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Water Use Efficiency of Four Dryland Wheat Cultivars under Different Levels of Nitrogen Fertilization

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ABSTRACT

It is suggested that cultivars of wheat (*Triticum aestivum* L.) with regulated growth and development would be able to produce higher yields under water-limited conditions, which is crucial in future food production. Water use efficiency (WUE) is worthy of exploration in this regard. In this study, the effects of nitrogen fertilizer levels (0, 40 and 80 kg Nha^{-1}) and a plant growth retardant (Chlormequat Chloride = CCC) on WUE of four dryland wheat cultivars (Agosta, Nicknejad, Azar-2 and Fin-15) were examined in a field experiment during 2006-07 and 2007-08 growing seasons at College of Agriculture, Shiraz University, Iran. The results showed that there existed significant differences between cultivars for grain yield, biomass and WUE. In the first season, the highest grain yield and biomass production (192.4 and 431.2 gm^{-2}, respectively) were obtained from Nicknejad cultivar, CCC application and using 80 kg Nha^{-1}, and in the second season, from Azar-2 cultivar (121.5 and 333.5 gm^{-2}, respectively). CCC and nitrogen had significant effects on photosynthesis rate and WUE in both seasons. Interaction of CCC and 80 kg Nha^{-1} on WUE were significant in both seasons (1.24 and 2.72 gm^{-2}mm^{-1}, respectively). It is suggested that interactive application of CCC and nitrogen fertilizer could have beneficial effects on wheat grain yield under similar agro-climatic conditions.

Keywords*:* Chlormaquat chloride, Drought Stress, Grain Yield, Photosynthesis Rate (An), Stomatal Conductance (gs), WUE.

INTRODUCTION

With increase in water resources deficit, biological water saving has become a hot topic in the world (Shen, 1991 and Chaves *et al.*, 2003). In an agricultural context, water deficit is one of the most important environmental factors constraining crop photosynthesis and productivity in arid and semi-arid areas (Zhenzhu and Guangsheng, 2008). Therefore, control in moisture and soil fertilization levels is vital for improving wheat yield (Clarke *et al.*, 1990; Blum and Johnson, 1993 and Li *et al.*, 2001). In semi-arid areas, production is mainly dependent on rainfall whereas water shortage and low nutrient availability are the main factors limiting the growth of crops in these areas (Li *et al.*, 2001).

Water use efficiency (WUE) is the ratio of net CO_2 assimilation to water used (Bacon, 2004). CO_2 assimilation may be in terms of net CO_2 exchange, dry matter growth, and economic yield, while water used may be determined by mass or molar unit (Bacon, 2004). According to Qiu *et al* (2008), WUE could be defined as: short-term gas exchange on a photosynthesis basis (WUE_{photo}), a biomass basis (WUE_{bio}), or a yield basis (WUE_{grain}). WUE_{bio} could be used to describe the behavior of a plant population in long-term (Qiu *et al.*, 2008).

Wheat WUE has been reported to be decreasing with the increase in irrigation

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times and amount of irrigation water per growing season (Qiu *et al.*, 2008). In treatments where drought was imposed, before or later anthesis, the primary cause of reduced efficiencies was a decrease in intercepted light which ultimately reduced the economic parts (Wajid *et al.*, 2007).

Fertilization in dryland can increase the use of soil moisture, and improve wheat yields to some extent. Fertilizer application has been reported to have a beneficial effect on improving WUE and grain yield of spring wheat (Zi-Zhen *et al.*, 2004). Also, precipitation use efficiency has increased with N addition above 56 kg $\mathrm{Nha^{-1}}$ (Holverson *et al.*, 2004).

Photosynthetic capacity in crop plants is the primary component of dry matter productivity (Ashraf and Bashir, 2003). The final biological or economic yield can be increased by increasing the rate of photosynthesis, by reducing wasteful respiration or by optimizing assimilate partitioning (Lawlor, 1995). Zhenzhu and Guangsheng (2008) reported that the stomatal size was obviously decreased with water deficit. The stomatal density has been found to be positively correlated with stomatal conductance (gs), net CO_2 assimilation rate (An), and WUE (Monneveux *et al.*, 2006). Drought stress is reported to have decreased wheat photosynthesis rate, stomatal conductance, shoot and grain mass, but it increased plant water-use efficiency (Shah and Paulsen, 2003 and Monneveux *et al.*, 2006).

For rainfed winter wheat, WUE has been reported to be about 0.40 $\mathrm{kgm^{-3}}$ on a yield basis with a yield of 1000–2000 kg $\mathrm{ha^{-1}}$ in the Texas High Plains (Musick *et al.*, 1994). A higher WUE of 0.70–1.51 $\mathrm{kgm^{-3}}$ in winter wheat was found in the north China plain (Wang *et al.*, 2001 and Zhang *et al.*, 2005). Zhang *et al* (2005) and Xue et al (2006) showed that deficit irrigation increased WUE of wheat. However, since deficit irrigation might reduce photosynthesis rate and accelerate leaf senescence if crop is over-stressed, it might cause a decrease in wheat yield (Wang *et al*, 2001).

A long-term research from 1982 to 2002 in the north China plain showed that wheat yield increased by 50% with a corresponding WUE increase from 1.0 to 1.5 $\mathrm{kgm^{-3}}$ (Zhang *et al.*, 2005). Baodi *et al*, (2008) suggested that higher WUE could be obtained in rainfed wheat by selecting breeding materials with higher photosynthesis rate, lower transpiration rate and stomatal conductance.

Application of plant growth regulators (PGRs), particularly growth retardants, may maintain internal hormonal balance, i.e. efficient sink–source relationship, thus enhancing crop productivity (Singh *et al.*, 1987 and Shekoofa and Emam, 2008). Chlormequat chloride (2- chloroethyl-trimelhyl ammonium chloride, CCC) is a retardant of plant growth (Ma and Smith, 1987 and Emam and Karimi, 1996) which prevents biosynthesis of gibberellic acid inside the plant when absorbed by organs (root, stem and leaves). It can make the plant shorter but stronger (Singh et al., 1987 and Shekoofa and Emam, 2008), make the leaves darker and thicker and increase the ability to resist collapse, drought and cold stresses (Ma and Smith, 1987 and Emam and Moaied, 2000). De *et al.* (1982) postulated that application of CCC on wheat grown under arid conditions increased root growth, resulting in more efficient water extraction from the deeper layers of soil and thereby higher grain yield (Emam and Moaied, 2000).

Most recent studies on WUE of wheat crop have been carried out solely under well-watered conditions and data regarding WUE for wheat under dryland conditions are scarce. This study was conducted to (i) determine the differences in WUE among selected dryland wheat cultivars, and (ii) evaluate the effects of N availability on WUE, grain yield, biomass, photosynthesis rate (An) and stomatal conductance (gs) of dryland wheat cultivars.

MATERIALS AND METHODS

Field experiments were conducted during 2006-07 and 2007-08 growing seasons at the Experimental Farm of the College of Agriculture, Shiraz University located at Badjgah, Iran (29° 50´ N and 52° 46´ E; elevation 1810 m above mean sea level). Characteristics of soil and amount of precipitation and temperature data of both seasons are presented in Table 1 and Table 2. This study was carried out in split-split-plot experiments, based on randomized complete block design with four replications. There were four wheat cultivars in the main plots (C1 =Agosta, C2= Nicknejad, C3=Azar-2 and C4= Fin-15) and three nitrogen levels in sub-plots (control (N1=0 kg Nha^{-1}), N2=40 kg Nha^{-1}, N3=80 kg Nha^{-1}). Application of Chlormequat Chloride (CCC) was in sub-sub plots (Ch1=2.5 kgha^{-1} and control (Ch2=0 kgha^{-1})). Two thirds of the N fertilizer was hand broadcasted as urea at planting and the remaining was applied at tillering stage. The size of each experimental plot was 5m×20m. Seedbed preparation consisted of fall plowing and disking.

Selected cultivars in both years were planted on December 7, 2006-07 and December 3, 2007-08. Planting was done at a seeding rate of 80 kg ha^{-1}. The seeds were treated with a fungicide (Vitawax) prior to planting. In both years, plots were kept free from pests, diseases, and weeds during the growing seasons.

Total grain yield and biomass production were measured for each treatment by measuring sample plants in 1 m^2. At least 2 m was left between harvested areas to minimize edge effects on subsequent harvests. Data collection for photosynthesis (An) and stomatal conductance (gs) at four stages of growth (stem elongation, booting, flowering and grain filling, each at 1 day) were made on fully expanded leaves from the top (10 leaves) by LCi Portable Photosynthesis System (BioScientific Ltd. ADC) at the midday. WUE was calculated based on the ratio of biomass yield (gm^{-2}) per unit of moisture supplied (mm) (Qiu *et al.*, 2008). Estimation of soil moisture for each sub-sub-subplot was performed using the following soil-water balance equation (Zhang *et al.*, 2005 and Qiu *et al.*, 2008):

$$ET = CR + P + DW - D - R \quad (1)$$

where CR = capillary rise, P = precipitation, D = drainage, R = runoff, and DW (mm) = change in soil content for the 1m depth. Soil water content was monitored gravimetrically for every 25 cm layer (down to 100 cm). In the experimental site, the values of drainage, upward flow and runoff were negligible. Thus ET = P + DW was used under our experimental conditions. Crop data were analyzed by analysis of variance using SAS and MSTAT-C software and the means were compared by Tukey's test at a P value of 0.05.

Table 1. Some physico-chemical properties of the soil at the field plots.

SP [a] %	EC dSm^{-1}	pH -	O.C. %	O.M. %	Sand %	Silt %	Clay %	TN %	K mgkg^{-1}	P mgkg^{-1}
38.6	0.395	7.7	0.49	0.84	5.12	40.72	54.16	0.077	560	26

[a] SP (Saturate Percentage); EC (Electrical Conductivity); O.C. (Organic Carbon) O.M. (Organic Matter) and TN (Total Nitrogen).

Table 2. Rainfall and temperature data during years of the experiment.

Data	Year	October	November	December	January	February	march	April	May	Annual Mean
Rainfall	2006-07	0	0	82	50.5	82.5	35	138.5	0	388.5
(mm)	2007-08	0	0	18	76	29.5	0	3.5	0	127
Temperature	2006-07	16.75	12.33	6.61	1.46	3.7	8.99	14	17.3	10.1
(◦C)	2007-08	15.79	11.34	2.67	0.38	4.54	7.4	11.56	17.37	8.8

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RESULTS

Grain Yield

Difference between cultivars on grain yield was significant in both years (Figure 1). In the first season (2006-07), the highest grain yield was obtained from Nicknejad cultivar (126.2 g m^{-2}) whereas the lowest grain yield was observed for Agosta (100.8 g m^{-2}). These were 83 g m^{-2} and 56.6 g m^{-2} in the second season for Azar-2 and Agosta, respectively (Figure 1). The grain yield was higher in the first season as a result of higher amount of rainfall (Table 2).

In the first season, with higher rainfall Nicknejad was the superior cultivar and in the second season with low rainfall Azar-2 showed a good resistance to late season drought stress, compared to other cultivars (Figure 1). In the first season, results also showed that the grain yield was increased due to CCC application (118.63 gm^{-2}) compared with control (111.87 g m^{-2}). The corresponding data in the second year were 74.19 and 66.29 g m^{-2}, respectively. The interaction of cultivars × CCC on grain yield was significant (Table 3). Nicknejad and Azar-2 cultivars had the greatest response to CCC application compared to other cultivars.

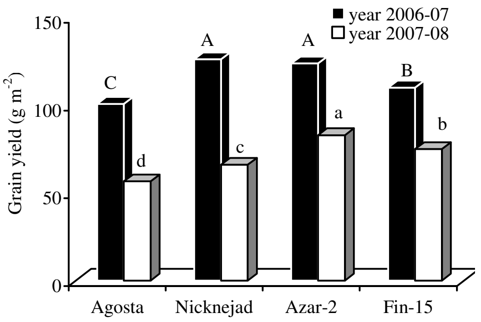

Figure1 . Grain yield of four dryland wheat cultivars for both years. Columns with the same letter in each year are not significantly different using Tukey's test (P value 5%).

The results also indicated that the grain yield response of wheat cultivars to CCC would vary under different N rates. The interactive effects of N rates × CCC applications on grain yield were significant (Table 4). Plants treated with CCC under different N rates showed higher grain yields compared with the control plants. Application of CCC increased grain yield in CCC treated plants; this increase was documented both for spike per square meter production and greater grain number per spike (Table 5). Also, interaction of cultivars × CCC × N was significant. In both years, application of N from 0 to 80 $kgha^{-1}$ increased earlier growth of all cultivars with 80 kg N ha^{-1} having the highest grain yield (Table 4).

Biomass Production

The result showed that total biomass differed

Table 3. Interaction of cultivars × CCC application on grain yield, biomass production and WUE (g m^{-2} mm^{-1}) in both years (Means followed by the same letter in each column are not significantly different at 5% probability level using Tukey's test).

Cultivars	CCC	Grain Yield (g m^2)		Biomass Yield (g m^2)		WUE (g m^{-2} mm^{-1})	
		2006-07	2007-08	2006-07	2007-08	2006-07	2007-08
Agosta	CCC	102.2 de	60.52 de	272.3 de	246.1 c	0.90 de	2.23 ab
	Control	99.49 e	52.67 e	264.7 e	235.5 d	0.88 e	2.14bc
Nicknejad	CCC	131.9 a	69.92 bc	326.8 a	225.8 e	1.08 a	2.05 cd
	Control	120.5 b	62.47 cd	314.3 b	209.3 f	1.05 b	1.90 d
Azar-2	CCC	127.5 a	87.85 a	283.5 c	268.3 a	0.93 c	2.43 a
	Control	120.3 c	78.21 b	276.2 cd	254.8 bc	0.92 cd	2.31 ab
Fin-15	CCC	112.9 c	78.47 b	271.9 de	259.3 ab	0.90 de	2.35 a
	Control	107.3 cd	71.83 b	264.8 e	246.6 c	0.88 e	2.24 ab

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significantly among four cultivars in both seasons of the study (Figure 2). The highest biomass in the first season was obtained from Nicknejad cultivar (320.6 g m^{-2}) and in the second season from Azar-2 cultivar (261.5 g m^{-2}).

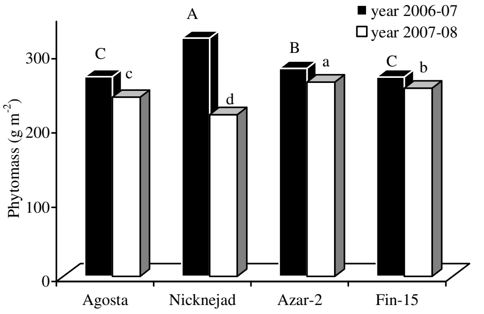

Figure 2. Biomass response in four dryland wheat cultivars in both years of the study (P value 5%). Means followed by the same letter in each year are not significantly different with 5% probability level using Tukey's test.

Biomass production was increased with increased application of N from 0 (control) to 80 kg ha^{-1} (Figure 3). The highest biomass (427.6 g m^{-2}) was obtained from Nicknejad at 80 kg N ha^{-1} whereas the lowest (130.2 g m^{-2}) from Azar-2 at 0 kg N ha^{-1} (i.e. control). The interaction of cultivars × CCC on biomass was significant in both seasons (Table 3). Interaction of N rates × CCC on biomass was also significant (Table 4). The highest biomass in both seasons of study was obtained using 80 kg ha^{-1} N and application of CCC (376.1 and 299.6 g m^{-2}, respectively) whereas the lowest biomass was from 0 kg N ha^{-1} with no application of CCC (control) (241.5 and 161.9 g m^{-2}, respectively).

Photosynthesis Rate (An) and Stomatal Conductance (gs)

An and gs differed significantly among the cultivars (Table 6). In both seasons the highest An and gs were obtained at stem elongation stage for all cultivars although that was reduced in the second year due to decreased rainfall (Tables 2 and 5). In the first season, the highest An and gs were obtained from Nicknejad cultivar (9.32 μmol CO_2 m^{-2} s^{-1} and 0.31 mol H_2O m^{-2} s^{-1}, respectively) and in the second season from Azar-2 (7.4 μmol CO_2 m^{-2} s^{-1} and 0.20 mol H_2O m^{-2} s^{-1}, respectively). In both seasons, 80 kg N ha^{-1} was associated with the highest An and gs at all stages of development. In the first season, An and gs of Nicknejad (11.84 μmol CO_2 m^{-2} s^{-1} and 0.36 mol H_2O m^{-2} s^{-1} respectively) were the highest and in the second season those of Azar-2 (9.21 μmol CO_2 m^{-2} s^{-1} and 0.28 mol H_2O m^{-2} s^{-1} respectively) showed the highest values at 80 kg N ha^{-1} application (Table 7). Response of cultivars to N application was significant (Table 7). An and gs were reduced in the second season as the rainfall decreased (Tables 5 and 6).

Water Use Efficiency

WUE, calculated as the biomass yield per unit of moisture supplied, was significantly

Table 4. Interaction of N Rates × CCC application on grain yield, biomass production and WUE (g m^{-2} mm^{-1}) in both years (Means followed by the same letter in each column are not significantly different at 5% probability level using Tukey's test)

Nitrogen Kg ha^{-1}	CCC	Grain Yield (g m^{-2})		Biomass Yield (g m^{-2})		WUE (g m^{-2} mm^{-1})	
		2006-07	2007-08	2006-07	2007-08	2006-07	2007-08
0	CCC	61.97 e	41.14 e	147.4 e	171.5 d	0.48 e	1.55 d
	Control	59.97 e	38.77 e	141.5 e	161.9 e	0.47 e	1.47 d
40	CCC	125.1 c	76.82 c	342.4 c	278.4 b	1.13 c	2.53 bc
	Control	118.1 d	69.17 d	332.4 d	263.4 c	1.10 d	2.39 c
80	CCC	168.8 a	104.6 a	376.1 a	299.6 a	1.24 a	2.72 a
	Control	157.5 b	90.96 b	366.5 b	284.3 b	1.22 b	2.58 ab

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Table 5. Mean of spikes per m^2, grains per spike and grains per m^2 for cultivars at both seasons (Means followed by the same letter in each column are not significantly different at 5% probability level using Tukey's test).

Cultivars	Spikes per m2		Grains per Spike		Grains per m^2	
	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08
Agosta	273.9 c	179 d	7.63 d	6.60 c	2089.8 c	1181.4 d
Nicknejad	297.5 b	194.5 c	10.47 a	6.67 c	3114.8 a	1297.3 c
Azar-2	312.2 a	224.8 a	9.25b	8.44 a	2887.8 b	1897.3 a
Fin-15	312.7 a	212.3 b	8.85 c	7.73 b	2767.3 b	1641 b

Table 6. Photosynthesis rate (An) and stomatal conductance (gs) of four dryland wheat cultivars at different stages of development in both years of the study (Means followed by the same letter in each column are not significantly different at 5% probability level using Tukey's test).

Years	Cultivars	An (μmol CO2 m-2 s-1)				gs (mol H2O m-2 s-1)			
		Stem elongation	Booting	Flowering	Grain filling	Stem elongation	Booting	Flowering	Grain filling
2006-07	Agosta	8.05c	7.16b	5.2c	2.32c	0.29b	0.19c	0.10d	0.05b
	Nicknejad	9.32a	8.32a	6.84a	4.55a	0.31a	0.26a	0.16a	0.09a
	Azar-2	8.69b	7.31b	6.17b	4.16a	0.31a	0.23b	0.13b	0.08a
	Fin-15	8.23c	7.27b	5.52c	3.67b	0.29b	0.20c	0.12c	0.06b
2007-08	Agosta	6.34b	5.14b	3.25c	[a]	0.17b	0.13c	0.08b	[a]
	Nicknejad	5.9c	4.42c	2.65d	[a]	0.16c	0.11d	0.06c	[a]
	Azar-2	7.4a	6.21a	4.67a	[a]	0.20a	0.17a	0.12a	[a]
	Fin-15	6.64b	5.27b	3.82b	[a]	0.20a	0.15b	0.10b	[a]

[a] Data for this stage in year 2007-08 were not measured.

Table 7. Photosynthesis rate (An) and stomatal conductance (gs) of four dryland wheat cultivars under different levels of nitrogen at stem elongation stage in both years of the study (Means followed by the same letter in each year are not significantly different at 5% probability level using Tukey's test).

Years	Cultivars	An (μmol CO2 m^{-2} s^{-1})			gs (mol H2O m^{-2} s^{-1})		
		Nitrogen (kg/ha)			Nitrogen (kg/ha)		
		0	40	80	0	40	80
2006-07	Agosta	6.50h	7.82fg	9.63cd	0.26f	0.28ef	0.32bc
	Nicknejad	7.24gh	9.17cd	11.84a	0.28de	0.32bc	0.36a
	Azar-2	6.62h	8.66de	10.89ab	0.28ef	0.31bc	0.34ab
	Fin-15	6.13h	8.32ef	10.24bc	0.27ef	0.30cd	0.32bc
2007-08	Agosta	4.71d	6.19bc	8.26ba	0.13d	0.17bc	0.22ab
	Nicknejad	4.54d	5.76bc	7.69a	0.13d	0.17bc	0.20ab
	Azar-2	5.22cd	6.31b	8.6a	0.16cd	0.21ab	0.27a
	Fin-15	5.85bc	8.56a	7.92a	0.16cd	0.19bc	0.24ab

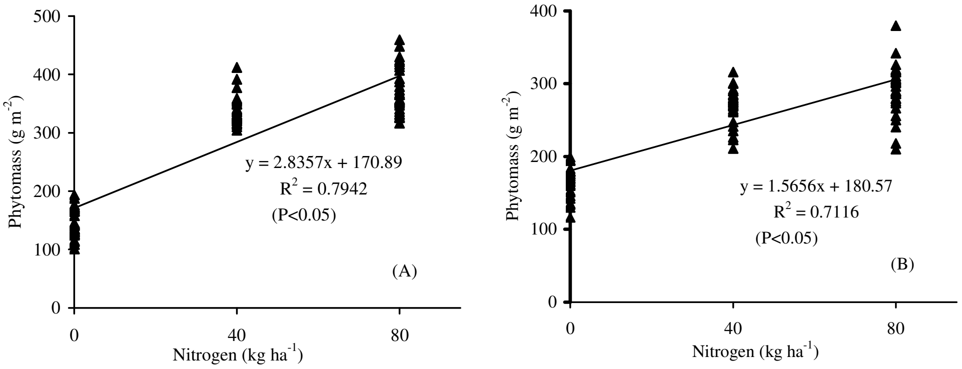

Figure 3. Biomass responses to three levels of N in years of 2006-07 (A) and 2007-08 (B) (n=96).

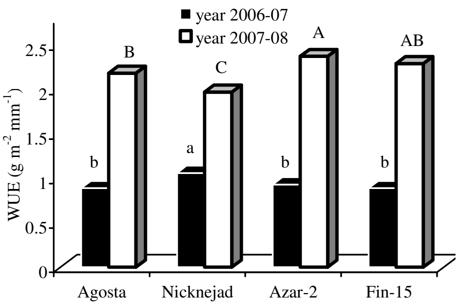

Figure 4. WUE of four dryland wheat cultivars in both years. Columns with the same letter in each year are not significantly different using Tukey's test (P value 5%).

different among cultivars in both seasons (Figure 4). In year 2006-07, the highest WUE was obtained from Nicknejad cultivar (1.06 g m^{-2} mm^{-1}), and the lowest from Agosta and Fin-15 cultivars (0.89 g m^{-2} mm^{-1}). In season 2007-08 the highest WUE was obtained from Azar-2 (2.37 g m^{-2} mm^{-1}) and the lowest from Nicknejad (1.97 g m^{-2} mm^{-1}).

WUE tended to decrease with increased rainfall (Table 2) and was significantly higher in the second year (Figure 4). It was also increased with the application of N in both years (Figure 5). The greatest WUE was recorded from 80 kg ha^{-1} N application (1.23 and 2.65 g m^{-2} mm^{-1}, respectively). Indeed, nitrogen seemed to promote photosynthesis activity which resulted in more dry matter accumulation before the late season drought stress when moisture supply was not limited (Figure 5).

Our data also suggested that N and CCC treatments were able to increase the biomass production per unit of moisture supplied (Table 4). We observed that in the second season, with decreased rainfall where drought was imposed before or after anthesis, the primary cause of increased WUE was decreased An and gs (Tables 5 and 6).

In the first season, CCC application had a significant effect on WUE (0.95 g m^{-2} mm^{-1}) compared with control (0.93 g m^{-2} mm^{-1}) and in the second season (2.27 compared to 2.15 g m^{-2} mm^{-1} for CCC and control respectively. This effect could be related to a reduced shoot growth by CCC application which reduced gs and plant transpiration (Ma and Smith, 1992; Emam and Karimi, 1996). Also, statistical analysis showed that interactions of CCC × cultivar and N on WUE in both seasons were significant (Tables 8 and 4).

DISCUSSION

Statistical analysis showed that grain yield, biomass production, photosynthesis (An) and stomatal conductance (gs) were increased remarkably with the increase in rainfall (Table 2) and N application (Tables 3, 5, 6 and 8). In the first season,

Table 8. Analysis of variance (ANOVA) over cropping seasons and wheat cultivars for different parameters.

Source	df	Mean sum of squares (MS)					
		Grain yield		Phytomass		WUE	
		2006-07	2007-08	2006-07	2007-08	2006-07	2007-08
Replicate	3	208.82ns	104.85*	947.16ns	1899.45*	0.0109*	0.1580*
Cultivar	3	3423.98*	3121.84*	14704.02*	8754.12*	0.1629*	0.7355*
Error	9	223.45	27.87	807.17	527.44	0.0091	0.0430
Nitrogen	2	84513.65*	26937.12*	478854.16*	143926.54*	5.3354*	11.865*
Cult. × N	6	695.96*	239.85*	1707.8ns	949.44*	0.0189*	0.0795*
Error	24	229.15	113.16	416.2	668.42	0.0046	0.0561
CCC	1	1096.87*	1494.68*	1790.55*	4253.34*	0.0112*	0.3516*
Cult. × CCC	3	79.74*	9.66ns	39.28ns	34.87ns	0.0006ns	0.0021ns
N × CCC	2	172.02*	255.16*	44.33*	84.50*	0.0004ns	0.0065ns
Cult. × N × CCC	6	26.85ns	24.65ns	120.31ns	39.98ns	0.0013ns	0.0030ns
Error	36	27.25	48.02	53.94	46.24	0.0007	0.0038

* and ns, significant at P≤0.05 probability level and not significant, respectively.

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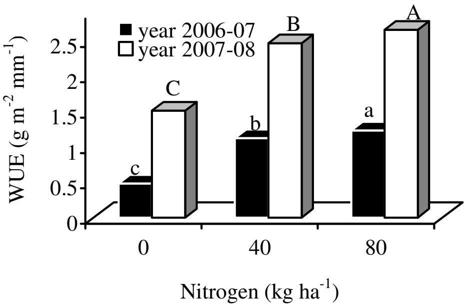

Figure 5. WUE responses to three levels of N in both years. Columns with the same letter in each year are not significantly different using Tukey's test (P value 5%).

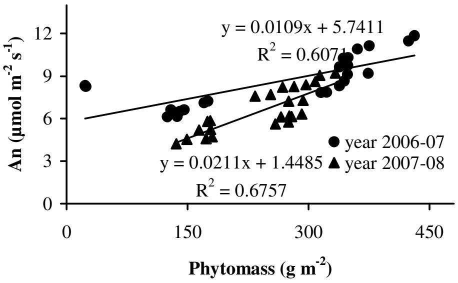

Figure 6. Relationship between biomass production and An in both years.

the highest grain yield and biomass production (192.4 and 431.2 g m^{-2}, respectively) were obtained from Nicknejad cultivar, CCC application and using 80 kg N ha^{-1}, and in the second year from Azar-2 cultivar (121.5 and 333.5 g m^{-2}, respectively). This increase in biomass production was sustained significantly with increased spike per square meter and grain number per spike per square meter and consequently, the grain yield (Table 5).

In semi-arid areas, rainfall quantity and distribution is a primary limiting factor for the development of dryland wheat (Zhenzhu and Guangsheng, 2008). In our study, increased rainfall with better distribution during 2006-07 increased the An and gs and enhanced grain and biomass yield. It was also shown that crop yield was positively related to An (Figure 6) and WUE (Figure 7) as reported by others (e.g. Lawlor, 1995; Ashraf and Bashir, 2003 and Qiu *et al.*, 2008).

The result also showed that in the first season the highest An and gs were obtained from Nicknejad cultivar (11.27 μmol CO_2 m^{-2} s^{-1} and 0.35 mol H_2O m^{-2} s^{-1} respectively) and in the second season from Azar-2 (9.13 μmol CO_2 m^{-2} s^{-1} and 0.27 mol H_2O m^{-2} s^{-1}, respectively). It showed that the highest An and gs were obtained at stem elongation and the lowest at grain filling stage. Indeed, An and gs were affected by rainfall and cultivars. Under drought stress, green area is reduced and senescence occurs earlier, which might have decreased An (Wang *et al.*, 2001) and gs (Zhenzhu and Guangsheng, 2008).

Increased grain and biomass yields were associated with increased An and gs at stem elongation stage (Figure 6). In fact, the increase in photosynthesis rates (An) with CCC and N application might be an alternative explanation for the yield enhancement. It might therefore be concluded that CCC was able to effectively increase resistance of wheat to drought stress and change the rate of photosynthesis and photo-assimilate partitioning to the grain. Similar attributions have been made by others such as Singh *et al.*, (1987); Ma and Smith (1992), Emam and Karimi (1997) and Shekoofa and Emam (2008).

Observations during this study revealed that growth rate and leaf canopy were promoted by N application at earlier stages

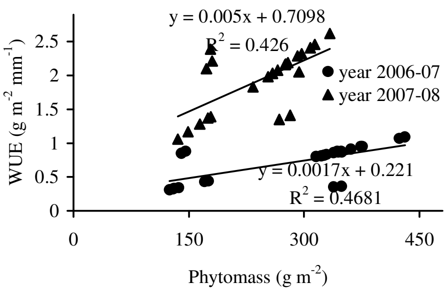

Figure 7. Relationship between biomass production and WUE in both years.

when moisture supply was not limited, and this was in association with higher An and gs. This supports the idea that nitrogen application was associated with both enhanced green area duration of the wheat canopy and dry matter production (Salvagiotti and Miralles, 2008).

In both years, N fertilizer affected WUE (Figure 5) and the values for the 80 kg N ha^{-1} application were the highest (1.23 and 2.65 g m^{-2} mm^{-1} for the first and second year, respectively). This suggests that in dryland wheat production, adequate N fertilization (Clarke *et al.*, 1990 and Wenlong *et al.*, 2004) and its balance with available seasonal moisture supplies seem to be crucial for improved WUE (Nielsen *et al*, 2002 and Halvorson *et al.*, 2004). The improved WUE appeared to be mainly due to the changes in LAI at earlier growth stages and accumulation of dry matter before anthesis, also noted by Zi-Zhen *et al* (2004).

Under dryland conditions, the most important factor responsible for higher photosynthetic efficiency after anthesis might be the ability of cultivars to sustain green leaf area and greater remobilization to the sinks. Under dryland climatic conditions, photosynthesis is restricted by moisture supply (Shah and Paulsen, 2003 and Monneveux *et al.*, 2006) and depends primarily on the amount of light intercepted by photosynthetic tissues (Zhenzhu and Guangsheng, 2008) which is determined by the canopy size and the ability of the crop for N uptake. In our study, reduced rainfall and increased temperature and evapotranspiration resulted in lower WUE. This has also been reported by others (e.g. Musick *et al.*, 1994; Wang *et al.*, 2001 and Zhang *et al.*, 2005).

Explanations for low WUE in our study are numerous. WUE deviation reflects the conditions of our environment, such as moisture deficit, nutrient stress, low and high temperatures and low density of plants. Variation in WUE can arise from differences in partitioning between root and shoot among the cultivars. The relatively small year-to-year variation in WUE (Figure 4) appeared to be due to differences in rainfall amount and its distribution (Table 2).

In moisture-limited conditions, the higher WUE should result in greater production in the short-term. A consistent feature of our experiment was the inability of dryland wheat cultivars to achieve full ground cover to enhance photosynthesis before the late season drought stress occurred thereby reducing the evaporation rate. This might be an area for further investigations. Agronomic management strategies aimed at maximizing the opportunity for dryland wheat to achieve benefits, may include timely/early sowing; adequate plant densities to achieve early canopy expansion and maximum ground cover, tactical fallowing for soil moisture conservation to minimize post-anthesis moisture stress, adequate nutrition and using appropriate cultivars. In this study we concluded that Nicknejad cultivar is more suitable for the higher rainfall conditions whereas Azar-2 and Fin-15 cultivars appeared to be more tolerant under reduced rainfall conditions.

CONCLUSION

With regard to climate change and water exigency in some regions of the world, it is needed to optimize water use by crops, both hydrologically and physiologically. Physiological water absorption and storing by plant could be controlled via agronomic practices such as moisture management, fertilization and selecting suitable cultivars. Our results indicated that there were significant differences among cultivars in coping with drought stress as well as grain yield, biomass and WUE. In the first season, the highest grain yield and biomass production (192.4 and 431.2 g m^{-2} respectively) were obtained from Nicknejad cultivar, CCC application and using 80 kg N ha^{-1}, and in the second

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season from Azar-2 cultivar (121.5 and 333.5 g m^{-2}, respectively). CCC and nitrogen had significant effects on photosynthesis rate and WUE in both seasons. Regarding the amount of rainfall, it might be recommended that application of N and selecting cultivars tolerant to later season drought stress be considered for improving WUE and wheat yields under dryland conditions. Also, future studies would need additional effort to consider WUE in pre and post anthesis periods, since many major physiological changes occur in these stages.

REFERENCES

1. Ashraf, M. and Bashir, A. 2003. Relationship of Photosynthetic Capacity at the Vegetative Stage and during Grain Development with Grain Yield of Two Hexaploid Wheat (*Triticum aestivum* L.) Cultivars Differing in Yield. *Eur. J. Agron*. **19**: 277-287.
2. Bacon, M. A. 2004. Water Use Efficiency in Plant Biology. In: Bacon MA, (ed): *Water Use Efficiency in Plant Biology*. Oxford: Blackwell Publishing: 1–26.
3. Baodi, D., Mengyua, L., Hongbob, S., Quanqi, L., lei, S., Feng D. and Zhengbin, Z. 2008. Investigation on the Relationship between Leaf Water Use Efficiency and Physio-biochemical Traits of Winter Wheat under Rainfed Condition. *Colloids and Surfaces B: Biointerfaces*, **62**: 280–287.
4. Blum, A. and Johnson, J. W. 1993. Wheat Cultivars Respond Differently to a Drying Top Soil and a Possible Nonhydraulic Root Signal. *J. Exptl. Bot.* **44**: 1149–1153.
5. Chaves, M. M., Maroco, J. and Pereira, J. 2003. Understanding Plant Responses to Drought-from Genes to the Whole Plant, Function. *Plant Biol*. **30**: 239–264.
6. Clarke, J. M., Campbell, C. A., Cutforth, H. W., Depauw, R. M. and Winkleman, G. E. 1990. Nitrogen and Phosphorus Uptake, Translocation, and Utilization Efficiency of Wheat in Relation to Environment, and Cultivar Yield and Protein Levels. *Can. J. Plant Sci*. **70**: 965–977.
7. De, R., Giri, G., Saran, G., Singh, R. K. and Chaturvedi, G. S. 1982. Modification of Water Balance of Dryland Wheat through the Use of Chlormequat Chloride. *J. of Agric. Sci*. **98**: 593-597.
8. Emam, Y. and Karimi, H. R. 1996. Influence of Chlormequat Chloride on Five Winter Barley Cultivars. *Ir. Agric. Res*. **15**: 89-104.
9. Emam, Y. and Moaied, G. R. 2000. Effect of Planting Density and Chlormequat Chloride on Morphological and Physiological Characteristics of Winter Barley (*Hordeum vulgare* L.) Cultivar Valfajr. *J. Agric. Sci. Tech*. **2**: 75-83.
10. Halvorson, A. D., Nielsen, D. C. and Reule, C. A. 2004. Nitrogen Fertilization and Rotation Effects on No-till Dryland Wheat Production. *Agron. J.* 96: 1196-1201.
11. Lawlor, D. W. 1995. Photosynthesis, Productivity and Environment. *J. Exp. Bot*. **46**: 1449-1461.
12. Li, F. M., Song, Q. H., Liu, H. S., Li, F. R. and Liu, X. L. 2001. Effects of Pro-sowing Irrigation and Phosphorus Application on Water Use and Yield of Spring Wheat under Semi-arid Conditions. *Agric. Water Manag*. 49: 173–183.
13. Ma, B. L. and Smith, D. L. 1991. Apical Development of Spring Barley in Relation to Chlormequat and Ethephon. *Agron. J.* **83**: 270-274.
14. Monneveux, P., Rekika, D., Acevedo, E. and Merah, O. 2006. Effect of Drought on Leaf Gas Exchange, Carbon Isotope Discrimination, Transpiration Efficiency and Productivity in Field Grown Durum Wheat Genotypes. *Plant Sci*. **170**: 867–872.
15. Musick, J. T., Jones, O. R., Stewart, B. A. and Dusek, D. A. 1994. Water–yield Relationship for Irrigated and Dryland Wheat in the US Southern Plains. *Agron. J*. **86**: 980–986.
16. Nielsen, D. C., Vigil, M. F., Anderson, R. L., Bowman, R. A., Benjamin, J. G. and Halvorson, A. D. 2002. Cropping System Influence on Planting Water Content and Yield of Winter Wheat. *Agron. J*. **94**: 962-967.
17. Qiu, G. Y., Wang, L., He, X., Zhang, X., Chen, S., Chen, J. and Yang, Y. 2008. Water Use Efficiency and Evapotranspiration of Winter Wheat and

Its Response to Irrigation Regime in the North China Plain. *Agric. and Forest Meteo*. **148**: 1848 – 1859.

18. Salvagiotti, F. and Miralles, D. J. 2008. Radiation Interception, Biomass Production and Grain Yield as Affected by the Interaction of Nitrogen and Sulfur Fertilization in Wheat. *Eur. J. Agron.* **28**: 282–290.
19. Shah, N. H. and Paulsen, G. M. 2003. Interaction of Drought and High Temperature on Photosynthesis and Grain-Filling of Wheat. *Plant and Soil*, **257**: 219–226.
20. Shan, L., 1991. Physiological and Ecological Base of Water Saving Agriculture. *J. Appl. Ecol.* **1**: 70–76.
21. Shekoofa, A. and Emam, Y. 2008. Effects of Nitrogen Fertilization and Plant Growth Regulators (PGRs) on Yield of Wheat (*Triticum aestivum* L. cv. Shiraz). *J. Agric. Sci. Tech.* **10**: 101-108.
22. Singh, V. P. N. and Uttam, S. K. 1992. Response of Wheat Cultivars to Different N Levels under Early Sown Conditions. *Crop Res*. **5**: 82-86.
23. Wajid, A., Hussain, K., Maqsood, M., Ahmad, A. and Hussain, A. 2007. Influence of Drought on Water Use Efficiency in Wheat in Semi-arid Regions of Punjab. *Soil and Environ*. **26**: 64-68.
24. Wang, H., Zhang, L., Dawes, W. R. and Liu, C. 2001. Improving Water Use Efficiency of Irrigated Crops in the North China Plain Measurements and Modeling. *Agric. Water Manag*. **48**: 151–167.
25. Wenlong, L., Weide, L. and Zizhen, L. 2004. Irrigation and Fertilizer Effects on Water Use and Yield of Spring Wheat in Semi-arid Regions. *Agric. Water Manag.* **67**: 35–46.
26. Xue, Q., Zhu, Z., Musick, J. T., Stewart, B. A. and Dusek, D. A. 2006. Physiological Mechanisms Contributing to the Increased Water-use Efficiency in Winter Wheat under Deficit Irrigation. *J. Plant Physiol*. **163**: 154–164.
27. Zhang, X., Chen, S., Liu, M., Pei, D. and Sun, H. 2005. Improved Water Use Efficiency Associated with Cultivars and Agronomic Management in the North China plain. *Agron. J.* **97**: 783–790.
28. Xu and Zho. 2008. Responses of Leaf Stomatal Density to Water Status and Its Relationship with Photosynthesis in a Grass. *J. Exper. Bot*. **59**: 3317–3325.
29. Zi-Zhen, L, Wei-Dea, L. and WenLong, L. 2004. Dry-period Irrigation and Fertilizer Application Affect Water Use and Yield of Spring Wheat in Semi-arid Regions. *Agric. Water Manag*. **65**: 133–143.

کارآیی مصرف آب در چهار رقم گندم دیم تحت سطوح مختلف کود نیتروژن

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چکیده

به نظر می رسد ارقامی از گندم (*Triticum aestivum* L.) که بتوانند در شرایط محدود آبی عملکرد مطلوبی داشته باشند، از اهمیت زیادی بر خوردار خواهند بود. بررسی کارآیی مصرف آب در این رابطه ضروری به نظر می رسد. بدین منظور، برای بررسی واکنش چهار رقم گندم دیم (آگوستا، نیک نژاد، آذر۲ و فاین ۱۵) به کند کننده رشد (کلرمکوات کلرید) و سطوح کود نیتروژن (صفر، ۴۰ و ۸۰ کیلوگرم در هکتار)، پژوهشی مزرعه ای در دو سال زراعی ۸۶-۱۳۸۵ و۸۷-۱۳۸۶ در مزرعه تحقیقاتی دانشکده کشاورزی دانشگاه شیراز واقع در منطقه باجگاه انجام شد. نتایج نشان داد که در هر

دو سال پژوهش بین ارقام از نظر عملکرد دانه، زیست توده و کارآیی مصرف آب تفاوت معنی‌داری وجود داشت. اثر کلرمکوات کلرید و نیتروژن بر عملکرد دانه و زیست توده معنی دار شد. بیشینه عملکرد دانه و زیست توده در سال اول (به ترتیب، ۱۹۲/۴ و ۴۳۱/۲ گرم بر متر مربع) از رقم نیک نژاد و در سال دوم از رقم آذر ۲ (به ترتیب، ۱۲۱/۵ و ۳۳۳/۵ گرم بر متر مربع) با تیمار کلرمکوات کلرید و کاربرد ۸۰ کیلوگرم نیتروژن در هکتار بدست آمد. در هر دو سال پژوهش، کلرمکوات کلرید و نیتروژن تاثیر معنی داری بر سرعت فتوسنتز و کارآیی مصرف آب داشتند. برهمکنش کلرمکوات کلرید و سطح ۸۰ کیلوگرم نیتروژن در هر دو سال پژوهش بر کارآیی مصرف آب معنی دار شد (به ترتیب در سال های اول و دوم، ۱/۲۴ و ۲/۷۲ گرم بر متر مربع بر میلی متر). به نظر می‌رسد کاربرد کلرمکوات کلرید و کود نیتروژن اثر بارزی در بهبود عملکرد دانه گندم در شرایط دیم مشابه با پژوهش حاضر داشته باشد.

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