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GENOTYPIC VARIABILITY IN DRY MATTER PRODUCTION, PARTITIONING AND GRAIN YIELD OF TEF [*ERAGROSTIS TEF* (ZUCC.) TROTTER] UNDER MOISTURE DEFICIT

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ABSTRACT: The response of fifteen diverse genotypes of pot grown tef [*Eragrostis tef* (Zucc.) Trotter] to two levels of moisture treatment (non-stressed and stressed) were investigated under greenhouse conditions. Moisture deficit generally resulted in a reduction in dry weight of individual plant parts, plant height and number of tillers, but increased dry matter partitioning [leaf weight ratio (LWR) and stem weight ratio (SWR)] except root shoot ratio (RSR). Genotypic variability was observed in the results from the moisture deficit treatments for grain yield, harvest index, panicle dry weight and panicle length. These values were markedly reduced by moisture deficit in all genotypes, except harvest index which increased in three of the genotypes studied. The genotypes Fesho, Gea-Lemi and Shewa-Gimira performed better than the rest while Gorradie, Goffarie and Key murrie were poor performers.

Key words/phrases: *Eragrostis tef*, **genotypic variability, harvest index, moisture deficit**

INTRODUCTION

In most cropping situations, soil moisture deficits develop as a result of low and/or poor distribution of rainfall and very high mean temperature, which cause high evapotranspiration (Kaufmann, 1981). This situation is a common occurrence, particularly in semi-arid regions of the world. Even in humid wet regions an unusual dry period can cause soil moisture deficits.

Soil moisture deficit causes a general reduction in plant growth and grain yield. One of the most important consequences of moisture deficit is a marked reduction in leaf area, through its effect on the initiation of new leaves and/or accelerated leaf drops. In tef [*Eragrostis tef* (Zucc.) Trotter] the most obvious morphological change following moisture deficit was a reduction in leaf area, through reduction in leaf size rather than any shedding or death of leaves (Belay Shiferaw and Baker, 1996). Moisture deficits also inhibit the initiation and growth of productive tillers in plants of the grass family (Clark and Durely, 1981). A 30% reduction in the number of tillers has also been reported in tef (Belay Shiferaw and Baker, 1996). Such effects lead to reduced herbage production in the case of forage crops or to a loss of seed yields in cereals.

In most parts of Ethiopia, tef is grown under non-irrigated conditions during both the main (June-September) and small (February-May) rainy seasons. As a result the crop is frequently subjected to soil moisture deficits which are of sufficient intensity and duration to reduce yield. It is well documented that considerable variation in drought tolerance exists between and within species (Fischer and Maurer, 1978; Blum, 1989). Belay Shiferaw and Baker (1996) reported variation between tef cultivars for agronomic and morphological traits in response to moisture deficits, indicating the possibility of improving the productivity of tef. Thus, the breeding of drought resistant tef genotypes should be an important issue, particularly for areas where moisture deficit is a common occurrence.

A successful effort to improve the drought resistance of tef through plant breeding techniques requires screening of a wide number of varieties and hybrids for yielding ability under field conditions. However, since evaluation is done under field conditions and only in years when rainfall is scant, such a procedure is not always convenient and efficient. An alternative approach is often to simulate the field condition in pot experiments or controlled environments. Results of such procedures may be difficult to extrapolate to field conditions, but still provide information on the responses of crop plants to the effects of moisture deficits. The present investigation was, therefore, carried out under glasshouse conditions to identify traits related to growth and yield under soil moisture deficits, and to evaluate genotypes of tef for drought tolerance.

MATERIALS AND METHODS

The experiments were carried out under glasshouse conditions at Holetta Research Centre, Ethiopia, between February and May, 1994. Mean maximum and minimum temperatures inside the glasshouse during the study period were 27° C and 11° C, respectively. Mean relative humidity was 55%. Fifteen diverse genotypes of tef were obtained from the Tef Improvement Program, at Holetta Research Centre. Seeds of each genotypes were sown in plastic pots, each 31 cm deep with an internal diameter of 14 cm. About 2 kg of black clay soil was used for each pot. Emergence occurred 4-5 days after planting (DAP) and all treatments were watered up to 15 DAP to ensure seedling establishment. Ten days after emergence, the pots were thinned to five plants per pot. Fifteen days after emergence, the plants were subjected to either control treatment (well watered frequently to avoid the development of a moisture deficit) or moisture deficit [where plants were under progressive stress until symptoms of stress were observed (wilting and curling of leaves)].

Visual rating systems are used extensively in drought resistance studies of cereal crops (Rosenow *et al.*, 1983; Willman *et al.*, 1987; Rosenow, 1993). Hence, in this study moisture deficit was imposed by withholding water through visual aid. When symptoms of moisture deficit on plants were observed, the stress treated plants were rewatered for five days until they were relieved from symptoms of stress.

Measurements

At maturity, each plant part (leaf, stem, panicle and roots) was harvested separately. Roots were washed free of soil. Each plant part was oven dried at 70° C for 24 h before weighing. From these measurements estimates of leaf weight ratio (LWR), stem weight ratio (SWR), root shoot ratio (RSR) and harvest index (HI) were computed. Plant height was measured from the soil surface to the tip. Panicle length was also measured from the panicle node to the tip. Individual analysis of variance was conducted for each character. To test overall differences among the various treatment means in the analysis of variance table, the F-ratio was used. To perform a pair-wise comparison of all treatment means, one of the multiple range tests, Least Significant Difference (LSD) was also used. Simple correlations were calculated between grain yield and selected parameters across genotypes in the moisture deficit treatment.

RESULTS AND DISCUSSION

The effects of moisture deficit on dry matter accumulation, partitioning and growth of tef

Generally, there was a reduction in dry matter accumulation and growth, except in dry matter partitioning (Table 1). Under stress conditions, root, panicle, total and stem dry weights, in their chronological order, had significantly greater percent reduction relative to other parameters. Root and panicle dry weights were reduced by moisture deficit to 36.08 and 41.44%, respectively, as compared with the control. Total and stem dry weights of stressed plants were also reduced to 46.23 and 50.79%, respectively as compared with the control plants. Leaf dry weight (g/plant), plant height (cm/plant), number of tillers/plant and RSR, were less affected by the moisture deficit. Leaf dry weight and plant height were reduced by moisture deficit only to 81.08 and 77.89%, respectively, of the control. Under the stress conditions, number of tillers and RSR were also reduced to 77.45 and 72.73%, respectively, of the control. This indicates that these parameters were less sensitive to the stress conditions compared with the other parameters considered in this study. The observed reduction in dry matter accumulation, partitioning and growth are typical responses of crop plants when subjected to moisture deficit (Kramer, 1983). However, the reduction observed in the present study was greater than that reported by Belay Shiferaw and Baker (1996). This probably reflects that this study was carried out in pots under glasshouse conditions which induce the development of moisture stress faster than in field conditions. In contrast, moisture deficits caused a significant increase in LWR and SWR. LWR of the stressed plants increased to 142.86% of the control whereas the increase in SWR was only 8.57%. The observed increase in the LWR and SWR of stressed plants, which represents the fraction of the total dry weight distributed to the leaf and stem development (Scott and Batchelor, 1979), may reflect the ability of tef to recover from stress upon rewatering and to continue vegetative growth.

Table 1. Effect of moisture deficit on dry matter accumulation, partitioning and growth of tef. (Values are means of fifteen varieties described in Table 2.)

	Non-stressed	Stressed	Relative (% control)
Dry weights (g/plant)			
leaf	0.37	0.30	81.08
stem	1.89	0.96	50.79
panicle	2.22	0.92	41.44
root	0.97	0.35	36.08
total	5.45	2.52	46.23
Dry weight partitioning			
LWR	0.07	0.17	142.00
SWR	0.35	0.38	108.57
RSR	0.22	0.16	72.73
Growth			
plant height (cm/plant)	119.48	93.06	77.89
number of tillers/plant	4.70	3.64	77.45

Varietal responses of tef under non-stress and stress conditions

Significant differences in the responses of the fifteen tef genotypes were observed in all parameters (Table 2) except in RSR (Table 3). In terms of mean dry matter production (g/plant) and growth, four genotypes namely Dz-01-354, Dz-cr-44, Gorradie and Balemi, tended to have consistently the highest leaf, stem, root and total dry matter weights (g/plant), plant height (cm/plant) and number of tillers/plant. Two genotypes, Fesho and Shewa Gimira had consistently the lowest leaf, stem, root and total dry weights (g/plant), plant height (cm/plant) and number of tillers/plant. Considering dry matter partitioning, the performance of the genotypes was not consistent (Table 3). The highest LWR was obtained by Curati (0.12) followed by Dz-01-354, Balemi, Key murrei, Goffarie and Hatalla each of them having a LWR of 0.11. In contrast, LWR was lowest in Shewa Gimira (0.06), Fesho and Gea-Lemi having a LWR of 0.05. Key murrie, Curati and Gorradie each had the highest SWR of 0.41 followed by Dz-01-196 which had a SWR of 0.40. There was no significant difference in RSR between tef genotypes. The absence of differences in RSR between tef genotypes may be attributed to the limited room available for root growth in the pots.

Table 2. **Mean leaf, stem, root, total dry weights (g/plant), plant height (cm/plant) and number of tillers/plant of fifteen genotypes of tef grown in pots under stress and non stress conditions.**

Genotypes	Dry weights (g/plant)					
	Leaf	Stem	Root	Total	Plant height (cm/plant)	Number of tillers/plant
Dz-01-354	0.47	1.64	0.92	4.80	106.80	4.13
Dz-cr-44	0.47	1.93	0.93	5.50	111.35	4.10
Dz-01-196	0.29	1.54	0.68	3.88	117.38	3.37
Dz-cr-37	0.30	1.18	0.56	3.64	87.02	5.65
Fesho	0.14	0.83	0.42	2.59	84.97	3.30
Gea-Lemi	0.18	1.19	0.54	3.54	85.70	6.57
Shewa-Gimira	0.17	0.96	0.41	3.11	98.67	4.63
Balemi	0.45	1.65	0.94	4.90	118.03	3.52
Key murrie	0.36	1.43	0.49	3.80	102.37	3.93
Ada	0.29	1.31	0.63	3.55	106.63	3.58
Curati	0.43	1.54	0.70	3.91	116.63	3.37
Purpurae	0.31	1.34	0.58	3.40	129.48	3.42
Gorradie	0.47	1.89	0.76	5.10	112.23	4.17
Goffarie	0.35	1.43	0.74	4.02	101.22	3.90
Hatalla	0.36	1.49	0.55	4.03	115.68	4.90
Mean	0.34	1.42	0.66	3.98	106.27	4.17
LSD (0.05)	0.21	0.83	0.44	1.96	19.84	1.02

LSD, Least significance difference ($\alpha = 0.05$).

Table 3. Mean dry matter partitioning (LWR, SWR and RSR) of fifteen tef genotypes grown in pots under stress and non stress conditions.

Genotype	LWR	SWR	RSR
Dz-01-354	0.11	0.34	0.29
Dz-cr-44	0.09	0.35	0.21
Dz-01-196	0.09	0.40	0.21
DZ-cr-37	0.09	0.34	0.18
Fesho	0.05	0.32	0.20
Gea-Lemi	0.05	0.33	0.18
Shewa-Gimira	0.06	0.30	0.14
Balemi	0.11	0.35	0.21
Key murrie	0.11	0.41	0.15
Ada	0.09	0.37	0.22
Curati	0.12	0.41	0.19
Purpurae	0.09	0.39	0.21
Gorradie	0.09	0.41	0.16
Goffarie	0.11	0.38	0.22
Hatalla	0.11	0.38	0.15
Mean	0.09	0.37	0.19
LSD (0.05)	0.05	0.07	NS

LSD, as in Table 2; NS, not significant.

Interaction effects

The interaction mean of the moisture deficit treatment and genotypes on panicle dry weight (g/plant) and panicle length (cm/plant) are presented in Table 4. Analysis of variance of the data are presented in Table 6. Moisture deficit treatment caused significant reduction ($p < 0.05$) in panicle dry weight and panicle length of all genotypes. Under stress conditions panicle dry weight ranged from 0.52 to 1.73 g/plant as compared with the control which ranged from 1.28 to 3.07 g/plant. Panicle dry weight in the genotypes Fesho, Dz-cr-44, Shewa-Gimira and Gea-Lemi was less affected. It was reduced to 88.28, 66.28, 56.72 and 56.46%, respectively relative to the control. Key murrie and Goffarie were the genotypes where panicle dry weight was reduced most by moisture deficit (20.97 and 20.87%, respectively of the control).

Table 4. Panicle dry weight (g/plant) and panicle length (cm/plant) of fifteen tef genotypes grown in pots under stress and non-stress conditions.

Genotype	Panicle dry wt (g/plant)		Panicle length (cm/plant)	
	Non stressed	Stressed	Non stressed	Stressed
Dz-01-354	2.70	0.84(31.11)	43.93	31.17 (70.95)
Dz-cr-44	2.61	1.73(66.28)	48.40	38.51 (79.69)
Dz-01-196	2.10	0.67(31.90)	46.30	36.63 (79.11)
Dz-cr-37	2.36	0.86(36.44)	35.53	29.70 (83.59)
Fesho	1.28	1.13(88.28)	34.10	32.57 (95.51)
Gea-Lemi	2.09	1.18(56.46)	30.40	25.60 (84.21)
Shewa-Gimira	2.01	1.14(56.72)	40.60	35.00 (86.21)
Balemi	2.75	0.97(35.27)	56.60	38.20 (67.49)
Key murrie	2.54	0.53(20.87)	41.23	31.80 (77.13)
Ada	1.72	0.92(53.49)	32.87	33.33 (101.30)
Curati	1.66	0.83(50.00)	47.17	41.07 (87.047)
Purpurae	1.54	0.87(51.95)	49.97	44.07 (88.19)
Gorradie	3.07	0.90(29.32)	46.00	33.47 (72.76)
Goffarie	2.48	0.52(20.97)	35.00	29.03 (82.94)
Hatalla	2.39	0.86(35.98)	43.10	37.10 (86.08)
Mean	1.57		38.37	
LSD (0.05)	0.82		6.16	

Numbers in parenthesis are relative panicle dry weight and panicle length (% of control).

Panicle length (cm/plant) also varied extensively among genotypes ranging from 25.60 to 56.60 cm/plant both under stress and non-stress conditions. Evidently moisture deficit had also caused a significant reduction in panicle length in all genotypes, with the exception of Ada. Panicle length of Fesho, Purpurae and Curati was less affected than that of the other genotypes. Overall, the data of panicle length indicated that moisture deficit treatment had less effect relative to the other parameters. The effect of moisture deficit on grain yield (g/plant) and harvest index of each genotype was assessed by two variables: absolute yield under stress and yield under stress as percent of the control (relative yield) (Table 5). A difference in response to moisture deficit for the two variables in both grain yield and harvest index was seen among genotypes. Gea-Lemi, for instance had both a high absolute grain yield and a high relative grain yield. Fesho had a high relative grain yield but a low absolute grain yield. On the other hand, certain genotypes, such as Dz-cr-44 had high absolute grain yield but low relative grain yield. Considering the harvest index, marked differences existed among genotypes and values ranged from 0.12 to 0.34 g/g. Harvest index was decreased or increased by moisture deficit within a range of 48 to 125.93% among genotypes as compared with the control. Reduction of grain yield and harvest index in the stressed plants indicated that a considerable portion of the available source was not mobilized from the vegetative parts of the plants. Other studies have also indicated that the mobilization of pre and post anthesis dry matter is differentially affected by the genotypes and the degree of stress (Austin *et al.*, 1977; Bidinger *et al.*, 1977; Aggarwal and Sinha, 1984; Aggarwal *et al.*, 1986). The variation in the values for grain yield, HI, panicle dry weight and panicle length of the fifteen genotypes of tef presented here clearly show the differing responses of these genotypes to moisture deficit. Taking both absolute yield and relative yield as indices of drought resistance, genotypes Fesho, Gea-Lemi and Shewa-Gimira could be regarded as the most drought resistant under the conditions of this experiment. On the other hand, considering the lower grain yield, HI, panicle dry weight, panicle length, absolute and relative yields of genotypes Gorradie, Goffarie and Key murrie can be regarded as drought susceptible. The remaining genotypes did not show consistent relationships between these variables in response to moisture deficit.

Table 5. Grain yield (g/plant) and harvest index (g/g) of fifteen tef genotypes grown in pots under stress and non-stress conditions.

Genotype	Grain yield (g/plant)		Harvest index (g/g)	
	Non stressed	Stressed	Non stressed	Stressed
Dz-01-354	1.62	0.38(23.46)	0.22	0.14(63.64)
Dz-cr-44	1.45	0.80(55.17)	0.22	0.18(81.82)
Dz-01-196	1.18	0.28(23.73)	0.20	0.15(75.00)
Dz-cr-37	1.40	0.39(27.86)	0.28	0.17(60.71)
Fesho	0.69	0.64(92.75)	0.24	0.29(120.83)
Gea-Lemi	1.16	0.77(66.38)	0.25	0.30(120.00)
Shewa-Gimira	1.12	0.71(63.39)	0.27	0.34(125.93)
Balemi	1.58	0.45(28.48)	0.22	0.17(77.27)
Key murrie	1.54	0.23(14.94)	0.27	0.13(48.15)
Ada	1.05	0.40(38.10)	0.24	0.15(62.50)
Curati	0.96	0.33(34.38)	0.18	0.13(72.22)
Purpurae	0.88	0.37(42.05)	0.20	0.15(75.00)
Gorradie	1.82	0.36(19.78)	0.25	0.12(48.00)
Goffarie	1.46	0.24(16.44)	0.23	0.13(56.52)
Hatalla	1.35	0.44(32.59)	0.24	0.18(75.00)
Mean		0.87		0.21
LSD (0.05)		0.49		0.07

Numbers in parenthesis are relative grain yield and harvest index (% of control).

Table 6. Analysis of variance summaries (mean squares) of parameters of fifteen genotypes of tef grown in pots under stress and non-stress conditions.

Source of variation	DF	GY (g/plant)	HI (g/g)	Panicle dry wt(g/plant)	Panicle length (cm/plant)
Replication	2	0.436^{ns}	0.006^{ns}	1.141^{ns}	3.603^{ns}
Moisture regime	1	15.509*	0.066*	37.947*	263.625*
Genotypes	14	0.151^{ns}	0.011*	0.504*	202.209*
Genotype x treatment	14	0.243*	0.006*	0.536*	32.306*
Error	58	0.09	0.002	0.251	14.224

ns, non significant; *, significant at 5% probability level.

Correlation analysis

The results of the correlation analysis indicated that panicle and total dry weights and harvest index were significantly and positively correlated with grain yield suggesting that any increase in these parameters would result in an increase in yield of tef. Leaf dry weight, plant height and panicle length although not significant, were negatively correlated. All other parameters like stem and root dry weights, and number of tillers would contribute indirectly to an increase in yield of tef through their influence on increased total dry matter as a whole.

Table 7. Correlation analysis between grain yield and other selected parameters.

	LDW	SDW	PDW	RDW	TDW	HI	PL.H	P.L	No. of tillers
GY	-0.06	0.17	0.92	0.13	0.51	0.81	-0.23	-0.11	0.22

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