Tropical Agricultural Research Vol. 144 -156 (2003)

Evaluation of Different Genotypes of Tomato Under Well-Watered and Water-Stressed Conditions on the Basis of Yield and Some Selected Physiological Parameters

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ABSTRACT: *In many natural locations, shortage of water is an important environmental constraint limiting plant productivity. To investigate how tomato yield and some selected physiological parameters are affected by soil water levels, 55 different genotypes were evaluated under two water regimes. The experiment was carried out in the planthouse of the Biotechnology Center, Peradeniya, from January – May 2003. Ten parental tomato varieties together with their 45 F1 hybrids (produced according to half-Diallel genetic design) were grown under the stress cycles as well as under well-watered conditions. Each genotype contained 4 replicates with 2 water treatments. To impose the water stress, the plants were subjected to 3 stress cycles. At each cycle soil moisture content was allowed to decrease down to -0.07 MPa and followed by re-watering to saturation. A significant ($p<0.001$) variation between the tomato genotypes was observed for yield and for four other physiological and growth parameters (i.e. Net photosynthesis rate, P_n, Root length per plant, Stomatal conductance, g_s, and Instantaneous transpiration efficiency, ITE). Under the water stress cycles, yield was significantly ($p< 0.05$) negatively correlated with stomatal conductance, but was significantly ($p<0.05$) positively correlated with root length. When the data of both water regimes were pooled, only instantaneous transpiration efficiency showed a significant ($p<0.05$) positive correlation with yield. The results of this study indicated that a significant ($p<0.001$) genotype x water regime interaction for all parameters measured. To identify higher yielding genotypes under water stress, root length and stomatal conductance could be used as selection criteria. Instantaneous transpiration efficiency could be a useful criterion for identification of higher yielding genotypes under well-watered conditions.*

INTRODUCTION

Tomato (*Lycopersicon esculentum*. Mill) is an important crop throughout the world in a wide range of climatic conditions. In Sri Lanka it is one of the most popular, and widely grown vegetable crops. In 2001/02, tomato was cultivated over an area of 5413 ha (Personal Communication, Department of Agriculture, Sri Lanka) with an average yield of approximately 7.62 mt ha^{-1}. However it is still below the current world average of 28 mt ha^{-1} (Anon., 2003). Therefore, there is wide scope for yield improvement of tomato in Sri Lanka. There are several possible ways to increase the production of tomato in Sri Lanka. These include breeding of high yielding varieties

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combined with superior fruit quality characters, improving management practices and expanding the cultivated land area.

In expanding the cultivated land area, one possibility would be to increase the cultivation of tomato in the dry zone of Sri Lanka. At present only about 1/5 (i.e. 1077 ha) of the island-wide cultivation of tomato is located within the dry zone (Personal Communication, Department of Agriculture, Sri Lanka). The major constraint to expand tomato cultivation in the dry zone is the variety of environmental stresses such as drought and high temperature. These stresses constitute some of the most serious limitations to tomato growth, productivity and distribution. The development of well-adapted cultivars for the dry zone conditions would improve productivity and yield stability in this environment. Therefore, to expand the extent of cultivation, there is a necessity to develop tomato varieties suitable for the environmental conditions prevailing in the dry zone of Sri Lanka. A primary requirement of such varieties would be the ability to tolerate periodic water stressed conditions.

Production of tomato varieties for water stressed conditions involves the identification and transfer of physiological traits, responsible for tolerance to water deficits, to existing high yielding cultivars.

In this study our objectives were to produce a large number of tomato genotypes by crossing existing parental varieties, to compare the behavior of these tomato genotypes under well-watered and water-stressed conditions, to determine whether there is a correlation between their yield performance and measurable physiological parameters and to identify physiological characters, which could be introduced into breeding programs as selection criteria, to identify higher yielding genotypes.

MATERIALS AND METHODS

Location and the genetic material used

The experiment was carried out in the plant house at the Biotechnology Center, Peradeniya, Sri Lanka, from January 2003 to May 2003. Ten local and foreign parental tomato genotypes together with their F1 hybrids produced by hand emasculation and pollination were used for the study. The crosses were made according to a half-Diallel genetic design (Gunasekara and Perera, 1999, Perera and Liyanaarachchi, 1993). Seeds of tomato varieties KWR, T-245, T-146, Marglobe, Bianz, Roma, Ravi, Vihara, Thilina and CL-9-0-0-1-3 obtained from the Plant Genetic Resource Center, Gannoruwa, Peradeniya, Sri Lanka, were used to obtain the parents for the hybridization programme. Fifty-five genotypes were evaluated under two water regimes in a completely randomized design with four replicates.

Growth conditions and application of stress

Seeds were sown in Styrofoam nursery trays, filled with a mixture of organic manure, coir dust and sand. The seeds were treated with Captan fungicide. Eighteen days old seedlings were transplanted in large bags (30 cm diameter and 100 cm high) filled with Reddish Brown Earth soil, transported from Mahailluppallama. The large sized bags were used in order to allow un-restricted root growth. Application of

fertilizer, and other cultural practices were done according to recommendations of the Department of Agriculture (Anon., 1990).

Table 1. Half-Diallel genetic design used for the hybridization programme G1-G55: The parental tomato genotypes together with their F1 hybrids.

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	*G1*									
2	*G2*	*G3*								
3	*G4*	*G5*	*G6*							
4	*G7*	*G8*	*G9*	*G10*						
5	*G11*	*G12*	*G13*	*G14*	*G15*					
6	*G16*	*G17*	*G18*	*G19*	*G20*	*G21*				
7	*G22*	*G23*	*G24*	*G25*	*G26*	*G27*	*G28*			
8	*G29*	*G30*	*G31*	*G32*	*G33*	*G54*	*G34*	*G35*		
9	*G36*	*G37*	*G38*	*G39*	*G40*	*G41*	*G42*	*G43*	*G44*	
10	*G45*	*G46*	*G55*	*G47*	*G48*	*G49*	*G50*	*G51*	*G52*	*G53*

1: Bianz *4: Thilina* *7: Vihara* *10: Roma*
2: T-146 5: Ravi 8:Marglobe
3: CL-9-0-0-1-3 6: T-245 9: KWR

When all the plants were fully established (i.e. 30 days after transplanting), water stress cycles were initiated to study the impact of water stress. Two plants of each genotype were kept continuously under well watered conditions while the remaining two were subjected to water stress cycles. The stress was applied as three discontinuous cycles by watering the plants after each stress cycle. Each cycle was carried out for 6 days. During the stress cycles, soil water potential at 20 cm and 30 cm depths were measured using a Soil Tensiometer (Model No. 2725, Soil Moisture Equipment Corp., USA). When the soil water potential at 20 cm depth reached a value of 70 cbars (i.e. -0.07 MPa), the stress cycle was stopped and the stressed plants were re-watered to saturation. A similar procedure was followed by Basiouny *et al.* (1994). The subsequent stress cycle was initiated immediately after re-watering.

Measurements

All measurements on all genotypes were recorded after subjecting the plants to all three stress cycles. The LICOR-6400 portable Photosynthesis Measurement System (LICOR, Nebraska, Lincoln. USA) was used to measure the net photosynthesis rate and transpiration rate of fully expanded young leaves. Ten readings were recorded in one plant. Instantaneous transpiration efficiency (ITE) was calculated as the ratio between instantaneous photosynthesis and transpiration rates.

Stomatal conductance, transpiration rate, incident light intensity and leaf temperature were recorded 55 days after transplanting, using the LI-1600 Steady State Porometer (LICOR, Nebraska, Lincoln, USA). Three leaves were used in each genotype. Youngest fully expanded leaves were crushed in liquid nitrogen, centrifuged at a speed of 8000 rpm for 5 minutes under refrigerated conditions. The cell sap was collected and the cell sap solute concentration was measured using a vapor pressure Osmometer (Wescor-5520, Wescor, USA). Pressure Chamber (Soil Moisture

Equipment Corporation, USA) was used to measure leaf water potential on the fully expanded young leaves under two water treatments.

The total dry weights of the roots and shoots were obtained by destructive sampling. All destructive measurements were done separately for each individual genotype under both water regimes. At each destructive sampling, the total leaf area was recorded using a digital leaf area meter (Model AAM-9, Hayashi Denko Co. LTD.). The plant samples were separated into leaves, roots and stems and their dry weights were determined by oven drying at 80°C for 48 hours. The total root length was determined according to Newman's method by using a root grid (Newman, 1966). The yield data were recorded in terms of fresh fruit weight up to three months after transplanting.

Data analysis

Data analysis was done using SAS computer software.

RESULTS AND DISCUSSION

Out of the several parameters measured, only a subset is presented below.

Yield distribution

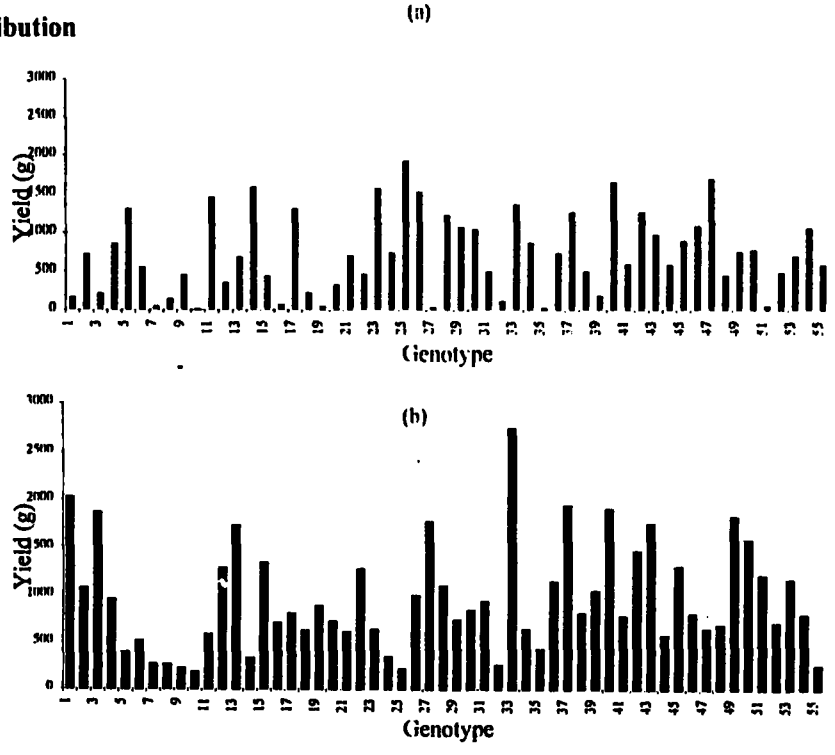

Fig. 1. Fruit yield of 55 tomato genotypes grown under (a) water-stress cycles (b) well-watered condition.

There was a highly significant ($p<0.001$) variation between tomato genotypes for all measured parameters. When plants were subjected to water stress cycles, the fruit yield of the tested genotypes ranged from 15 g plant^{-1} (genotype 10) to 1927 g pl^{-1} (genotype 25), (Figure 1a). Under well-watered conditions, the corresponding yields ranged from 167 g pl^{-1} (genotype 10) to 2732 g pl^{-1} (genotype 33) (Figure 1b). In the majority of the 55 genotypes tested, stress cycles caused a yield reduction. However, contrary to the expectations, 19 genotypes yielded higher under water stress cycles. Genotypes 28, 33, 37, 40 and 42 were able to maintain a high yield under both water regimes.

Net photosynthetic rate (P_n)

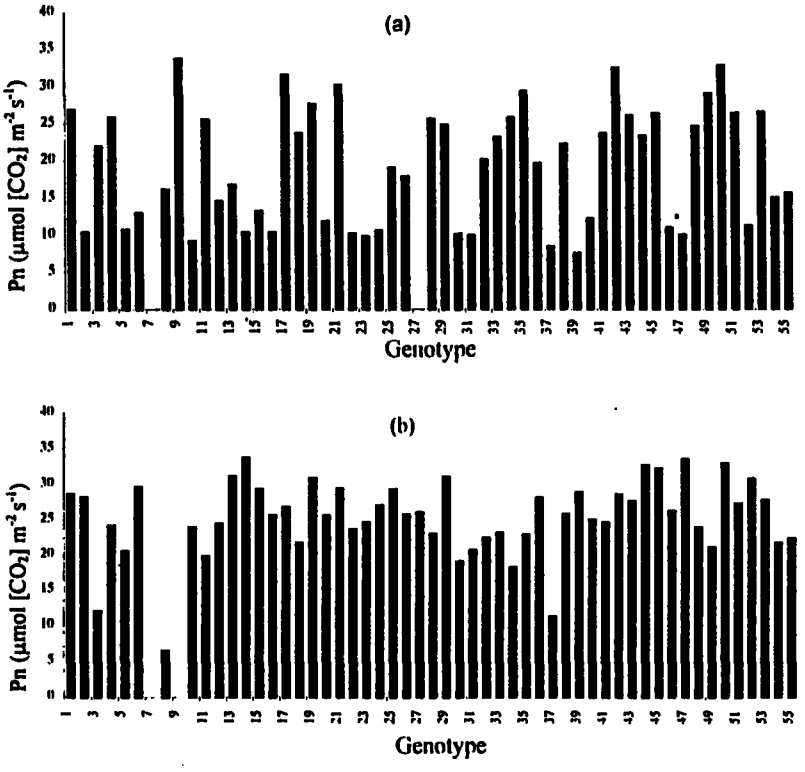

Fig. 2. Net photosynthetic rate (Pn) of different tomato genotypes under (a) water-stress cycles (b) well-watered condition.

There was significant ($p<0.001$) genotypic variation in P_n under both well-watered and water-stressed treatments. Under both water regimes, the range of genotypic variation in P_n was approximately similar. It ranged from 7.37 µmol [CO_2] m^{-2} s^{-1} (genotype 39) to 35.6 µmol m^{-2} s^{-1} (genotype 9) under water stress cycles (Figure 2 a) while the corresponding range under well-watered conditions was from 6.35 (genotype 8) to 33.63 µmol m^{-2} s^{-1} (genotype 14) (Figure 2 b). However, only three genotypes showed P_n values below 15 µmol m^{-2} s^{-1} in the well-watered treatment. In contrast, a much larger number of genotypes (i.e. 22 out of 55) had P_n values below 15 µmol m^{-2} s^{-1} in the treatment receiving stress cycles. Overall, photosynthetic rate was 28% higher in the adequately watered treatment as compared to that under drying

cycles. This trend was present in the majority of genotypes tested (i.e. 42 out of 55). However, there was a significant ($p<0.001$) genotype x water regime interaction effect on P_n. This was because 13 genotypes showed a higher P_n value under stress cycles. Genotypes G4 , G_{11} , G_{17} , G_{18} , G_{19} , G_{21} , G_{42} , G_{43} , G_{45} , G_{50} , G_{51} , and G_{53} were having higher rates of P_n under both water regimes.

Instantaneous transpiration efficiency (ITE)

Instantaneous transpiration efficiency (ITE) showed significant ($p<0.001$) variation between the tested tomato genotypes as well as the two water regimes (Figure 3). Except for 19 genotypes, the rest had a higher ITE under water stress cycles. There was a significant ($p<0.001$) genotype x water interaction. For both water treatments, ITE showed a similar range, i.e. 1.32 – 7.66 µmol $[CO_2]$ µmol $[H_2O]^{-1}$ under stress cycles (Figure 3 a) and 1.28 – 7.50 µmol $[CO_2]$ µmol $[H_2O]^{-1}$ under well-watered conditions (Figure 3b). Genotypes 33, 37, 16 and 41 had significantly higher ITE levels under both water regimes.

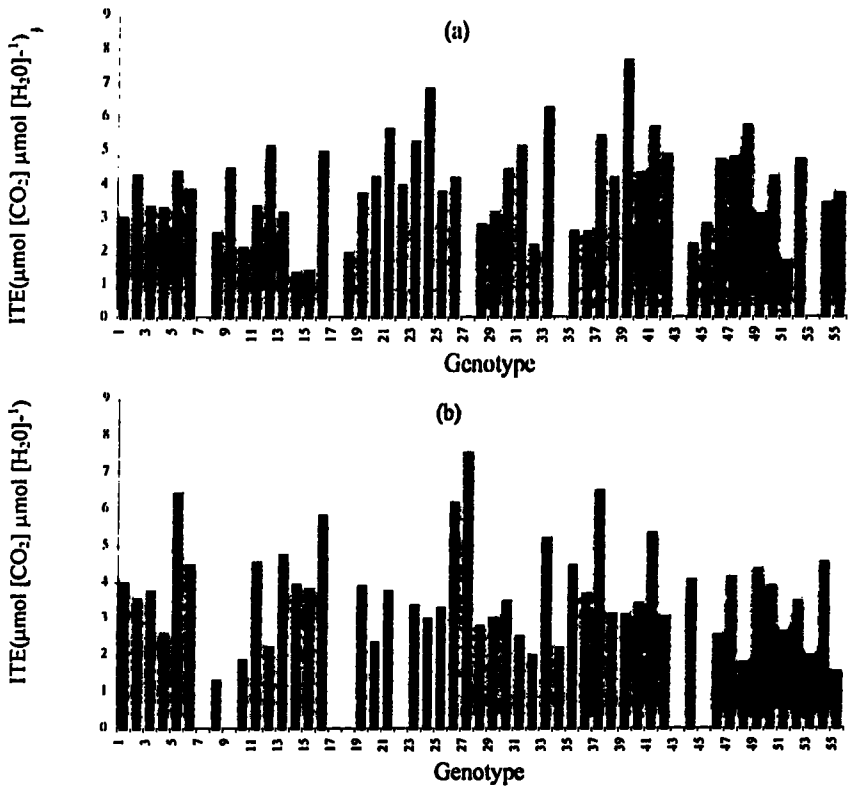

Fig. 3. Instantaneous transpiration efficiency of different tomato genotypes under (a) water-stress cycles (b) well-watered condition.

Root length

Apart from the expected variation between genotypes, a significant genotype x water interaction was observed in root length per plant (Figure 4). In the treatment receiving stress cycles, genotype 16 contained the shortest root system (2.35 m) while

genotype 55 had the longest root system (18.89 m). When the plants were continuously watered root length varied from 0.82 m (genotype 29) to 31.43 m (genotype 55). Out of the 55 genotypes tested, in 21 genotypes we observed more vigorous root growth under stress cycles than under well-watered conditions. Genotypes 55, 43, 47, 14, 25 and 10 were the once which had higher root lengths under both water regimes.

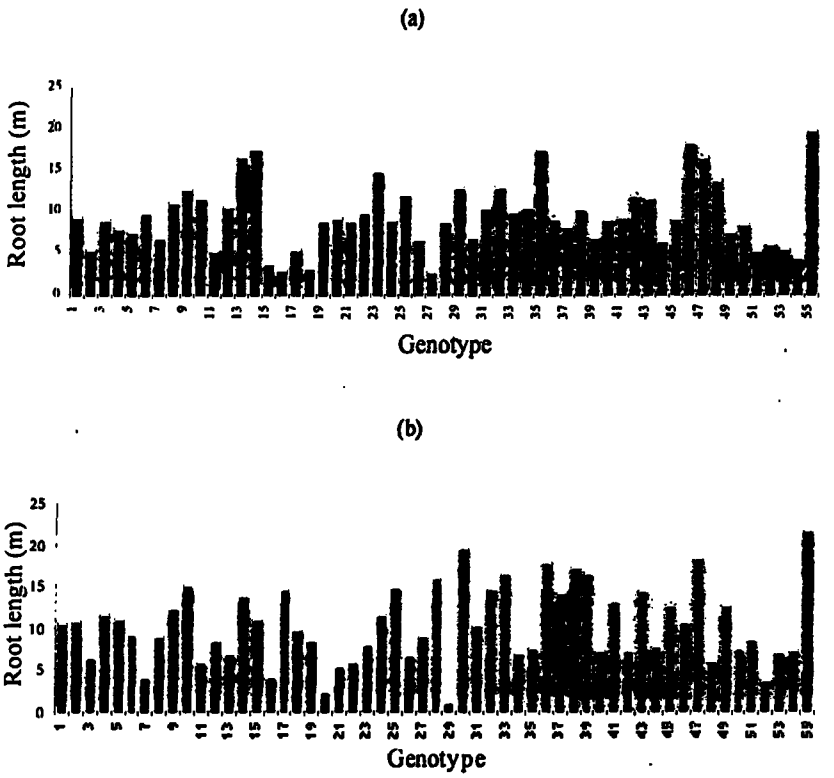

Fig. 4. Variation of root length per plant observed under (a) water-stress cycles (b) well-watered condition in different tomato genotypes.

Stomatal Conductance (g_s)

We could observe a significant ($p<0.001$) genotypic variation under both water regimes (Figure 5). Out of the 43 genotypes in which g_s could be measured, 22 genotypes decreased their stomatal conductance when stress cycles were imposed. G_1, G_{33}, G_{34}, G_{38}, G_{36} and G_{41} showed only slight variation in g_s under the two treatments. When the plants were experiencing stress cycles, genotype 29 and 43 decreased their g_s to 0.04 cm s^{-1} which was the lowest recorded, while genotype 53 maintained the highest g_s value of 0.76 cm s^{-1}. Moreover, in the well-watered situation, genotype 27 had the lowest g_s (0.02 cm s^{-1}) while genotype 45 had the highest (i.e. 0.70 cm s^{-1}).

Correlations between yield and measured parameters

Under water stress cycles, yield was significantly ($p<0.05$) positively correlated with root length per plant while stomatal conductance was showing a significant ($p<0.01$) negative correlation with yield. There was a significant ($p<0.05$) positive correlation between yield and instantaneous transpiration efficiency under well-watered conditions. None of the other correlations showed statistical significance at $p=0.05$.

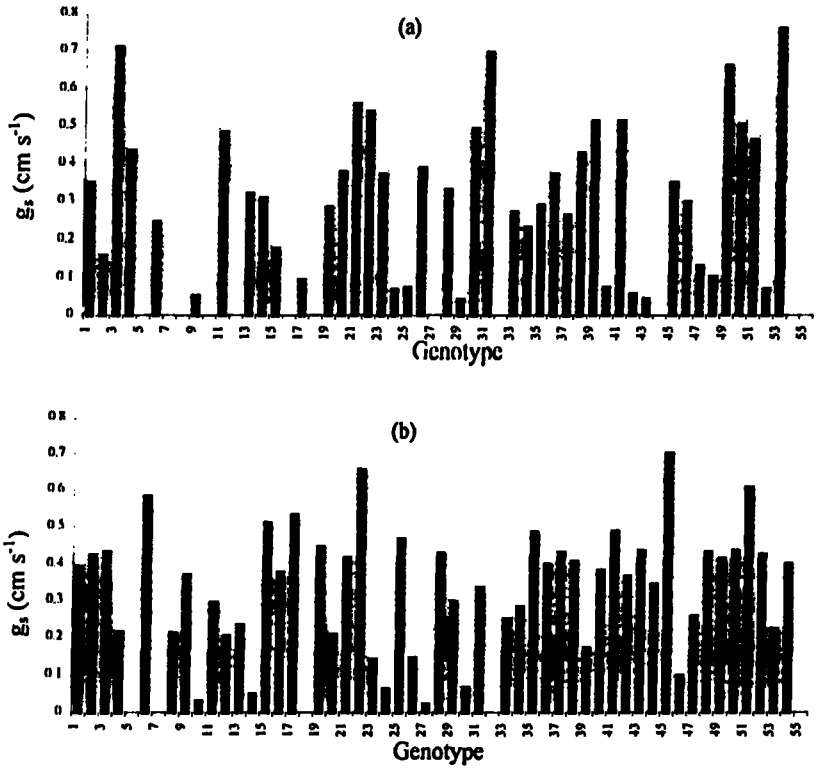

Fig. 5. Stomatal conductance of different tomato genotypes grown under (a) deficit condition (b) well- watered condition.

The present study involved screening of a large number of tomato genotypes for yield as well as a number of growth and physiological parameters. As expected all the measured characters showed highly significant variation between genotypes. However, in all the parameters measured, there was a significant genotype x water regime interaction. This means that selection of higher yielding genotypes has to be based on different approaches for different water regimes. For example, results of the present study showed that genotypes that would give a higher yield under water stress could be identified by screening for longer root length and lower stomatal conductance (Table 2). A longer root length would enable a tomato crop growing under soil water deficits to explore a larger volume of soil. Therefore, it would have access to a greater pool of soil water. This would be a particular advantage under water stress as it would ensure a greater supply of water to the plant through root water absorption. Hence, this could be the reason for the positive correlation observed in the present study between tomato yield under water stress and root length per plant. Although we could not find in literature similar relationships observed on tomato, several workers have observed it for rice (Yoshida and Hesegawa, 1982), wheat (Hurd, 1974), sorghum (Wright and Smith, 1983), and maize (Lorens *et al.*, 1987). Moreover De Costa and Nayakeratne (2001) also observed a positive correlation between yield of groundnut under water stress and the number of primary roots, which is an indirect indication of root length. This provides further supporting evidence that yield under water stress and root length is positively correlated in both cereals and dicots such as tomato and groundnut.

Table 2. Linear correlation matrix between yield and selected plant characters under well-watered conditions (above the diagonal) and under water-stress cycles (below the diagonal).

	Yield	P_n	g_s	Rt. lg.	Sol. conc.	ψ_{H2O}	ITE
Yield	-	-0.015	0.153	-0.040	-0.125	0.142	*0.349
P_n	0.061	-	0.006	- 0.057	0.122	-0.156	0.052
g_s	*0.313	0.026	-	-0.009	-0.110	-0.001	0.082
Rt. lg	*0.311	-0.043	-0.297	-	-0.260	0.132	-0.116
Sol. conc.	0.042	0.102	0.084	0.250	-	-0.160	0.007
ψ_{H2O}	-0.191	-0.076	-0.127	0.046	-0.203	-	0.068
ITE	0.177	-0.227	-0.057	0.059	0.125	-0.196	-

Note: * - Indicates correlation coefficients which are significant at $p = 0.05$

Pn: Net photosynthetic rate — Sol. Conc.: Solute concentration

g_s : Stomatal conductance — ψ_{H2O}: Water potential

Rt. lg. : Root length — ITE: Instantaneous transpiration efficiency

A lower stomatal conductance means partially closed stomata. This is a common response in plants growing under water deficits to reduce transpirational water losses (Lawlor, 1995). By regulating water losses through stomatal closure, a plant attempts to conserve a limited supply of water so that it could continue its important physiological functions (Jones, H.G. 1979, Jones, 1987). In the tomato genotypes tested in the present study also, different genotypes showed different capabilities of regulating transpiration rate through stomatal closure (Fig. 5). Results of the present study showed that those genotypes (eg: G17, G25, G40, G47, G42) that were able to partially close their stomata in response to water stress cycles conserved water more efficiently and thereby achieved higher yields under water stress. Haupt-Herting and Fock (2000) also observed a reduction in stomatal conductance in tomato under water stress. However, no studies could be found in which stomatal conductance had been correlated with yield in tomato. On the other hand, such correlations have been found for other crop species such as sorghum (Henzell *et al.*, 1976), millet (Henson *et al.*, 1981), wheat (Quarrie and Jones, 1979), groundnut (De Costa and Nayakaratne, 2001). While root length and stomatal conductance showed significant correlations with tomato yield under water stress, only instantaneous transpiration efficiency showed a significant correlation with yield under well-watered conditions. The absence of correlations with stomatal conductance and root length is not surprising as water supply is not a limiting factor under well-watered conditions. Therefore, the need to explore a greater volume of soil (by having a longer root length) or to conserve water (by partial stomatal closure) does not arise. A higher instantaneous transpiration efficiency means that the plant is able to fix a greater amount of CO_2 molecules per unit of water lost as transpiration. This would enable the plant to produce a greater amount of biomass and ultimately yield. This is probably the reason for the positive correlation between instantaneous transpiration efficiency and yield.

The present study showed that photosynthetic rate of tomato decreased under water stress in the majority of genotypes tested. This is supported by a large body of literature on tomato (Farquhar and Sharkey, 1982, Cornic *et al.*, 1992, Dubey, 1997, Makela *et al.*, 1999). One of the possible reasons for reduction of photosynthesis under water stress would be, the partial closure of stomates, which restricts the diffusion of CO_2 into leaves (Farquhar and Sharkey, 1982; Boyer, 1976). Another reason would be mesophyll resistance for gas exchange (Kriedeman and Downton, 1981). Non-stomatal responses have also been reported (Seemann and Sharkey 1982, Mayer and Kouchkovsky, 1993). Direct inhibition of biochemical processes by altered osmotic conditions may affect ATP synthase and Rubisco activity, which could lead to decline in photosynthetic rate under stress cycles (Haupt-Herting and Fock, 2000).

However, in the present study, the individual leaf photosynthetic rate per unit leaf area did not show a clear correlation with yield under both water regimes. But it is possible that canopy photosynthesis rate may have a positive correlation with yield. However measurement of canopy photosynthesis rate is cumbersome and time consuming. Therefore it cannot be used as a selection criterion.

Moreover, there have been many reports of negative correlations between yield potential and light saturated maximum photosynthesis. This has been observed in rice (Evans et al., 1984), wheat (Johnson *et al.*, 1987), peas (Mohan, 1982), brassica (Hobbs, 1988), and soybean (Kokobun and Wardlaw, 1988).

CONCLUSION

Based on the results of the present study, we could conclude that in breeding tomato varieties suitable for drought-prone regions of Sri Lanka (i.e. dry and intermediate zones), longer root length and lower stomatal conductance can be used as selection criteria for screening genotypes. On the other hand, higher instantaneous transpiration efficiency can be used as a criterion in selecting genotypes suitable for areas which do not experience significant drought (i.e. wet zone of Sri Lanka). Moreover, the present study which involved screening a large number of genotypes showed that there is adequate genotypic variation in yield potential and all the major growth and physiological parameters within the tomato germplasm. This genotypic variation can be used for successful yield improvement either through conventional plant breeding or through molecular techniques.

ACKNOWLEDGEMENTS

The authors wish to thank the Asian Development Bank for the financial assistance, the Director of the Postgraduate Institute of Agriculture, the staff members at the Department of Agriculture Biology, University of Peradeniya and to all who helped during this experiment.

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