Research Article

www.ekinjournal.com

Ekin International biannual peer-reviewed journal

Ekin
Journal of Crop Breeding and Genetics

2(1):82-89, 2016

The Effect of Supplementary Irrigation on Leaf Area, Specific Leaf Weight, Grain Yield and Water Use Efficiency in Durum Wheat (*Triticum durum* Desf.) Cultivars

Ali Guendouz[1*] **Nadjim Semcheddine**[2] **Lyes Moumeni**[1] **Miloud Hafsi**[2]

[1] National Institute of Agronomic Research of Algeria, Research Unit of Setif (INRAA).
[2] Department of Agronomy, Ferhat ABBAS University of Setif (Algeria).

[*] Corresponding author e-mail: guendouz.ali@gmail.com

Citation:
Guendouz A., Semcheddine N., Moumeni L., Hafsi M., 2016. The effect of supplementary irrigation on leaf area, specific leaf weight, grain yield and water use efficiency in durum wheat (*Triticum durum* Desf.) cultivars. Ekin J. 2(1):82-89.

Received: 07.09.2014 ***Accepted: 19.07.2015*** ***Published Online: 29.01.2016*** ***Printed: 29.01.2016***

ABSTRACT

The main aim of the present study is to understand the impact of irrigation on Leaf area, Specific Leaf Weight, Grain yield and Water use efficiency. Ten durum wheat (*Triticum durum* Desf.) genotypes of diverse origin were evaluated under two conditions (Irrigated and non irrigated conditions). After flowering, ten flag leaf of each plot were cut for measuring the length, width and mass of leaf. Leaf area (LA) while Specific Leaf Weight (SLW) was measured mathematically . Water use efficiency of yield was calculated using the following equation: WUE_{yield} = Grain Yield / evapo-transpired water. In this study the difference between Leaf area under stressed and non stressed condition equal 17.24%. In addition, water stress reduced the specific leaf weight (41.86%). Irrigation condition affects positively the grain yield (12.42%) and negatively water use efficiency (12.11%). WUE_{yield} of wheat under Mediterranean conditions was the highest with a deficit irrigation consisting of two-thirds of the water required at full irrigation (i.e. WUE_{yield} at full irrigation was lower).

Keywords: durum wheat, leaf area, specific leaf weight, WUE, irrigation.

Introduction

Durum wheat (*Triticum durum* Desf.) is widely grown in stressful environments. Under stressed conditions, the maintenance of high leaf net CO_2-exchange rates and higher water use efficiency was associated with higher wheat yields (Austin, 1987). Leaf area (LA) plays an important role in plant growth analysis. Leaf area and leaf weight measurements are required to calculate several growth indices, which are leaf area index (LAI), net assimilation rate (NAR), specific leaf area (SLA), specific leaf weight (SLW), and leaf area duration (LAD) (Gardner *et al*. 1985). The leaves, being the site of photosynthetic activity, appear to have an obvious relation to the plant's grain yield ability (Sharma *et al*. 2003). Flag leaf makes a major contribution towards the grain weight (41-43%) and is the major photosynthetic site during the grain filling period (Ibrahim and Elenein, 1977). Flag leaf area is an indicator of potential grain yield in wheat and since the flag leaf plays a predominant role, its size is likely to be important (Monyo and Whittington, 1973). Photosynthesis is the primary source of dry matter production and grain yield in crops. The improvements of leaf photosynthesis have occurred with the advance of high-yielding cultivars breeding (Jiang *et al*. 2002). The flag leaf is considered to be a primary source of assimilates for grain filling and grain yield due to its short distance to the pike and the fact that it stays green for longer than the rest of the leaves. Positive correlations have been found between flag leaf size and yield (Briggs and Aytenfisu, 1980). Recently, the leaf area index or other indices of vegetation have been used in agricultural models for biomass estimation and yield prediction (Major *et al*. 1986). There are various methodological approaches to measure plant leaf area. Direct measurement of leaf area is usually time consuming and labor intensive and this action usually causes canopy damage. But leaf area can be estimated non-destructively by using mathematical formulae, which only require simple measurements of the leaf lamina. Potdar and Pawar (1991) evaluated non-destructive leaf area estimation in banana (*Musa acuminata* Colla.) and showed a strong relationship between leaf area and various combinations of leaf length (L) and leaf width (W). Pekson (2007) also showed that there was a high correlation between leaf area and a combination of lamina length (L) and lamina width (W) in *Vicia faba* L. Serdar and Demirsoy (2006) developed a mathematical equation to estimate leaf area in chestnut (*Castanea sp*.) by measuring leaf length and leaf width and calculated different combination of them. Their result showed that there was a strong relationship between estimated leaf area and actual leaf area (R^2=0.99). Cho *et al*. (2007) found that estimation of individual LA, leaf fresh weight (LFW) and LDW in hydroponically grown cucumbers (*Cucumis sativus L*.) can be done with high accuracy using leaf length, leaf width and leaf chlorophyll value (R^2=0.98, R^2=0.96, R^2=0.96 respectively). McKee (1964), Pearce *et al*. (1975), and Dwyer and Stewart (1986), reported a general equation to estimate individual leaf area of maize (*Zea mays L*.):

$$\text{Leaf area} = L \times W \times A$$

Where LA, L, W and A are leaf area, leaf length, leaf maximum width and A constant (A=0.75), respectively. Other researchers obtained A values between 0.72 and 0.79, for example 0.72; (Keating and Wafula, 1992), 0.73; (Stewart and Dwyer, 1999), and 0.79; (Birch *et al*. 1998). Specific leaf area (SLA), that is, the light-capturing surface built by the plant per unit investment of dry mass, is an indirect measure of the return on investments in a productive organ (Niklas *et al*. 2007). If light capture was the sole governing factor of leaf function, SLA would tend to be infinite to maximize return on dry mass investment. However, maximum SLA is constrained by a minimum of dry mass needed to construct support, protection or transport tissues, such as veins or epidermis, which are generally dense. SLA is further particularly sensitive to changes in the external environment and in the internal functioning of the plant, as extensively documented both by experimental and observational studies (Gunn *et al*. 1999; Niinemets, 2001; Poorter and Nagel, 2000). However, until recently the dependence of SLA on leaf size had not been comprehensively assessed (Milla and Reich, 2007). SLA and leaf size (measured as A (cm^2) are functionally linked by definition (SLA=A/M (cm^2/mg) where M is leaf mass (g). Thus, to quantify how a given change in leaf size affects SLA we examined the scaling relationship of M to A. Landsberg (1990) used the inverse of SLA, namely specific leaf weight (SLW in mg/cm^2), as an indicator of leaf toughness in her studies of insect herbivory and eucalypt dieback. Water is the main abiotic factor limiting plant production in several regions of the world, with crop growth and economic yield being severely affected by water availability (Araus *et al*. 2002).

The water use (WU; i.e. the water consumed) and water use efficiency (WUE; in general terms, the efficiency of this consumed water to assimilate carbon, produce biomass or grain yield) are crucial parameters where water is scarce, as in semi-arid regions with Mediterranean climate (e.g. Mediterranean basin in south Europe, North Africa and West Asia as well as Western Australia and parts of South Africa and Chile). Agronomists and crop physiologists, however, define WUE rather from an integrative approach, i.e. the accumulated dry matter divided by the water used by the crop in the same period (Abbate *et al*. 2004). In a broad sense, assimilated dry matter can be considered as the total biomass (commonly, aboveground parts) or, alternatively, as the accumulated dry matter partitioned the economical product (for cereals, the grains). Thus, it may be defined as WUE for the biomass ($WUE_{biomass}$) and the grain yield (WUE_{yield}) (Hatfield *et al*. 2001). The aim of this study is to evaluate the effect of stressed and non stressed conditions on Leaf area (LA) and Specific Leaf Weight (SLW) and its relationships with grain yield and water use efficiency in ten durum wheat Cultivars.

Material and methods

The experiments (under rain-fed and irrigation conditions) were conducted in the experimental field of ITGC (Technical Institute of Field Crops) of Sétif (5°20'E, 36°8'N, 958m above sea level), Algeria; during the 2010-2011 cropping season. A set of 10 genotypes (Table 1) of durum wheat (*Triticum durum* Desf.) were planted on November 30, 2010, genotypes were grown in randomized block design with four replicates. The seeds were sown using an experimental drill in 1.2mx2.5m plots consisting of

6 rows with a 20 cm row space and the seeding rates for both experiments were about 300 seeds per m^2. The plots were fertilized with SULFAZOT (26% N, 35% S, 120 Kg/ha) at tillage stage. Weeds were removed chemically by TOPIC (0.75L/ha) and GRANSTAR (15g/ha). All plots of the irrigation experiment were irrigated by using a Sprinklers system and the volume of water input for each plot was controlled. Two irrigation regimes were applied. The first irrigation was performed at the time of Elongation (20/04/2011) (30 zadoks cods). The second irrigation was applied on (08/05/2011) after heading (50 zadoks cods). After flowering, ten flag leaf of each plot were cut for measuring the length, width and mass of leaf. Leaf area (LA) and Specific Leaf Weight (SLW) were measured mathematically. LA=L × W × A (Spagnoletti Zeuli and Qualset, 1990); where LA, L, W, and A are leaf area, leaf length, leaf maximum width and A constant (A=0.607) respectively. SLW and leaf area (LA) are functionally linked by definition (SLW=M/LA (mg/cm²)) when M is leaf mass (g) (Radford, 1967). Water use efficiency was calculated using the following equation:

$$WUE_{yield} = \text{Grain Yield / evapo-transpired water}$$
(Tambussi *et al.* 2007)

Grain yield was determined from sub-samples taken from harvested grains of each plot.

Evapo-transpired water is estimated by using software AquaCrop Version 3.1. The input necessary to estimate the evapo-transpired water by AquaCrop software were:

– Daily rainfall of growing season;

– Daily Reference evapo-transpiration (ET_0) estimated by using ET_0 software (2000) and according to Penman Montheil equation modified and recommended by FAO (1998);

– The different layers and types soil of experimental field;

– Morpho-physiological characteristics of crop (Genotypes) and growing cycle of each genotype.

Results and discussion

As shown in Table 2, analysis of variance revealed that Leaf area, Specific Leaf Weight, WUE_{yield} and grain yield were highly significant ($P<0.001$) under irrigation regime treatment. In addition, the genotypic effect was highly significant ($P<0.001$) for Leaf area, Specific Leaf Weight and grain yield under both conditions, WUE_{yield} was highly significant ($P<0.001$) under irrigated condition and significant ($P<0.01$) under non irrigated condition. Moreover, interaction effect of irrigation regime × genotype was highly significant for Leaf area and Specific Leaf Weight.

3.1. Leaf area (LA)

The results of the present study indicated that the two different conditions of growth (stress and non stress conditions) had different considerable effects on leaf area. Under stressed condition, leaf area ranged from 11.46 cm² for Polonucum to 19.37 cm² for Oued Zenati with an average of 14.96 cm² over all genotypes, but under irrigated condition (non stressed) leaf area varied between 13.83 cm² for Altar to 30.66 cm² for Oued Zenati with an average of 18.09 cm² over all genotypes. In this study, the difference between Leaf area under stressed and non stressed condition amounted to 17.24% (Figure 1). The maximum leaf area *per* culm was observed just before heading when the flag leaf had fully emerged (Puckridge, 1971). The water stress significantly reduced leaf area due to the reduced cell division. Water stress may reduce turgor pressure and hence cell expansion, resulting in approximately the same dry mass being contained within a smaller leaf area, thus raising density (Hsiao, 1973; Rascio *et al.* 1990).

3.2. *Specific Leaf Weight (SLW)*

A survey of literature revealed that morpho-physiological traits such as flag leaf area (Fischer and Wood, 1979), specific leaf weight, leaf dry matter (Aggarwal and Sinha, 1984; Misra, 1995) had been widely used as selection parameters contributing towards drought tolerance for various crop plants in addition to grain yield. With regard to genotype effects and under stressed condition, Polonucum had high value of SLW 0.0349 mg cm^{-2}, but Mexicali had low value 0.0162 mg cm^{-2}. Under non stressed condition, specific leaf weight ranged from 0.062 mg cm^{-2} for Bousselem to 0.062 mg cm^{-2} for Dukem with an average of 0.043 mg cm^{-2} over all genotypes. Figure 2 shows that water stress reduced the specific leaf weight (41.86%). Munamava and Riddoch (2001) reported that specific leaf weight (SLW) and specific leaf area (SLA) decreased with stress, especially when water stress was applied at booting stage.

3.3. Grain Yield (GY)

The results of the present study indicated that the two different conditions of growth (stress and non stress condition) had different considerable effects on grain yield. Under stressed condition, grain yield ranged from 52.20 Qx ha^{-1} for genotype

Oued Zenati to 64.63 Qx ha^{-1} for genotype Waha with an average of 58.50 Qx ha^{-1} over all genotypes, but under well watered condition, grain yield ranged from 57.45 Qx ha^{-1} for genotype Oued Zenati to 75.55 Qx ha^{-1} for genotype Sooty with a mean of 66.8 over all genotypes. Drought resistance is usually quantified by grain yield under drought. Wheat grain yield under drought, however, depends on yield potential as well as the phenology of the genotype (Acevedo, 1991) . In this study, the difference between grain yield under stressed and non stressed condition equal 12.42% (Figure 3). Although stress typically depresses grain yield (Hsiao, 1973), it can elevate the value of other components of the economic yield, such as quality of grain protein (Guttieri *et al*. 2000). Moreover, Donaldson (1996) and Nazeri (2005) have reported that water deficit after anthesis stage decreased grain filling period, kernel weight and crop production. According to Blum (1988), identification of high potential varieties under optimum moisture and water deficit conditions (slow stressing) has been a principal breeding approach for durum and bread wheat genotypes.

3.4. Water use efficiency (WUE_{yield})

The results of the present study show that there is a highly significant difference between stressed and non stressed conditions and genotypes. Under stressed condition, WUE_{yield} ranged from 9.21 kg mm^{-1} ha^{-1} for Oued Zenati to 12.44 kg mm^{-1} ha^{-1} for Sooty. In irrigated condition WUE_{yield} varied between 9.25 kg mm^{-1} ha^{-1} for Oued Zenati and 14.29 kg mm^{-1} ha^{-1} for Waha; the difference in WUE_{yield} between irrigated and non irrigated conditions accounted 12.11% (Table 2). Oweis *et al*. (2000) reported that WUE_{yield} of bread wheat under Mediterranean conditions was the highest with a deficit irrigation consisting of two-thirds of the water required at full irrigation (i.e. WUE_{yield} at full irrigation was lower). In fact, increase in WUE_{yield} under water limitation are reported in several studies and climatic conditions (Abbate *et al*. 2004). However, there are other reports in wheat where no increase in WUE (neither WUE_{yield} nor $WUE_{biomass}$) was found under water-deficit treatments (Xue *et al*. 2003).

Conclusion

This study confirmed that the supplementary irrigation affect significantly Leaf area, Specific Leaf Weight, Grain yield and Water use efficiency. The difference between Leaf area under stressed and non stressed condition was 17.24%, this suggest that the water stress significantly reduced leaf area due to the reduced cell division. In addition, water stress reduced the specific leaf weight by 41.86%. Many studies reported that specific leaf weight (SLW) and specific leaf area (SLA) decreased with stress, especially when water stress was applied at booting stage. The difference between grain yield under stressed and non stressed condition was 12.42 %. Water deficit after anthesis stage decreased grain filling period, kernel weight and crop production. The difference in WUE_{yield} between irrigated and non irrigated conditions was 12.11%. Many studies reported that WUE_{yield} of bread wheat under Mediterranean conditions was the highest with a deficit irrigation consisting of two-thirds of the water required at full irrigation (i.e. WUE_{yield} at full irrigation was lower).

Table 1. Name and origin of the ten genotypes used in the study

Cultivar	Name	Origin	Cultivar	Name	Origin
1	Bousselem	Algeria	**6**	Altar	CIMMYT
2	Hoggar	Algeria	**7**	Dukem	CIMMYT
3	Oued Zenati	Algeria	**8**	Kucuk	CIMMYT
4	Polonicum	Algeria	**9**	Mexicali	CIMMYT
5	Waha	Algeria	**10**	Sooty	CIMMYT

Table 2. Response of Leaf area (LA), Specific leaf weight (SLW), water use efficiency of grain yield (WUE_{GY}) and grain yield (GY) of ten durum wheat genotypes tested.

	LA		SLW		WUE_{GY}		GY	
Genotype	**Irr**	**Non-Irr**	**Irr**	**Non-Irr**	**Irr**	**Non-Irr**	**Irr**	**Non-Irr**
Oued Zenati	30,66 a	19,37 a	0,0457 bc	0,0251 bc	9,25 d	9,21 e	57,46 d	52,20 d
Altar	13,83 d	14,75 bcd	0,0395 bcd	0,0262 b	12,37 bc	11,38 abc	69,14 abc	55,94 bcd
Sooty	16,43 cd	13,12 de	0,0486 b	0,0250 bc	13,96 ab	12,44 a	75,55 d	63,15 abc
Polonucum	24,41 b	11,46 e	0,0426 bcd	0,0349 a	10,01 d	9,65 de	60,18 cd	56,48 abcd
Waha	17,11 c	12,02 de	0,0454 bc	0,0333 a	14,29 a	10,86 abcd	65,94 abcd	64,63 a
Dukem	14,66 cd	17,15 ab	0,0620 a	0,0205 bcd	14,14 a	11,97 ab	72,70 ab	63,94 ab
Mexicali	15,77 cd	17,29 ab	0,0454 bc	0,0162 d	13,18 abc	10,45 abce	63,44 bcd	59,64 abcd
Kucuk	15,67 cd	16,35 abc	0,0343 cd	0,0196 cd	11,93 c	12,11 a	73,53 a	53,96 d
Hoggar	14,93 cd	13,36 cde	0,0381 bcd	0,0226 cd	13,28 abc	10,27 cde	62,36 cd	60,05 abcd
Bousselem	16,48 cd	14,75 bcd	0,0304 d	0,0215 bcd	12,16 c	11,16 abcd	67,75 abc	55,01 cd
Mean	18,099	14,967	0,043	0,025	10,95	12,46	66,80	58,50
Min	13,83	11,46	0,0304	0,0162	9,25	9,21	57,45	52,20
Max	30,66	19,37	0,062	0,0349	14,29	12,44	75,55	64,63
CV %	30,20	17,04	20,10	23,89	9,75	13,7	9,00	7,55
LSD 0,05	2,68	3,18	0,0122	0,0060	1,67	1,6	9,77	8,15
Genotype effect	***	***	***	***	***	**	***	***
Irrigation effect	***		***		***		***	
Interaction effect	***		***		*		ns	
% Differences	17,24 ↑		41,86 ↑		13,78 ↓		12,42 ↑	

Means followed by the same latter are not significantly different, CV: coefficient of variation, ns: no significant, * Significant difference at $P < 0.05$, ** significant difference at $P < 0.01$, *** significant difference at $P < 0.001$

Figure 1. The effect of irrigation on leaf area in all genotypes tested.

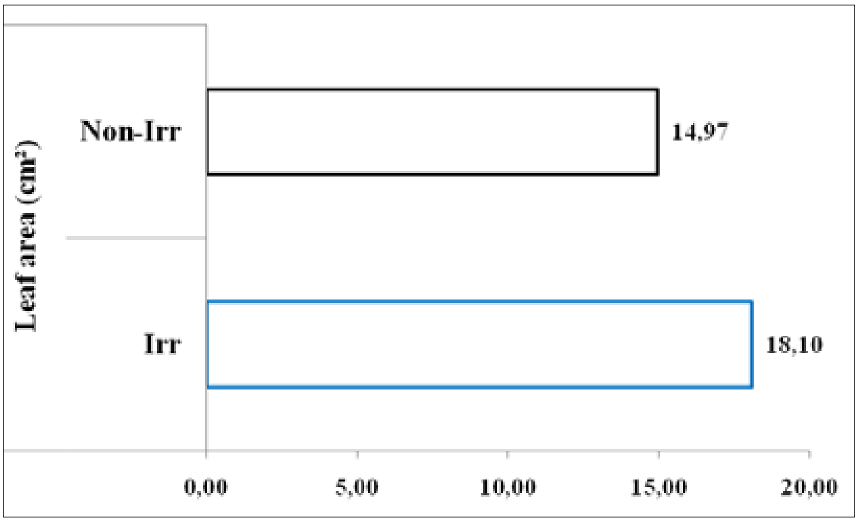


Figure 2. The effect of irrigation on Specific leaf weight in all genotypes tested.

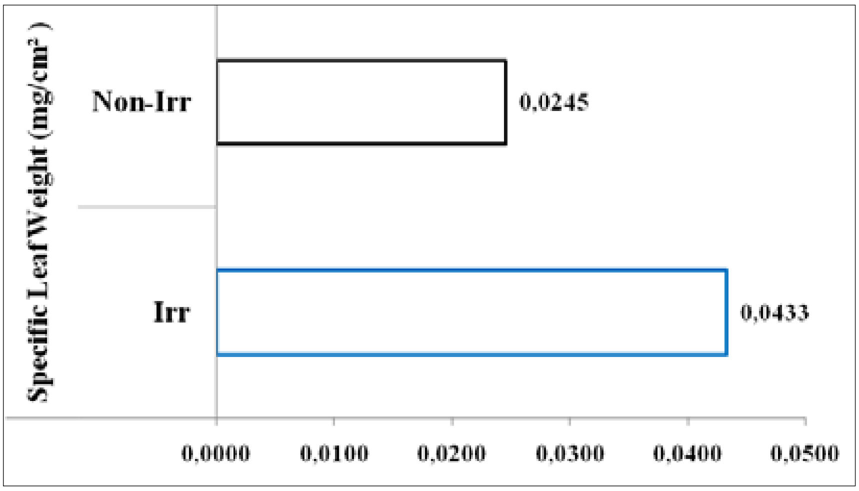
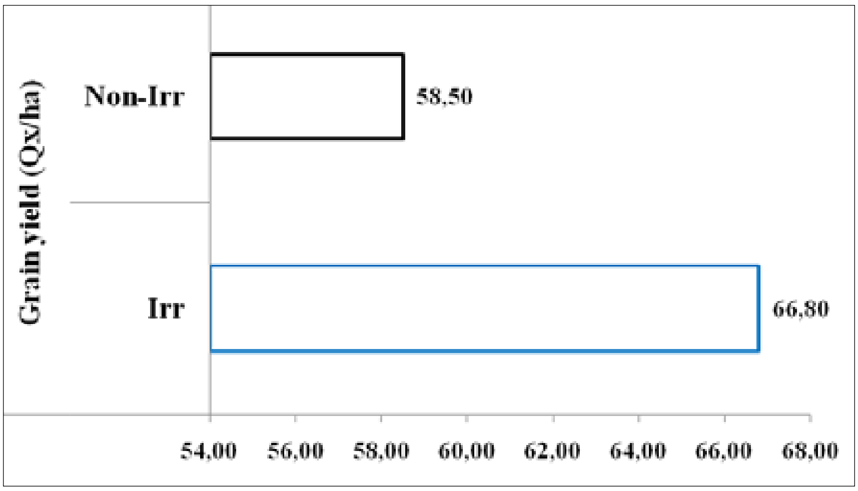


Figure 3. The effect of irrigation on Grain yield in all genotypes tested.



References

Abbate PE, Dardanelli JL, Cantarero MG, Maturano M, Melchiori RJM, Suero EE (2004). Climatic and water availability effects on water-use efficiency in wheat. Crop Science 44, 474-483.

Acevedo E (1991). Improvement of winter cereal crops in Mediterranean environments: use yield, morphological and physiological traits. In: E Acevedo, AP Conesa, P Monneveux and P Srivastava (eds.), Physiology Breeding of Winter Cereals for Stressed Mediterranean Environments. INRA, France, 273-305.

Aggarwal PK, Sinha SK, (1984). Differences in water relations and physiological characteristics in leaves of wheat associated with leaf position on the plant. Plant Physiol 74, 1041-1045.

Araus JL, Slafer GA, Reynolds MP, Royo C (2002). Plant breeding and drought in C3 cereals: what should we breed for? Annals of Botany 89, 925-940.

Austin RB (1987). Some crop characteristics of wheat and their influence on yield and water use. In: Drought Tolerance in Winter Cereals, Srivastava JP, Porceddu E, Acevedo E and Varma S, John Willey & Sons, Chichester, 321-336.

Blum A (1988). Physiological selection criteria for drought resistance. In: Wittmer G (eds.), The future of cereals for human feeding and development of biological research. Int.fair of Agric., 39 , FOGGIA, Italy, pp: 191-199.

Birch CJ, Hammer GL, Rickert KG (1998). Improved methods for predicting individual leaf area and leaf senescence in maize (*Zea mays*) Australian Journal of Agricultural Research 49, 249-262

Briggs KG, Aytenfisu A (1980). Relationship between morphological characters above the flag leaf node and grain yield in spring wheat. Crop Science 20, 350-354.

Cho YY, Oh S, Oh MM, Son JE (2007). Estimation of individual leaf area, shoot fresh weight, and shoot dry weight of hydroponically growth cucumbers (*Cucumis sativus* L.) using leaf length, width, and SPAD value. Scientia Horticulturae 111, 330-334.

Donaldson E (1996). Crop traits for water stress tolerance. American Journal of Alternative Agriculture, 11: 89-94.

Dwyer LM, Stewart DW (1986). Leaf area development in field-grown maize. Agronomy Journal 78, 334-343.

Fischer RA, Wood JT (1979). Drought resistance in spring wheat cultivars. III. Yield association with morpho-physiological traits. Australian J. Agric. Res 30, 1001-1020.

Gardner FP, Pearce RB, Mitchell RL (1985). Physiology of Crop Plants. Iowa State University Press Ames, IA.

Gunn S, Farrar JF, Collis BE, M, N (1999). Specific leaf area in barley: individual leaves versus whole plants. New Phytologist, 143, 45-51.

Guttieri M, Ahmad JR, Stark JC, Souza E (2000). End-use quality of six hard red spring wheat cultivars at different irrigation levels. Crop Science, 40: 631-635.

Hatfield JL, SauerTJ, Prueger JH (2001). Managing soil to achieve greater water use efficiency. Agronomy Journal, 93, 271-280.

Hsiao TC (1973). Plant responses to water stress. Annu Rev Plant Physiol 24, 519-570.

Ibrahim HA, Elenein RA (1977). The relative contribution of different wheat leaves and awns to the grain yield and its protein content. Z. Ack. Pflanz, 144, 1-7.

Jaleel CAP, Manivannan A, Kishorekumar B, Sankar R, Somasundaram R, Panneerselvam R (2007). Alterations in osmoregulation, antioxidant enzymes and indole alkaloid levels in Catharanthus roseus exposed to water deficit. Colloids Surf. B: Biointerfaces 59, 150-157.

Jiang H, Wang XH, Deng QY, Yuan LP, Xu DQ (2002). Comparison of some photosynthetic characters between two hybrid rice combinations differing in yield potential. Photosynthetica 40, 133-137.

Keating BA, Wafula BM (1992). Modeling the fully expanded area of maize leaves. Field Crops Research 29, 163-176.

Landsberg J (1990). Dieback of rural eucalypts: Does insect herbivory relate to dietary quality of tree foliage? Australian Journal of Ecology 15:73-87.

Major DG, Schaalje GB, Asrar G, Kanemasu ET (1986). Estimation of whole plant biomass and grain yield from spectral reflectance of cereals. Canadian Journal of Remote Sensing 12, 47-54.

McKee GW (1964). A coefficient for computing leaf area in hybrid corn. Agronomy Journal 56, 240-241.

Milla R, Reich PB (2007). The scaling of leaf area and mass: the cost of light interception increases with leaf size. Proceedings of the Royal Society of London Series B 274, 2109-2114.

Misra AN (1995). Assimilate partitioning in pearl millet (*Pennisetum glaucum* L.R.Br.). Acta Physiol. Plant 17, 41-46.

Monyo JH, Whittington WJ (1973). Genotypic differences in flag leaf area and their contribution to grain yield in wheat. Euphytica 22, 600-606.

Munamava M, Riddoch I (2001). Responses of three sorghum [Sorghum bicolor (L.), Moench] varieties to soil moisture stress at different developmental stages. South African J Plant Soil 18:75-79.

Nazeri M (2005). Study on response of triticale genotypes at water limited conditions at different developmental stages. PhD thesis, University of Tehran, Iran.

Niinemets Ü (2001). Global-scale climatic controls of leaf dry mass per area, density, and thickness in trees and shrubs. Ecology 82, 453-469.

Niklas KJ, Cobb ED, Niinemets Ü, Reich PB, Sellin A, Shipley B, Wright I (2007). Diminishing returns' in the scaling of functional leaf traits across and within species groups. Proceedings of the National Academy of Sciences of the United States of America 104, 8891-8896.

Oweis T, Zhang H, Pala M (2000). Water Use Efficiency of Rainfed and Irrigated Bread Wheat in a Mediterranean Environment. Agronomy Journal 92: 231-238.

Pearce RB, Mock JH, Bailey TB (1975). Rapid method for estimating leaf area per plant in maize. Crop Science 15, 691-694.

Pekson E (2007). Non-destructive leaf area estimation for faba bean (*Vicia faba* L.). Scintica Horticulturae 113, 322-328.

Potdar MV, Pawar KR (1991). Non-destructive leaf area estimation in banana. Scintica Horticulturae 45, 251-254.

Poorter H, Nagel O (2000). The role of biomass allocation in the growth response of plants to different levels of light, CO2, nutrients and water: a quantitative review. Australian Journal of Plant Physiology 27, 595-607.

Puckridge DW (1971). Seasonal trends in carbondioxide uptake of crop communities Australian Journal of Agriculture 23, 1-4.

Radford PJ (1967). Growth analysis formulae-use and abuse. Crop.Sci.7:171-175.

Rascio A, Cedola M, Topani M, Flagella Z, Wittmer G (1990). Leaf morphology and water status changes in Tritieum durum under water stress. Physiol Plant 78, 462-467.

Serdar U, Demirsoy H (2006). Non-destructive leaf area estimation in chestnut. Scintica Horticulturae 108, 227-230.

Sharma S, Sain RS, Sharma RK (2003). The genetic control of the flag leaf length in normal and late sown durum wheat. Journal of Agricultural Science 141, 323-331.

Spagnoletti Zeuli PL, Qualset CO (1990). Flag leaf variation and the analysis of diversity in durum wheat. Plant Breeding 105, 189-202.

Stewart DW, Dwyer LM (1999). Mathematical characterization of leaf shape and area of maize hybrids. Crop Science 39, 422-427.

Tambussi EA, J Bort, JL Araus (2007). Water use efficiency in C3 cereals under Mediterranean conditions: a review of physiological aspects. Annals of Applied Biology 150, 307–321.

Xue Q, Zhu Z, Musick JT, Stewart BA, Dusek DA (2003). Root growth and water uptake in winter wheat under deficit irrigation. Plant and Soil 257, 151-161.