 and S = 205217; Key to varieties: D = DZ-01-196,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

are only half of the former in terms of their quantity in this study. Furthermore, accession 237186 was the most salt tolerant of all accessions and varieties. This affirms that its salt tolerance is not due to simple plant vigor rather owing to its ability to regulate the osmotic and/or toxic effects of NaCl efficiently and effectively. Similar results were reported for soybean (Abel and Mackenize, 1964), sorghum (Azhar and McNeilly, 1989), perennial ryegrass (Horst and Dunning, 1989), alfalfa (Al-Neimi *et al*., 1992), chickpea, lentil, durum wheat and tef (Mamo *et al*., 1996), cowpea (Murillo-Amador and Troyo-Die'guez, 2000) and tomato (Agong *et al*., 2003).

In both accessions and varieties of tef, plant height was comparatively more salt sensitive during heading than at harvest. This may be due to the fact that accessions and varieties could not be able to develop a mechanism to combat effects of salinity during heading due to time factor. That is, plants need enough time to develop mechanisms that enable them to regulate the mechanism to combat effects of salinity during heading due to time factor. That is, plants need enough time to develop mechanisms that enable them to regulate the internal Cl^- and Na^+ concentrations effectively (Bolarin *et al*., 1993). That is why presalinized soil profile poses only little impact on growth and development of plants(Francois *et al*., 1986, 1988). Nevertheless, it opposes the finding of Dua (1992) where he reported that salt sensitivity of chickpea genotypes increased along with salinity level and plant growth advance

Culm Length per Plant (CLE): The two ways ANOVA found to be significant with respect to Culm Length per plant (CLE) for both accessions/varieties ($p<0.01$) and

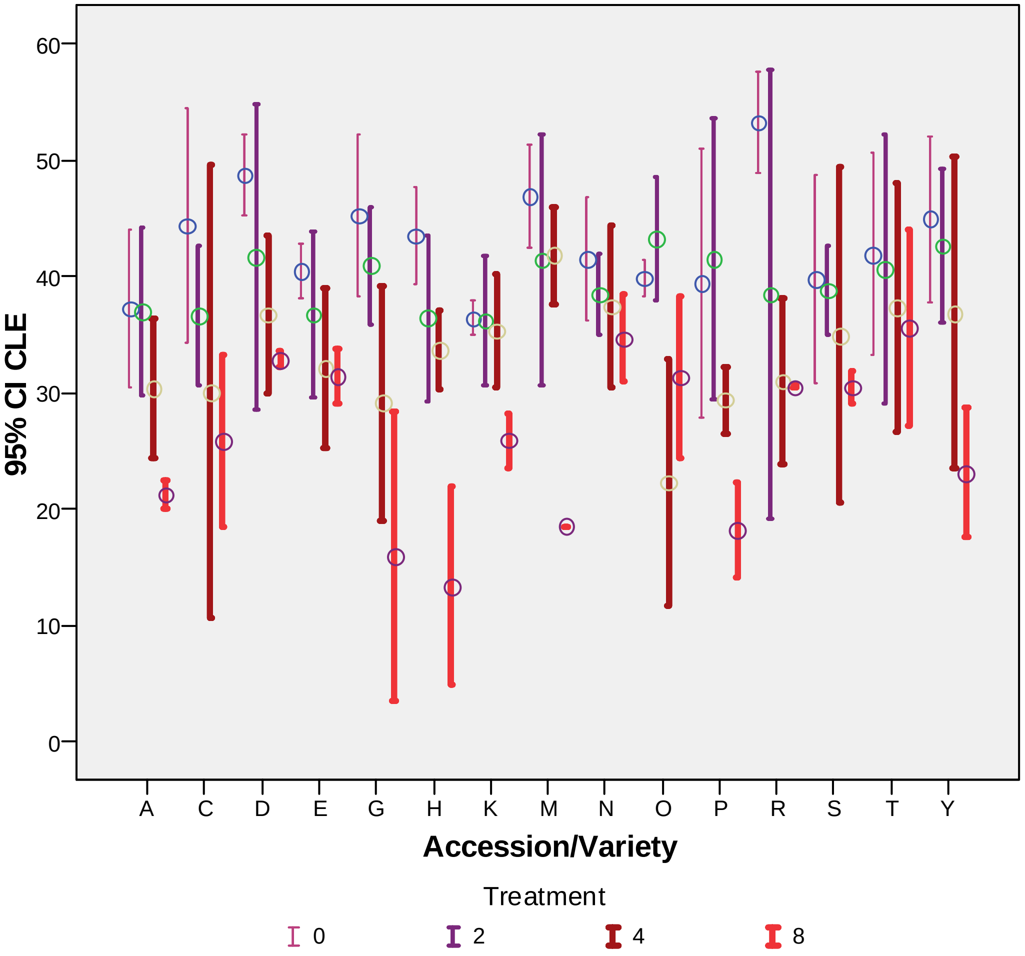

Fig. 2: Effects of salinity on Culm Length per plant (CLE) of tef [*Eragrostis tef* (Zucc.) Trotter)] accessions and varieties, Key to accessions: A = 231217, C = 212611, E = 229747, G = 236514, H = 236512, M = 55017, N = 237186, O = 237131, R = 212928 and S = 205217; Key to varieties: D = DZ-01-196,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

treatments (p<0.001). Furthermore, it was also significant for treatment*accession/variety interaction (p<0.01). Culm length was stimulated at 2 dS/m in accession 237131 and variety DZ-01-1281 in comparison with the control. This character was affected by each salinity level and was significant at 8dS/m particularly in salt sensitive accessions and varieties. At the highest treatment level, a reduction of 16.4-77% in accession and 15.3-53.8% in varieties was obtained. Accession 236512 was the most salt affected genotype whereas accessions 237186, 237131, 202517 and 229747 and varieties DZ-01-1681 and DZ-Cr-37 were the least salt affected genotypes. Variety DZ-01-1681 and accessions 237186, 205217 and 229747 were the most salt tolerant of all genotypes (Fig.2).

Culm Diameter per Plant (CDI): The two ways ANOVA found to be significant with respect to Culm Diameter per plant (CDI) for both accessions/varieties (p<0.01) and treatments (p<0.001). However, it was insignificant for treatment*accession/variety interaction (p>0.05). Culm Diameter (CDI) was stimulated at 2 dS/m in accessions 236512 and 237186 and variety DZ-01-1281. This character was not significantly influenced at 2 and 4 dS/m; nevertheless, it was strongly salt affected at 8 dS/m. At this treatment level, a reduction of 25-56.3 and 21.4-46% in accessions and varieties was recorded respectively. Nevertheless, CDI showed no variation from its control value in accession 237186. Thus this accession was the most salt tolerant of all accessions and varieties under consideration; moreover, variety DZ-Cr-37 and

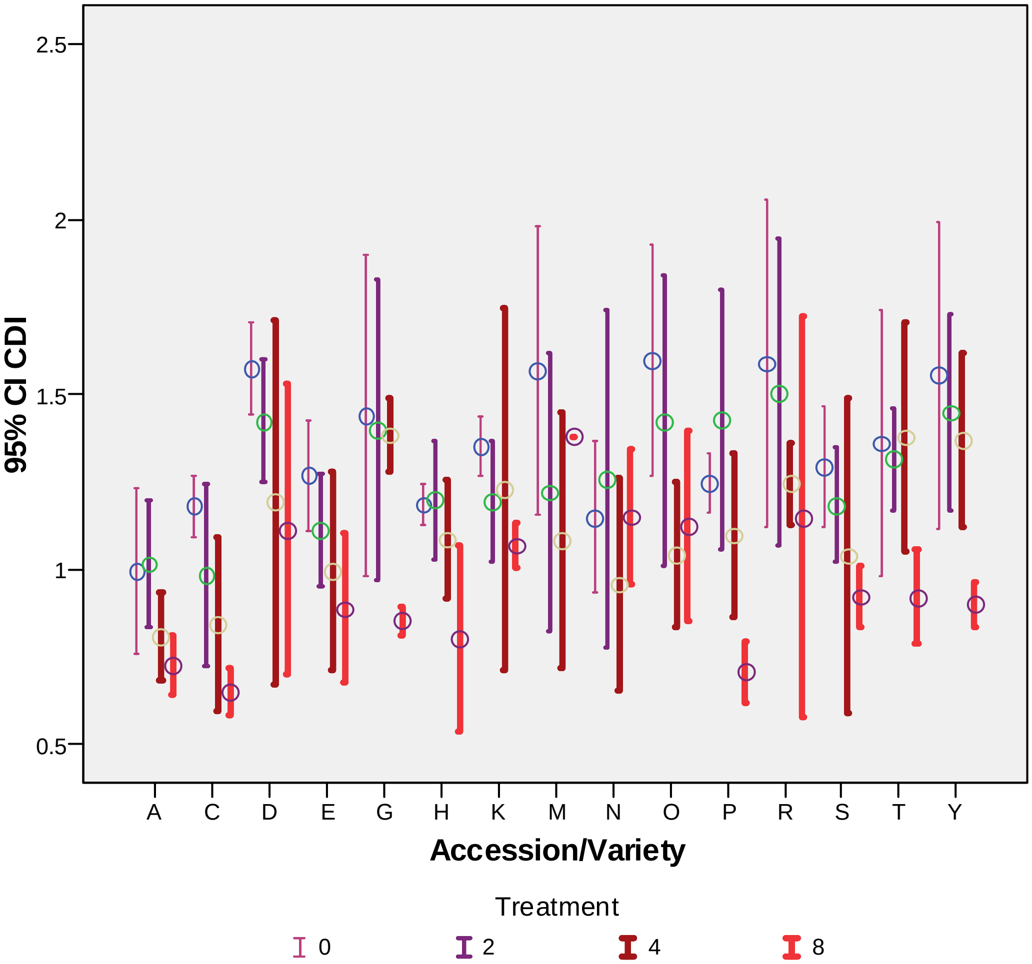

Fig. 3: Effects of salinity on Culm Diameter per plant (CDI) of tef [*Eragrostis tef* (Zucc.) Trotter)] accessions and varieties, Key to accessions: A = 231217, C = 212611, E = 229747, G = 236514, H = 236512, M = 55017, N = 237186, O = 237131, R = 212928 and S = 205217; Key to varieties: D = DZ-01-196,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

accession 212611 were also salt tolerant. No variety as well as accession appeared salt sensitive with respect to CDI (Fig. 3). Thus no pronounced intraspecific variation was observed. Hence culm diameter was not a good parameter to screen tef accessions and varieties for salt tolerance. It is in conformity with similar finding reported in Kenaf (Francois *et al*., 1992).

Reduction in plant height (PHDH, PHAH and CLE) and thickness (CDI) means, reduction in assimilates reserve and relative water content. Furthermore, the resulting low demand for assimilates would indirectly decrease source strength (Grieve *et al*., 1992). Consequently, roots would receive only limited amount of photosynthates. But it is reported that effective translocation of assimilates from shoots to roots; lead to elaborate root growth under salt stress (Agong *et al*., 2003). Such aggressive root growths in turn would enable plants to tolerate osmotic and nutritional stress (Dudeck *et al*., 1983). More over, facilitated growths could dilute the toxic effects of salt ions through their increased water content (Lee and Senadhira, 1998).

However, in the absence of efficient photosynthates translocation, facilitated roots and shoots growth; the excess Na^+ and Cl^- would interfere with different biochemical processes (Jena and Rao, 1988; Yang *et al*., 1990) and also cause membrane damage (Rogers and Noble, 1991). Furthermore, unlike shoots; roots have only limited ability to act as reservoir of excess salt ions (Boursier and Lauchli, 1992). Consequently, roots would be more affected by salt ions than other plant parts (Papadopoulos and Rendig, 1983). Therefore, once roots are affected seriously, they could not absorb water and nutrients affectively. In turn, this would cause scarce supply of needed substances to shoots and leaves.

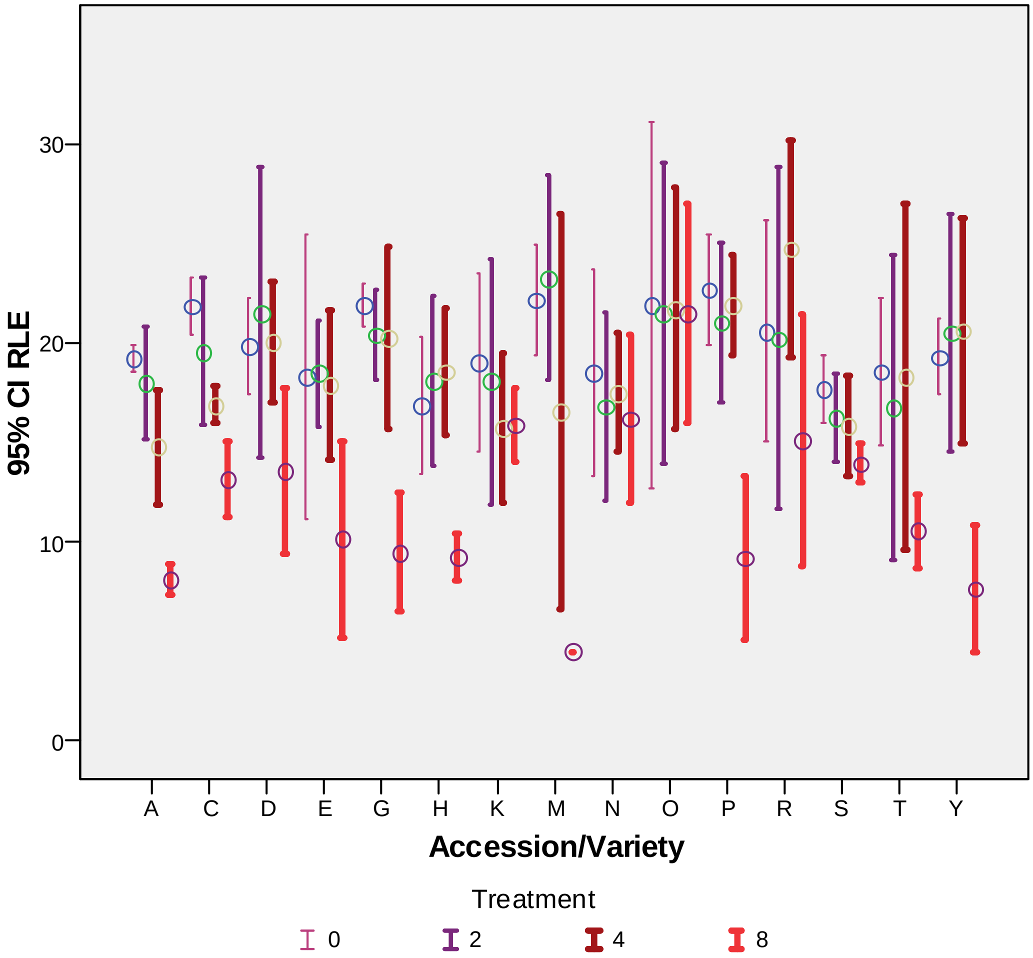

Fig. 4: Effects of salinity on Root Length per plant (RLE) of tef [*Eragrostis tef* (Zucc.) Trotter)] accessions and varieties, Key to accessions: A = 231217, C = 212611, E = 229747, G = 236514, H = 236512, M = 55017, N = 237186, O = 237131, R = 212928 and S = 205217; Key to varieties: D = DZ-01-196,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

Eventually, as a cumulative effect of all the above disturbances and constraints, growth and yield would be deteriorated and even inhibited.

Root Length per Plant (RLE): The two ways of ANOVA found to be significant with respect to Root Length per plant (RLE) for treatment*accession/variety interaction (p<0.01). Moreover, it was also significant for both accessions/varieties (p<0.01) and treatments (p<0.001). Root Length per plant (RLE) was affected more or less similarly by 2 and 4 dS/m treatment levels and there was no significant effect even on the salt sensitive genotypes. It was stimulated at 2 dS/m in accession 55017 and variety DZ-01-196 and at both 2 and 4 dS/m in accession 212928 and variety DZ-Cr-358. Generally, root length was stimulated at intermediate salinity levels. Similar results were reported in Bermuda grasses, manila grasses and seashore paspalum (Marcum and Murdoch, 1990). This is a mechanism that enables them to efficiently absorb water and nutrients from the ground, and consequently get rid of the osmotic effect of NaCl. However, root length was significantly influenced at 8 dS/m especially in salt sensitive accessions and varieties As a result, a reduction of 13.5-79.6% and 41.1-75.3% in accessions and varieties respectively was recorded as compared to the control. Even at this highest salinity level, RLE was stimulated in accession 237131, so it was the most salt tolerant of all genotypes under investigation. Moreover, accession 237186, variety DZ-Cr-37, accessions 205217 and 212928 as well as variety DZ-01-196 were the least salt affected genotypes (Fig. 4). Similar findings were reported in perennial ryegrass (Horst and Dunning, 1989) and cotton (Lin *et al*., 1997). The root is responsible to supply water, ions and nutrients to the shoots. As the root length decreased, its surface area also minimized. This caused reduced absorption of

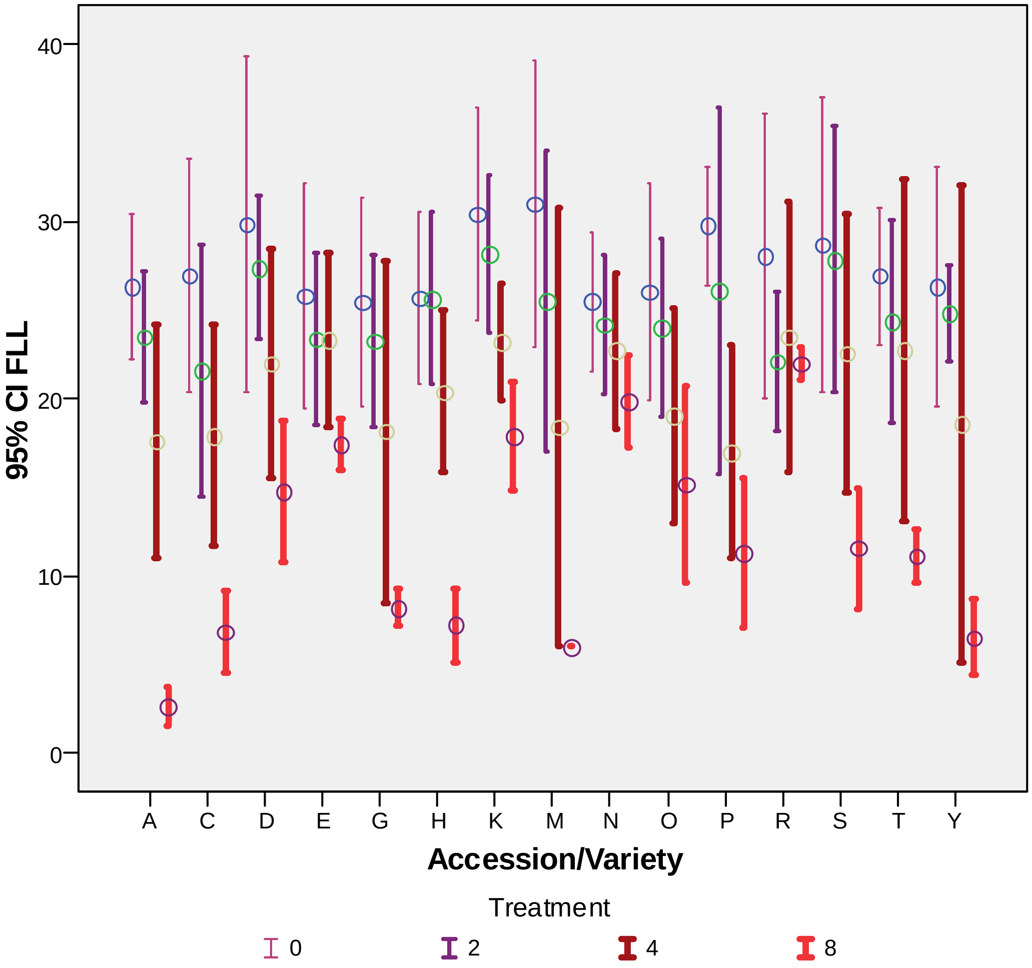

Fig. 5: Effects of salinity on Flag Leaf Length per plant (FLL) of tef [*Eragrostis tef* (Zucc.) Trotter)] accessions and varieties, Key to accessions: A = 231217, C = 212611, E = 229747, G = 236514, H = 236512, M = 55017, N = 237186, O = 237131, R = 212928 and S = 205217; Key to varieties: D = DZ-01-196,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

the substances and in turn, shoot and leaves will receive reduced quantity of ions, nutrients and water. Consequently, there would be reduced plant growth, development and economic yield. Root mass was also reduced by salt stress especially at 8 dS/m. The reduction was remarkable in sensitive genotypes than in intermediate and tolerant ones. As the case in plant height, salt sensitive and the most salt tolerant genotypes were found in accessions rather than in varieties. This also reflects the presence of broad gene pool within accessions for salt tolerance unlike varieties.

It has been reported that tef has shallow root system (Gorham and Hardy, 1990) and grows 2-8 cm (Ebba, 1975). Nevertheless, in this work a contrasting result was obtained. That is, on average roots grew 19.9, 19.5, 18.7 and 12.5 cm at 0 dS/m (control), 2, 4 and 8 dS/m salinity levels respectively. Moreover, in variety DZ-Cr-37 on one block on the control, a root length of 45 cm was identified. The variation between the result of this work and the previous reports could probably emanate from the difference in uprooting techniques and/or the substrate on which it had grown (pots or field)

Flag Leaf Length per Plant (FLL): The two ways of ANOVA found to be significant with respect to Flag Leaf Length per plant (FLL) for treatments ($p<0.001$). However, it was insignificant for both treatment* accession/variety interaction and accessions/varieties ($p>0.05$). This character was recorded at full heading. It was affected by every salinity level. The impact became pronounced at 8dS/m and this level caused a reduction of 21.1-90.2% in accessions and 41.1-75.3% in varieties as compared to the control. Accessions 231217, 55017, 212611 and 236512 and variety DZ-Cr-358 were the most susceptible whereas accessions 212928 and 237186 were least salt affected genotypes. No variety happened salt tolerant with respect to FLL (Fig. 5). From all genotypes investigated, accessions 231217 and 212928 were the most salt sensitive and salt tolerant of all genotypes respectively. This result also confirms the presence of broad range of salt tolerance among accessions unlike varieties.

Reduction in leaf length could cause disruption of different biochemical reactions taking place within the leaf such as photosynthesis (Jeffries and Rudmik, 1984). In turn, reduction in photosynthesis would lead to reduction in growth and yield of the crop. Accession 212928 had failed to germinate and/or establish on two of the entire four blocks at 8 dS/m. In this respect it seems sensitive; however, with regard to flag leaf length; it was the most salt tolerant of all. The former might be due to its poor seedling emergence and vigor that could limit its establishment. Similarly, Rogers and Noble (1991) found that balansa clover which had poor seedling emergence and vigor, become more tolerant than subterranean clover which had better seedling emergence and vigor.

CONCLUSION

In comparison with the control, 2 dS/m salinity level enhanced growth with respect to most vegetative growth characters in some accessions and varieties; however, at 16dS/m all accessions and varieties found to be salt sensitive with regard to all vegetative growth parameters. Accessions 205217, 55017, 231217 and variety DZ-Cr-358 were salt sensitive whereas accessions 237186, 212928 and variety DZ-Cr-37 were salt tolerant of all the genotypes studied. Plant height during heading (PHDH) was the most salt affected whereas Culm Diameter per plant (CDI) was the least salt affected vegetative growth characters. The sensitivity of vegetative growth characters could be expressed as PHDH> FLL>PHDM>CLE > RLE> CDI in decreasing order of sensitivity. In general, accessions showed broad gene pool for salt tolerance in comparison with varieties with respect to vegetative growth characters.

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