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Effect of Three Moisture Levels on Growth and Yield of Four Durum Wheat Cultivars Grown under Greenhouse Conditions

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Abstract: A pot experiment was conducted in a greenhouse as rainout shelter to investigate the response of diverse durum wheat cultivars under three levels of soil moisture. Four wheat cultivars namely Om-quais, Hourani-27, Safra Ma'an and Al-Samra were grown under three levels of soil moisture which are 50 (M1), 65 (M2) and 85% (M3) of field capacity. Results indicated that the cultivars were good drought tolerant because they were able to produce at M1 which is 4% below the wilting point. Cultivars didn't differ significantly for yield and yield component, based on this similarity in response, cultivars can be alternatives to each other within the soil moisture levels. Soil moisture very significantly affected all characters, except harvest index, thus, increasing soil moisture levels from M1 to M2 and from M2 to M3 caused a great increase of 136 and 77% for biological yield/plant, 143 and 63% for grain yield/plant, 93 and 77% for straw yield/plant, 93 and 43% for number of spikes/plant, 137 and 44% for number of kernels/plant and by 7 and 10% for thousand kernels weight respectively. Under rainfed conditions, supplementary irrigation can improve wheat yield and avoid crop failure by limited amount of water.

Key words: Durum wheat, soil moisture, irrigation, field capacity, water stress, yield

INTRODUCTION

The average annual consumption of wheat in West Asia and North Africa is more than 150 kg/person, which is the highest level in the world (Ferrara, 1994).The semi arid areas of the Middle East where average annual rainfall ranges from 350-500 mm are characterized by being highly variable and unpredictable in terms of rainfall (amount and distribution) and other climatic factors such as temperature and humidity. Such variability makes shortage of soil available water the most serious constraint to production improvement (Ketata, 1987).

Agricultural drought occurs when the amount and distribution of precipitation are adequately low to cause serious reduction in crop yield. Therefore, plants suffer from water deficits whenever atmospheric demand exceeds the supply of water from the soil (Turner, 1986). Plant breeders on their attempts to improve drought tolerance of crop cultivars have emphasized that high priority should be given to improve the efficiency of water use through selection of cultivars that have fast early growth that provide them with the best advantage of the low transpiration conditions during the winter period with low radiation and evaporative demand and better soil management practices (Cooper *et al*., 1987).

Genotypic variability for water stress have been reported by many researchers, Moustafa *et al*. (1996), showed that the yield of three spring wheat cultivars reduced significantly due to water stress applied at heading, yield of Giza 165, Gemmiza 1 and SPHE3 decreases by 44, 43 and 18%, respectively. Comparison between drought resistant and drought susceptible durum wheat cultivars which were exposed to water stress at tillering (early), flowering (mid) and at grain filling (late), revealed that early stress delayed time to anthesis and physiological maturity, while mid and late season moisture stress shortened the grain-filling period by 10 and 11 days. Also drought-resistant cultivars reached anthesis earlier than the susceptible one. The moisture stress treatments gave low dry-matter accumulation compared to the control (Simane *et al*., 1993). Motzo *et al*. (1996), found significant difference among seven Italian durum wheat cultivars grown under different moisture levels and soil types for the traits, days to flowering, kernels weight and rate of grain-filling. Large kernels were obtained by genotypes characterized by high rates of grain filling, irrespective of earliness. Also in a field study, significant differences were observed among four bread wheat cultivars tested under a package of cultural practices including the effects of four rates of Supplemental Irrigation (SI) (i.e., full SI and 1/3 and 2/3 of that amount, as well as rainfed conditions), also found that the addition of only limited irrigation (1/3 full SI) with 100 and 150 kg N ha^{-1} doubled yield compared with rainfed conditions (Oweis *et al*. 1998). Abou El-Fotouh *et al*. (2002), studied the effect of three amounts of irrigation water on the performance of wheat cultivar Gemmiza 7 at Eastern Delta in Egypt. The levels were equal to 100 (T1), 80 (T2) and 60% (T3) of class A Pan evaporation given at weekly intervals. Results showed no significant differences between the effects of T1 and T2 for plant height, grain weight/ spike, 1000 grain weight and grain and straw yields. However, T1 and T2 treatments were superior to T3 irrigation level. As a result, there is a possibility of saving about 16% of the amount of irrigation water by applying T2 level as compared with T1 level. The aim of this study was to investigate the effect of three soil moisture levels on yield, yield components and some phonological attributes of four durum wheat cultivars. Also, it aimed to detection of cultivars with higher level of water productivity

MATERIALS AND METHODS

A pot experiment was conducted in an open green house, as a rainout shelter in winter and for protection from bird attacks at grain filling stage, at college of Agriculture, Mu'tah University, Jordan. The kernels were sown in a 10 kg capacity pots (25 cm upper diameter and 30 cm height). Three levels of soil moisture (i.e., 50 M1, 65 M2 and 85% M3 of field capacity). and four locally adapted spring durum wheat (*Triticum turgidum* L. sub sp. *durum*) cultivars namely Om-quais (C1) is a semi- dwarf that was developed from Omrabi 6 introduced from ICARDA, Hourani-27 (C2) is a selection from a tall landrace originating from Lebanon (Elings, 1993), Safra Ma'an (C3) is a landrace adapted to the high lands of south Jordan and was named after the name of Ma'an city and Al-Samra (C4) is a landrace grown in Jordan and took its name from the black color of its awns at maturity. The first two cultivars are improved, certified and recommended for wheat growers in Jordan, while the other two cultivars are local land races collected from the wheat growers from their cultivation areas. The twelve treatment combinations were replicated three times in a Randomized Complete Block Design (RCBD).

Soil was dugout from the depth (0-10 cm) of a field in the College of Agriculture in Al-Rabba town. Soil was air-dried and sieved through 2 mm sieve. Each pot was filled with 8 kg of air-dried soil then corrected to the oven dry weight by using the following equation (Marshal and Holmes, 1979):

$$\text{Oven Dry wt. of soil sample} = \frac{\text{Air Dry wt.}}{100 + \%\text{ of Initial moisture (on oven dry wt. basis)}} \times 100$$

Two pots per treatment were filled with the prepared sandy loam soil and the 72 pots arranged in the middle of the greenhouse according to the design (the soil characteristics are shown in Table 1).

On January 25, 2006, ten wheat kernels treated with fungicide were sown in each pot and the pots were irrigated to field capacity. Emergence was completed after 10 days from sowing and seedlings were thinned to five healthy plants per pot on February, 20 when the second leaf was not fully expanded. Moisture stress treatments were applied directly after emergence and the moisture status in the pots was determined gravimetrically by weighing and watering the pots in Sunday, Tuesday and Thursday of every week to the moisture level required by treatments. Diammonium phosphate fertilizer (18% N and 46% P_2O_5), as granules, was dissolved in water and applied at irrigation time as 100 mL of fertilizer solution for each pot, at March, 16 and April, 23 at a fertilization rate of 100 kg ha^{-1}. Weeding of pots was frequent to keep the pots free of weeds. Correction for plants weight in the pots was based on the results presented by Noggle and Fritz (1976). Irrigation of the pots continued according to the schedule until the plants reach physiological maturity which is identified by lose of green color from head and peduncle (Zadoks *et al*., 1974). After this stage, irrigation withholds at May, 29 and plants in each pot were hand harvested and kept in separate bags.

Data were recorded and calculated for many characters such as biological yield, seed yield, harvest index, number of spikes and number of kernels per plant, 1000 kernels weight, plant height and heading date. The data were analyzed statistically using the analysis of variance (ANOVA) technique by MSTATC program model number 8 (Michigan State University, East Lansing, Mich., USA) and the significance of mean difference was tested by Duncan's Multiple Range Test.

Table 1: Physical and chemical characteristics of the soil used

Particle size distribution	
Clay (%)	13.3
Silt (%)	18.3
Sand (%)	68.4
Texture class	Sandy loam soil
Permanent wilting point (%)	20.0
Field capacity (%)	32.0
Saturation capacity (%)	61.7
Bulk density (g cm^{-3})	1.60
Particle density (g cm^{-3})	2.88
pH	6.03
Total nitrogen	
0.142%	
Available phosphorous (ppm)	409
Available potassium (ppm)	610
Organic matter (%)	2.2
Electrical Conductivity (EC) (ms cm^{-1})	1.83

RESULTS AND DISCUSSION

Yield and yield attributes: Analysis of variance showed no significant variations among cultivars for biological, grain and straw yield/plant (Table 2). This result could be due to the similarly in the response of cultivars to moisture levels by increasing all the traits. However, the highest values for the previous traits obtained from Al-samra for biological yield and from Om-quias for grain yield and from Safra-ma'an for straw yield. Variations due to moisture levels were highly significant for biological, grain and straw yields/plant (Table 2), as moisture levels increased from M1 to M2 and from M2 to M3, biological yield/plant increased sharply by 136 and 77%, respectively (Table 3). Similar trend was observed for grain and straw yield/plant. The same response was obtained by Alderfasi *et al.* (1999), Alderfasi (2001) and Abou El-Fotouh *et al.* (2002). Moreover, Oweis *et al.* (1998), found that applying 1/3 of full irrigation with 100 and 150 kg N ha^{-1} doubled yield compared with rainfed conditions, thus, emphasized that saving in irrigation water is possible with little or no loss in yield. The interactions between cultivars and moisture levels were significant only for biological yield but not for grain and straw yield/plant (Table 2). It is possible that, genotypic differences among cultivars for biological, grain and straw yield cannot be expressed at M1 level, thus under such growing conditions, the four cultivars gave similar production potential. Therefore, it is not of value to look for improved, high yielding and expensive cultivars for such environments. At M2 and M3 moisture levels, biological yield/plant increased for the three cultivars and slight differences among cultivars starts to appear at M2 and the differences among cultivars become evident at M3. So at M3 level, Safra-ma'an and Om-quais gave the highest values for biological yield/ plant. Also, no significant interactions for grain and straw yields/plant showed similar response to that of biological yield. Such consistent response of cultivars to moisture levels could be responsible for absence of significant differences among cultivars for biological, grain and straw yields/ plant; moreover it indicates that the four cultivars are responsive to improvement in soil moisture levels for the above yield traits.

Harvest index represents the grain fraction of the above-ground biomass. Many studies with wheat reported that most of the genetic gain comes from improvement in harvest index. Harvest index was affected very significantly by cultivars (Table 2), Om-quais as a semi-dwarf gave the highest harvest index, while Hourani-27 and Safra-ma'an as tall one's showed the lowest values. This could be attributed to the smaller amount of biomass partitioned to the straw in semi-dwarf cultivars. Such genotypic variability for harvest index reported in barley by Wahbi and Gregory (1989) and Cantero- Martinez *et al.* (1995). Harvest index did not differ significantly due to moisture levels (Table 2), this result ascribed to the principle that, under normal growth conditions (as absence of late season drought or spring frost), there is a positive correlation between biological and grain yield and between the two factors and the moisture level. Thus, when adequate moisture is available, it allows full expression of cultivars capabilities for remobilization and assimilation during grain filling (Loomis and Conner, 1992). Even though analysis results indicated that interaction did not significantly affect harvest index (Table 2), Om-quais cultivar gave values of harvest index ranging from 41, 3 to 45.7%, such values approaches 45 to 50% values obtained from recently released cultivars in developed countries (Loomis and Conner, 1992). In contrast, the harvest index values for Safra-ma'an ranged from 33-35%. Similar genotypic variation for harvest index reported by Nagarajan *et al.* (1999), they found that harvest index values ranging from 32-38% in two double dwarf cultivars and two tall ones that were exposed to post-anthesis water stress.

Average number of fertile spikes (contain kernels)/ plant is a very important yield component. Its analysis did

Table 2: Summary of analysis of variance and results for yield, yield components and phonological traits of four spring wheat cultivars as affected by three levels of soil moisture

Treatments	Biological yield (g/plant)	Seed yield (g/plant)	Straw yield (g/plant)	Harvest index (%)	No. spikes/ plant	No. of kernels/ plant	1000 kernels wt. (g)	Plant height (cm)	No. of day to heading	No. of day to maturity
Cultivars	NS	NS	NS	**	NS	NS	NS	**	**	**
Om-quais	7.743^{a}	3.337^{a}	4.407^{a}	43.890^{a}	2.290^{a}	64.490^{a}	50.520^{a}	61.170^{b}	73.900^{c}	110.800^{b}
Haurani 27	7.332^{a}	2.567^{b}	4.950^{a}	36.000^{bc}	2.270^{a}	49.900^{b}	50.000^{a}	76.000^{a}	76.100^{b}	109.100^{c}
Safra Ma'an	7.723^{a}	2.880^{ab}	5.580^{a}	34.110^{c}	2.510^{a}	57.970^{ab}	49.510^{a}	74.300^{a}	82.200^{a}	116.000^{a}
Al-Samra	7.783^{a}	3.062^{ab}	4.720^{a}	39.110^{b}	2.540^{a}	58.700^{ab}	51.290^{a}	58.300^{b}	75.200^{bc}	109.600^{bc}
Moisture levels	**	**	**	NS	**	**	**	**	**	**
M1	3.040^{c}	1.200^{c}	2.316^{c}	39.250^{a}	1.230^{c}	25.530^{c}	46.420^{c}	59.500^{c}	75.400^{c}	108.600^{b}
M2	7.181^{b}	2.916^{b}	4.479^{b}	38.080^{a}	2.360^{b}	60.420^{b}	49.860^{b}	65.700^{b}	76.800^{b}	112.700^{a}
M3	12.720^{a}	4.768^{a}	7.948^{a}	37.500^{a}	3.370^{a}	87.350^{a}	54.650^{a}	77.100^{a}	78.300^{a}	112.800^{a}
Interaction	*	NS	NS	Ns	NS	NS	NS	NS	NS	NS

M1 = 50%, M2 = 65% and M3 = 85% of soil field capacity, *, ** Significant at 5% and 1% probability levels, respectively; NS = Non-Significant at $p<0.05$, Means in each column for each of the two treatments followed by the same letter(s) are not significantly different

Table 3: Percentage of increase in yield, yield components and some phonological traits of four durum wheat cultivars in response to increases in its soil moisture level

Characters	M1 to M2	M2 to M3	M1 to M3
Biological yield (g/plant)	136	77.0	318
Seed yield (g/plant)	143	63.0	297
Straw yield (g/plant)	93	77.0	243
Harvest index (%)	-1	-2.0	-4
No. spikes/plant	93	43.0	176
No. of kernels/ plant	137	44.0	242
1000 kernels wt. (g)	7	10.0	18
Plant height (cm)	10	17.0	30
No. of days to heading	2	2.0	4
No. of days to maturity	4	0.1	4

M1 = 50%, M2 = 65% and M3 = 85% of soil field capacity

not show significant variations among cultivars and their interaction with moisture levels; on the contrary, variation in the average number of fertile spikes/plant was highly significant for moisture levels (Table 2). The absence of the significant difference among cultivars for this trait could be attributed to the similarity in their response to the increase in moisture levels. This result contradict with that of Nagarajan *et al.* (1999), who found that the taller cultivars had higher number of fertile tillers than the dwarfs when subjected to post-anthesis water stress. The effect of moisture levels on the trait revealed high increases in the number of spikes/plant which equal to 93 and 42% as moisture level increased from M1 to M2 and from M2 to M3, respectively (Table 3). This result is not in agreement with Moustafa *et al.* (1996) finding that the number of spikes per plant was not affected by the water stress treatments that were applied at different growth stages by withholding water for different periods.

The average number of kernels/plant did not differ significantly among cultivars and their interaction with moisture levels (Table 2). In spite of the similarity in cultivars response for the trait, the number of kernels in Om-quais plants exceeds that of Hourani-27 by 29%. Different response reported by Motzo *et al.* (1996), in which fertility in different wheat cultivars exposed to different moisture levels ranged from 37 kernels per spike for Creso cultivar in 1987 to 61 kernels per spike for Vespro cultivar in 1986. The effect of moisture levels on the trait was very significant (Table 2), therefore, increasing moisture levels from M1 to M2 and from M2 to M3 leads to 137% and 44% increase in the number of kernels/plant (Table 3). This observation is in agreement with the finding of Mohammady-D *et al.* (2003), which indicate that apical fertility in wheat is determined by two dominant genes and their expression is dependent on high temperature and/ or the degree of water stress. This result supports the idea that M1 moisture level was stressful enough to express the genes and induce apical sterility when compared to the other moisture levels tested. Moreover, Rizza *et al.* (2004) reported that kernel number per square meter was highly variable across years and the number of kernels per square meter under rainfed treatments reduced by 6, 10 and 16% in three growing seasons compared with irrigated treatment.

Weight of 1000 kernels is very important quality parameter. It was not significantly affected by the cultivars and its interaction with the moisture levels, in contrast, highly significant effect for the trait obtained due to moisture treatments (Table 2). This similarity among cultivars for the trait contradict with Motzo *et al.* (1996), finding of genotypic variability for kernel weight in wheat grown under different moisture levels ranged from 51.8 mg for Creso cultivar in 1987 to 59.5 mg of Messapia in 1986. The effect of moisture treatments indicated that M3 level gave the highest weight and as moisture levels decline from M3 to M2 and from M2 to M1 the weight of the kernels decreases by 9 and 7% respectively. This result goes parallel with that of Abou El-fotouh *et al.* (2002) and Rizza *et al.* (2004).

Morphological traits: Plant height was found to be highly affected by cultivars and moisture levels (Table 2). Hourani-27 and Safra-ma'an cultivars gave the tallest plants (average 75 cm), while the other two were shortest (average 60 cm). This result is consistent with their characterization as tall for Hourani-27 and Safra-ma'an and as semi-dwarf for the other two cultivars. Such significant genotypic variability for plant height was observed among ten wheat genotypes (Alderfasi, 2001). Response to the moisture levels showed that plant height increased significantly with increasing moisture levels (Table 2). As moisture level increased from M1 to M2 and from M2 to M3, plant height increased by 10 and 17 % respectively (Table 3). This response may be attributed to the improvement in soil moisture that enhances cell expansion and enlargement processes that are responsible for plant elongation (Larson, 1992). This result is in agreement with findings of Alderfasi (2001), in which plant height declined from 89 cm in the control compared to 83.6 cm in the stressed treatment. Also, Rizza *et al.* (2004), found that plant height of barley grown under rainfed condition was reduced by 12, 13 and 45% as compared with irrigated condition in the first, second and third year, respectively. The non-significant interaction for plant height indicated that plant height for all cultivars increases as moisture level rose from M1 to M3 (Table 2). Moreover at each moisture level, genotypic differences between tall and semi-dwarf cultivars were expressed, thus, they can be distinguished easily.

Number of days to heading, determined when 75% of the head is pushed out of the flag leaf sheath and days to maturity, recorded when head and peduncle lose their green color (Zadoks *et al.*, 1974), affected very significantly by cultivars and moisture levels, but their interaction for the two traits was not significant (Table 2). Om-quais was the earliest to reach heading (74 days); it was earlier than Safra ma'an which was the latest by 8 days. Also Safra ma'an was the latest to reach maturity, it matures after 116 days, while the other three cultivars were earlier by 6 days (Table 2). Such genotypic variability for days to anthesis observed in barley, Tina cultivar was 5-7 days later than in Dobla and Tina reached physiological maturity 10 to 17 days later than Dobla (Cantero-Martinez *et al.*, 1995). Similarly, Motzo *et al.* (1996), results of two experiments in a Mediterranean environment revealed that the early wheat cultivar Messapia reached flowering between 132 and 139 days after sowing while Vespro and Creso reached flowering between 141 and 148 days. Moreover Simane *et al.* (1993) reported that drought resistant cultivars reached anthesis and physiological maturity earlier than susceptible ones and the three Ethiopian durum wheat cultivars reached anthesis 5 days earlier than Omrabi-5 cultivar. The effect of moisture levels on the two traits revealed highly significant response (Table 2), as moisture level increases from M1 down to M3 the number of days to heading and maturity increases by 4 days to both (Table 3). This result goes parallel with that reported by Rizza *et al.* (2004) that water stress generally affect plant earliness, so barley heading occurred 1 or 2 days earlier under rainfed conditions with respect to the irrigated treatment every year. An exception to this general statement is Safra-ma'an whose number of days to heading remain constant (81 days) at the different moisture levels.

Finally, the absence of significant interaction between the cultivars and the moisture treatments tested for most of the traits evaluated (Table 2) emphasized the idea that the cultivars behave similarly under the different moisture levels. Therefore, the four cultivars can be alternatives to each other under the moisture levels tested

CONCLUSIONS

It can be concluded that the four cultivars have a very good potential for survival under stressful conditions, because they grow and produce at soil moisture level about 4% below wilting point, also they prove to be responsive to improvement in level of soil moisture. Moreover, the four cultivars can be substitutes for each other within the moisture levels tested. Improvements in management practices of wheat production as selecting the proper combination between the cultivar and its environment or applying supplementary irrigation seems to be promising approaches in rainfed areas for avoiding crop failure and for improving wheat production and quality by limited amount of water. Further research is required to investigate the water relations of the cultivars under similar environments to obtain deeper and better understanding for the performance of the cultivars.

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REFERENCES

Abou El-Fotouh, N.Z., Y.E. Atta and W.M. Shaalan, 2002. Effect of amount of irrigation water calculated from class A pan on growth and yield of wheat and some related water relations. Zagazig J. Agric. Res., 29: 1411-1427.

Alderfasi, A.A., M.O. Ghandorah and K.A. Moustafa, 1999. Evaluation of some wheat genotypes under drought stress in arid region of Saudi Arabia. Alex. J. Agric. Res., 44: 209-217.

Alderfasi, A.A., 2001. Evaluation of certain traits associated with drought resistance in wheat under field conditions. Ann. Agric. Sci., Ain Shams Univ., Cairo, 46: 71-83.

Cantero-Martinez, C., J.M. Villar, L. Romagosa and E. Fereres, 1995. Growth and yield responses of two contrasting barley cultivars in a Mediterranean environment. Eur. J. Agron., 4: 317-326.

Cooper, P.J.M., P.J Gregory, D. Tully and H.C. Harris, 1987. Improving water use efficiency of annual crops in the rain fed farming systems of West Asia and North Africa. Exp. Agric., 23: 113-158.

Elings, A., 1993. Durum wheat landraces from Syria. III. Agronomic performance in relation to collection regions and landrace groups. Euphytica, 70: 85-96.

Ferrara, G.O., 1994. Experiences, difficulties and prospects for stress resistance breeding in wheat in WANA. Melhoramento, 33: 105-118.

Ketata, H., 1987. Actual and Potential Yields of Cereal Crops in Moisture Limited Environments. In: Drought tolerance in winter cereals: Srivastava, J.P., E. Porcedu, E. Acevedo and S.Varma (Eds.), ICARDA, John Wiley and sons, Chichester, pp: 55-61.

Larson, K.L., 1992. Drought Injury and Resistance of Crop Plants. In: Physiological Aspects of Dry land Farming Gupta, S.U. (Ed.). Oxford and IBH Publishing Co. Pvt. Ltd.: New Delhi, pp: 147-162.

Loomis, R.S. and D.J. Conner, 1992. Crop Ecology: Productivity and Management in Agricultural Systems. Cambridge University Press. UK.

Marshal, T.J. and J.W. Holmes, 1979. Soil Physics. Cambridge University Press, U.K.

Mohammady-D, S., K. Moore and J. Ollerenshaw, 2003. Qualitative inheritance of water-stress induced apical sterility in wheat (*Triticum aestivum)*. Hereditas, 138: 237-240.

Motzo, R., F. Giunta and M. Deidda, 1996. Relationships between grain filling parameters, fertility, earliness and grain protein of durum wheat in a Mediterranean environment. Field Crops Res., 47: 129-142.

Moustafa, M.A., L. Boersma and W.E. Kronstad, 1996. Response of four spring wheat cultivars to drought stress. Crop Sci., 36: 982-986.

Nagarajan, S., J. Rane, M. Maheswari and P.N. Gambhir, 1999. Effect of post-anthesis water stress on accumulation of dry matter, carbon and nitrogen and their partitioning in wheat varities differing in drought tolerance. J. Agron. Crop Sci., 183: 129-136.

Noggle, G.R. and G.J. Fritz, 1976. Introductory plant physiology. Englewood Cliffs, N.J. Prentice-Hall.

Oweis, T., M. Pala and J. Ryan, 1998. Stabilizing rain fed wheat yields with supplemental irrigation and nitrogen in a Mediterranean climate. Agron. J., 90: 672-681.

Rizza, F., F.W. Badeck, L. Cattivelli, O. Lidestri, N. DiFonzo and A.M. Stanca, 2004. Use of water stress index to identify barley genotypes adapted to rainfed and irrigated conditions. Crop Sci., 44: 2127-2137.

Simane, B., J.M. Peacock and P.C. Struik, 1993. Differences in developmental plasticity and growth rate among drought-resistant and susceptible cultivars of durum wheat (*Triticum turgidum* L. var. durum). Plant and Soil., 157: 155-166.

Turner, N.C., 1986. Crop water deficit: A decade of progress. Adv. Agron., 39: 1-51.

Wahbi, A. and P.J. Gregory, 1989. Genotypic differences in root and shoot growth of barley (Hordeum Vulgare). II Field studies of growth and water use of crops grown in Northern Syria. Exp. Agric., 25: 389-399.

Zadoks, J.C., T.T. Changes and C.F. Knozak, 1974. A decimal code for growth stages of cereals. Weed Res., 14: 415-421.