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Productivity and Radiation Use Efficiency of Four Dryland Wheat Cultivars under Different Levels of Nitrogen and Chlormequat Chloride

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ABSTRACT

The impact of climate change in the next few decades will increase risks of wheat production under dryland conditions. Therefore, it is important to find cultivars that are tolerant to these conditions and can provide reasonable yield under future climates. Radiation use efficiency (RUE) is the key factor determining the crop yield and is related to crop biomass and leaf area index (LAI). To obtain a high yield from a given cultivar under dryland conditions, it is necessary to achieve optimum RUE. In this study, the effects of different levels of nitrogen fertilizer (N) and plant growth retardant (chlormequat chloride= CCC) on LAI, dry matter accumulation, biomass yield, and RUE of four dryland wheat cultivars were examined. The field experiment was carried out during 2006-07 and 2007-08 growing seasons at the experimental agriculture research station of Shiraz University, Iran. The results suggested that different cultivars varied significantly in LAI, biomass and RUE under similar conditions and demonstrated the dependency of RUE on LAI and biomass yield. During 2006-07, the highest biomass production (431.2 g m^{-2}) and RUE (0.99 g MJ^{-1} m^{-2}) were obtained from Nicknejad cultivar, CCC application, and using 80kgN.ha^{-1}. During 2007-08, the highest biomass production (333.5 g m^{-2}) and RUE (0.76 g MJ^{-1} m^{-2}) were obtained from Azar-2 cultivar, CCC application, and 80 kg N ha^{-1}. Based on the results of this study, application of N and selecting cultivars resistant to late season drought stress could be considered for improving RUE in dryland farming.

Keywords*:* Chlormequat chloride, Dryland wheat cultivars, LAI, Biomass, Nitrogen, RUE.

INTRODUCTION

Crop yield is determined by biomass accumulation and its partitioning into the economical plant organ (Van der Werf, 1996). Crop biomass production depends on the ability of the canopy to (i) intercept the incoming photosynthetically active radiation, which is a function of leaf area index (LAI) and canopy architecture, and (ii) convert this radiation into new biomass, i.e. radiation use efficiency (RUE) (Monteith, 1977; Sinclair and Muchow, 1999). Abbate *et al*. (1995) demonstrated that the intercepted photosynthetically active radiation (IPAR) was the main factor determining crop growth in bread wheat (*Triticum aestivum* L.).

Lower LAI and hence lower IPAR reduced the maximum photosynthetic rate per unit ground area (O'Connell *et al*., 2004). LAI is determined by two mechanisms: the leaf area development (leaf appearance and leaf expansion) and leaf senescence, both of which are driven and affected by the availability of water.

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RUE is affected by abiotic factors such as drought (Jamieson *et al*., 1995) and nutrient availability (Sinclair and Horie, 1989). Evidence from the literature suggests that one or both physiological components of biomass production may be modified by genotype (Calderini *et al*., 1997), or water availability (Jamieson *et al*., 1995). Wajid *et al.* (2007) reported that when drought stress was imposed before or after anthesis, the primary cause of reduced RUE was a decrease in intercepted light, which ultimately reduced the photosynthetic products being sent to the economical organ of the plant.

Nutrient deficiencies may affect both IPAR (Quanqi *et al*., 2008) and RUE. LAI was reduced in crops grown under N deficiency (Caviglia and Sadras, 2001). Increase in nitrogen content of soil affects all growth stages of the crops. For example, an increase in nitrogen concentration at anthesis can result in an increase of LAI by as much as 62% and IPAR by up to 20% (Salvagiotti and Miralles, 2008). RUE in wheat has been reported to be reduced when nitrogen was limited (Muurinen and Peltonen-Sainio, 2006). Dreccer *et al*. (2000) observed that nitrogen limitation affected wheat growth via reduction of the intercepted PAR.

Sinclair and Horie (1989) determined that increase in leaf photosynthetic rate increased the RUE nonlinearly, with a maximum RUE value attained at a high photosynthetic rate. Other analyses have indicated that stresses reducing wheat leaf photosynthetic rate could result in lower RUE (Uhart and Andrade, 1995). However, reduced RUE values can occur at extremely high nitrogen rates (Garcia *et al*., 1988; Olesen *et al*., 2000; Muurinen and Peltonen-Sainio, 2006). RUE is dependent on the net CO_2 assimilation rate (Loomis and Amthor, 1999) and N is a source of variation for this efficiency through its effect on the RuBisCO content in mesophyll cells (Sinclair and Horie, 1989).

In arid environments, water stress tends to reduce RUE progressively by preventing utilization of photosynthates for growth as lower IPAR occurs from reduced LAI (Wilson and Jamieson, 1985). This might be the result of either excessive leaf death after imposition of drought stress conditions or wheat plants adjusting to limited soil-water availability by producing fewer tillers and smaller LAI. If crops function in a continual adjustment phase to stress, there might be little benefit to reducing RUE in response to water stress. Rather, the reduction should be on the leaf area dynamics to limit IPAR in arid environments (O'Connell *et al*., 2004). Water-stress related reductions in RUE are reported to occur in barley (Legg *et al*., 1979). Irrigated crops allow RUE to remain relatively stable throughout the growth cycle; however, water deficits decrease RUE, particularly during early grain filling.

Based on the aboveground biomass, RUE of dryland wheat has been estimated at 1.81 g MJ^{-1} IPAR (O'Connell *et al*., 2004). In Western Australia, reported RUE values based on PAR measurements in non-stressed conditions for wheat ranged from 1.43–1.68 g MJ^{-1} (Gregory *et al*., 1992) depending on the growing location and crop varieties. However, the mean RUE of 2.8 g MJ^{-1} stated in the review of Kiniry *et al.* (1989) is greater than those reported by the latter researchers. Post-anthesis RUE often appears lower than pre-anthesis RUE, since leaf senescence occurs during the post-anthesis period and plant organs other than leaves that intercept radiation demonstrate lowered photosynthetic capacities (Gallo *et al*., 1993).

There is strong experimental evidence that RUE of wheat depends on water vapour pressure deficit, environmental radiation, and crop nitrogen status (Sinclair and Muchow, 1999; Wajid *et al*., 2007). However, it remains unclear whether these changes in RUE are related to growth stage or temperature or sinks size of the grains (Fischer, 1993; Miralles and Slafer, 1997). Acreche *et al*. (2009) reported that, in the future, breeding advances for improving sink size will necessarily focus on the increase of biomass yield.

Application of plant growth regulators (PGRs), particularly growth retardants, may maintain internal hormonal balance, i.e. efficient sink–source relationship, thus

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enhancing crop productivity (Singh *et al*., 1987). Chlormequat chloride (2-chloroethyl-trimelhyl ammonium chloride, CCC) is a plant growth retardant (Ma and Smith, 1987; Emam and Karimi, 1996). It prevents biosynthesis of gibberellic acid inside the plant, when absorbed by the plant organs (root, stem, and leaves). It can make the plant short-statured but strong with stiff straw (Singh *et al*., 1987); make the leaves darker and thicker, and increase the ability to resist mechanical stress, drought, cold, and alkaline conditions (Ma and Smith, 1987; 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, thereby higher grain yield (Emam and Moaied, 2000).

Most studies on RUE in wheat crops have been conducted under well-watered conditions and information about RUE of wheat under dryland growing conditions is rather scarce. The objectives of the present investigation were to (i) determine RUE of various dryland wheat cultivars, and (ii) evaluate the effects of nitrogen availability on RUE, biomass, and LAI of these dryland wheat cultivars.

MATERIALS AND METHODS

Climate, Site and Experimental Design

Field experiments were conducted during 2006-07 and 2007-08 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). Soil characteristics and the meteorological conditions for both years are presented in Tables 1 and 2. This study was carried out with split-split-plot experiments in randomized complete block design and four replications. The four wheat cultivars planted in the main plots were Agosta (C1), Nicknejad (C2), Azar-2 (C3), and Fin-15 (C4). The three nitrogen levels applied in subplots were 0 N as the control (N1), 40 kg N ha^{-1} per yr (N2), and 80 kg N ha^{-1} per yr (N3). In addition, chlormequat chloride (CCC) was applied at the end of tillering in sub-sub plots (Ch1= 2.5 kg ha^{-1} and the control, Ch2= 0 kg ha^{-1}). Two thirds of the N fertilizer was broadcasted as urea at planting time and the remaining was applied at the tillering stage. Seedbed preparation consisted of fall plowing and disk harrowing. Seeds

Table 1. Physico-chemical properties of the soil.

Soil texture										
Sand %	Silt %	Clay %	SP[a] %	EC[b] dS m^{-1}	pH	OC[c] %	OM[d] %	TN[e] %	K Mg kg^{-1}	P mg kg^{-1}
5.12	40.72	54.16	38.6	0.395	7.7	0.49	0.84	0.077	560	26

[a] Saturate Percentage; [b] Electrical Conductivity; [c] Organic Carbon; [d] Organic Matter, [e] Total Nitrogen.

Table 2. Summary of growing season conditions for both years of the experiment.

Data	Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Annual mean
Precipitation (mm)	2006-07	0.00	0.00	82.00	50.50	82.50	35.00	138.50	0.00	388.50
	2007-08	0.00	0.00	18.00	76.00	29.50	0.00	3.50	0.00	127.00
Mean Temperature (°C)	2006-07	16.75	12.33	6.61	1.46	3.70	8.99	14.0	17.30	10.10
	2007-08	15.79	11.34	2.67	0.38	4.54	7.40	11.56	17.37	8.80
PAR (MJ m^{-2})	2006-07	10.39	6.78	14.48	8.44	11.45	13.8	15.28	18.06	12.33
	2007-08	9.22	5.39	12.87	9.10	12.87	16.19	17.32	19.06	12.75

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were treated with a fungicide (Vitawax) and planted on 7 December 2006 and 3 December 2007, at the rate of 80 kg ha^{-1}. In both years, plots were kept free of pests, diseases, and weeds during the growing seasons.

Crop Measurements

Plots were hand sampled (1 m^2) for determination of the aboveground dry matter and LAI at five growth stages (tillering, double ridge, stem elongation, flowering, early grain filling and maturity stage). Dry matter was determined after drying the plants in an oven with forced air circulation at 75°C for 48 hours. Leaf area index (LAI) was measured using leaf area meter (Delta-t devices LTD). Total biomass production was measured for each plot by weighing all the plants harvested in 1 m^2. At least 2 m was left between the harvested areas to minimize marginal effects on subsequent harvests.

Calculation of PARd and IPARd

$IPAR_d$ (daily incident photosynthetically active radiation) was calculated by using the following equations:

$$IPAR_d = \varepsilon_{id} \times PAR_d \quad (1)$$

$$\varepsilon_{id} = \varepsilon_{i\max}(1 - \exp^{-kLAI}) \quad (2)$$

Where, PARd (daily photosynthetic active radiation, 400–700 nm, MJ m^{-2} d^{-1}) was measured above the plant canopies with a Sun Scan Canopy Analysis System (507-260 Quantum (PAR) Radiation Sensor) in mid afternoon, ε_{id} is radiation intercepted by the plant, ε_{imax} is the maximum value of intercepted radiation (0.96), k is the light extinction coefficient that was assumed to be 0.82 for the dryland wheat cultivars (O'Connell *et al*., 2004). Radiation use efficiency was calculated as the slope of the relationship between the accumulated biomass and the cumulative IPAR (Sinclair and Muchow, 1999).

Statistical Analysis

Data were analyzed by analysis of variance using MSTAT-C and SAS software and the means were compared by Tukey's test at P value of 0.05. Also, RUE for each treatment was determined (Walpole *et al*., 1998).

RESULTS

LAI Responses

Differences between cultivars on LAI were significant (P< 0.05) (Figure 1). In the 2006-2007 growing season, the highest LAI during anthesis was obtained from Nicknejad cultivar (1.73) and the lowest LAI belonged to Agosta (1.51). In the 2007-2008 growing season, the highest LAI during anthesis was obtained from Azar-2 (1.27) and the lowest LAI from Agosta (1.05), (Figure 1). In 2006-2007 growing season, the annual precipitation was 388.5 mm (Table 2), while in the 2007-2008 growing season it was 127 mm, which caused the difference in plant growth and LAI between the two successive years. Although Nicknejad cultivar showed the greatest response to the higher precipitation in the 2006-2007 growing season, with the reduced precipitation of the 2007-2008 growing season, it did not indicate good performance compared to Azar-2 (Figure 1). In both

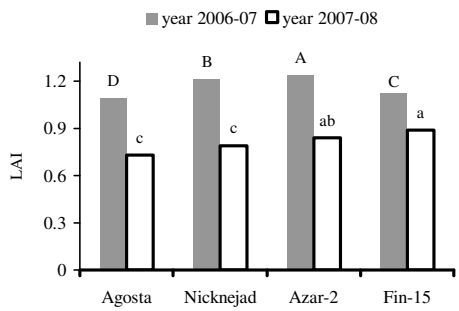

Figure 1. LAI of four dryland wheat cultivars for both years. Columns with the same letter in each year are not significantly different; using Tukey's test (P value 5%).

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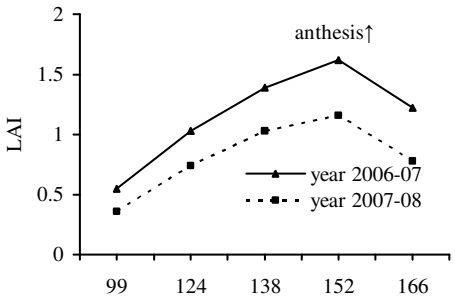

Figure 2. Mean LAI at five developmental stages (days after planting) of dryland wheat cultivars for both years.

years, the highest LAI was obtained at anthesis (Figure 2).

The results also showed that the interaction of cultivars×CCC on LAI at anthesis was significant (Table 3). Nicknejad and Azar-2 cultivars had the greatest response to CCC application compared to the rest of the cultivars. The results also indicated that the LAI response of wheat cultivars to CCC would vary under different N rates (Table 4). The interaction effects of N rates×CCC applications on LAI were significant (Table 4). Plants treated with CCC and receiving supplemental N showed higher LAI compared to the control plants that had not been treated with CCC. The CCC-induced increase in LAI was due to increased tiller survival. In both years, interaction of cultivars×CCC×N was significant (Figure 3) and N application increased early growth in all cultivars, while 80 kg N ha^{-1} had the highest LAI (Figure 3). In the 2006-2007 growing season, with higher precipitation, Nicknejad was the superior cultivar, however, in the 2007-2008 growing season with low precipitation, Azar-2 showed a good resistance to late season drought stress, compared with the other cultivars.

Dry Matter Accumulation

Differences among cultivars for dry matter were significant (Figure 4). In the 2006-2007 growing season, the greatest dry matter during anthesis was obtained from Nicknejad (237.5 g m^{-2}) and the lowest belonged to Agosta (198.8 g m^{-2}). But, in the 2007-2008 growing season, the maximum and the minimum values were recorded for Azar-2 (193.8 g m^{-2}) and Nicknejad (160.5 g m^{-2}), respectively (Figure 4). In both years of this study, dry matter was measured during five stages of plant development plus maturity stage and showed an increasing

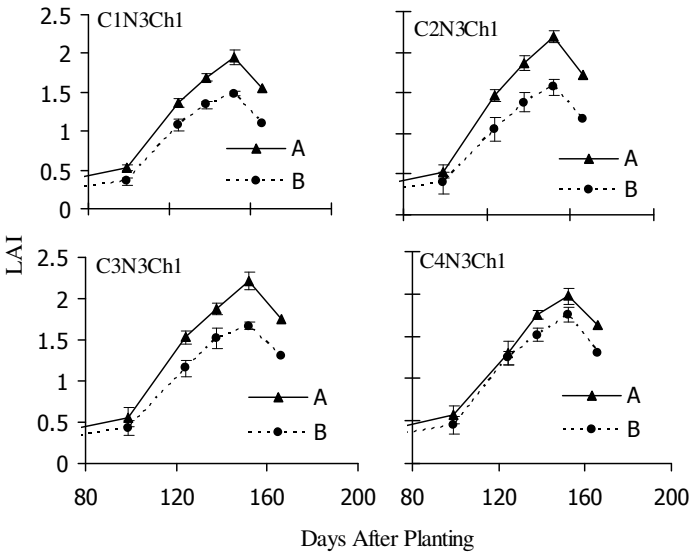

Figure 3. LAI responses at five developmental stages of dryland wheat cultivars to 80 kg N ha^{-1} and application of CCC in year 2006-2007 (A) and 2007-2008 (B).

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Table 3. Interaction of four cultivar×CCC applications on LAI and dry matter at anthesis and total biomass for both years. Means followed by the same letter in columns are not significantly different; using Tukey's test (P value 5%).

Cultivars	CCC	LAI at anthesis		Dry matter at anthesis ($g \cdot m^{-2}$)		Total biomass ($g\ m^{-2}$)	
		2006-07	2007-08	2006-07	2007-08	2006-07	2007-08
Agosta	CCC	1.539 d	1.074 d	200.6 bc	182.3 c	272.3 de	246.1 c
	Control	1.493 e	1.028 e	197.3 c	174.5 d	264.7 e	235.5 d
Nicknejad	CCC	1.794 a	1.216 b	241.3 a	166.0 e	326.8 a	225.8 e
	Control	1.648 c	1.063 de	233.7 a	155.1 f	314.3 b	209.3 f
Azar-2	CCC	1.737 b	1.328 a	208.6 b	198.8 a	283.5 c	268.3 a
	Control	1.682 c	1.148 c	206.5 b	188.8 bc	276.2 cd	254.8 bc
Fin-15	CCC	1.656 c	1.247 b	201.5 bc	192.1 b	271.9 de	259.3 ab
	Control	1.490 e	1.217 b	196.2 c	182.7 c	264.8 e	246.6 c

trend in all of the treatments (Figure 5). The highest dry matter in all cultivars was obtained at maturity stage (Figure 5), although the greatest LAI was reached at anthesis (Figure 2). This means that photosynthesis by flag leaf and spikes caused more dry matter accumulation after anthesis i.e. towards physiological ripening.

The results showed that interaction effects of cultivars×CCC and N rates×CCC on dry matter production was significant (Tables 3 and 4). Plants treated with CCC under different N rates showed higher dry matter compared with the control plants. Application of CCC increased the dry matter as a result of the increased spikes per m^2 due to the increased tiller survival. Also, for both years of the study, interaction of cultivars×CCC×N on dry matter production is shown in Figure 6. Comparison of the treatments means indicated that 80 kg N ha^{-1} had significant effects on the dry matter accumulation (Figure 6).

In both growing seasons, the results showed that the total biomass among the four cultivars varied significantly (Figure 7). The maximum was obtained in the 2006-2007 season from Nicknejad cultivar (320.6 g m^{-2}), while in the 2007-2008 growing season Azar-2 cultivar yielded the highest (261.5 g m^{-2}). The interaction of cultivars×CCC on biomass was significant in both years (Table 3). Increased dry matter accumulation and leaf area indicated that higher LAI at anthesis was correlated with increased biomass yield. In fact, the increase in source size i.e. leaf area of the treated plants, or photosynthesis rate with the CCC

Table 4. Interaction of N rates×CCC application on LAI and dry matter at anthesis and total biomass for both years. Means followed by the same letter in each column are not significantly different; using Tukey's test (P value 5%).

Nitrogen kg ha^{-1}	CCC	LAI at anthesis		Dry matter at anthesis ($g \cdot m^{-2}$)		Total Biomass ($g \cdot m^{-2}$)	
		2006-07	2007-08	2006-07	2007-08	2006-07	2007-08
0	CCC	1.294 e	0.828 e	108.6 c	127.1 e	147.4 e	171.5 d
	Control	1.235 f	0.770 f	105.4 c	120.0 f	141.5 e	161.9 e
40	CCC	1.668 c	1.203 c	253.0 b	204.4 c	342.4 c	278.4 b
	Control	1.548 d	1.083 d	246.7 b	195.1 d	332.4 d	263.4 c
80	CCC	2.082 a	1.617 a	277.4 a	222.9 a	376.1 a	299.6 a
	Control	1.952 b	1.487 b	273.1 a	210.7 b	366.5 b	284.3 b

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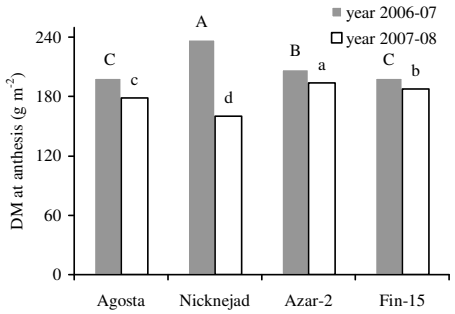

Figure 4. Dry matter (DM) response at anthesis in four dryland wheat cultivars for both years of study. Columns with the same letter in each year are not significantly different; using Tukey's test (P value 5%).

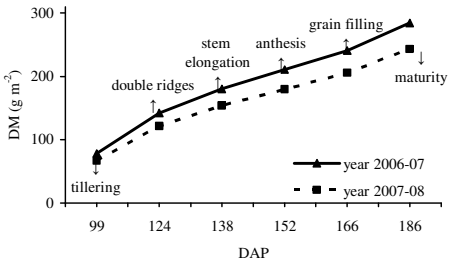

Figure 5. Mean dry matter accumulation in six developmental stages (days after planting) of dryland wheat cultivars for both years of study.

treatments might explain the yield enhancement associated with CCC application.

Averaged over CCC application and wheat varieties, increased application of N from 0 kg ha^{-1} (control) to 80 kg ha^{-1} improved biomass production (Table 5). The highest biomass (427.6 g m^{-2}) was obtained from Nicknejad at 80 kg N ha^{-1} and the lowest biomass (130.2 g m^{-2}) belonged to Azar-2 at 0 kg N ha^{-1}. Interaction of N rates×CCC on biomass were significant (Table 4). The greatest biomass was obtained in the treatment using 80 kg N ha^{-1} and application of CCC and amounted to376.1 and 299.6 g m^{-2}, respectively, in the first and the second seasons. The control treatment of using no N and CCC produced the least biomass in both years (241.5 and 161.9 g m^{-2}, respectively). Higher application of N from 0 to 80 kg ha^{-1} with sufficient soil moisture increased turgor, which resulted in greater growth and dry matter (Halvorson *et al*., 2004). Application of CCC caused lower vegetative growth due to production of more fertile tillers and more grains per spike, which increased the total biomass.

Radiation Use Efficiency

RUE differences among cultivars were significant (Figure 8). In 2006-2007, the highest and the lowest RUE was obtained from Nicknejad cultivar (0.84 g MJ^{-1} m^{-2})

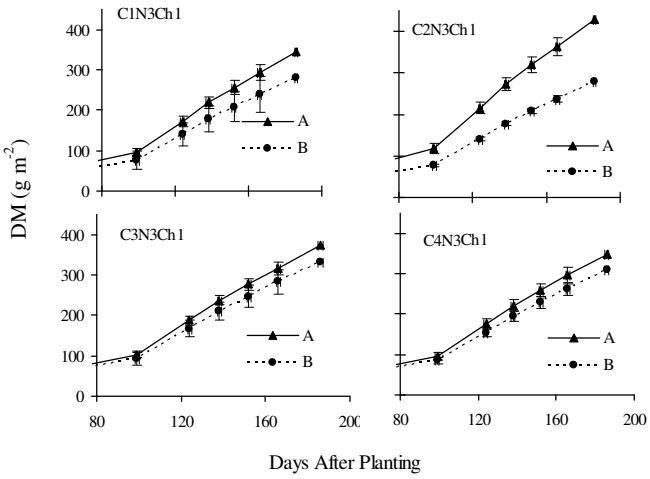

Figure 6. Dry matter responses during six developmental stages of dryland wheat cultivars to 80 kg ha^{-1}N and application of CCC for year 2006-2007 (A) and 2007-2008 (B).

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Table 5. Total Biomass responses to three levels of N for both years of study.

Nitrogen kg ha^{-1}	Years	
	2006-07	2007-08
0	144.4	166.7
40	337.2	270.9
80	371.3	292.0

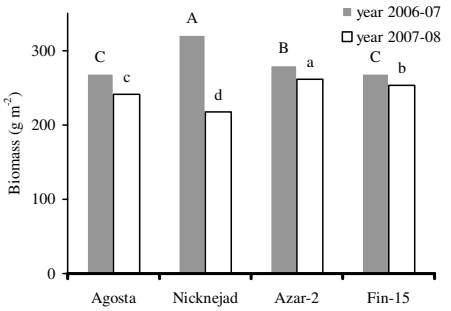

Figure 7. Total biomass response in four dryland wheat cultivars for both years of study (P value 5%). Columns with the same letter in each year are not significantly different; using Tukey's test (P value 5%).

and Agosta (0.68 g MJ^{-1} m^{-2}), respectively. However, in 2007-2008, the highest RUE was obtained from Azar-2 (0.65 g MJ^{-1} m^{-2}), while Nicknejad had the lowest (0.52 g MJ^{-1} m^{-2}). RUE was strongly affected by precipitation and N application rate. Increase in RUE with more PAR interception results from increased precipitation and N application (Figure 8). RUE appeared to be more associated with N application since it was only slightly affected by CCC.

DISCUSSION

The CCC treated plants had greater leaf area and more dry matter accumulation at anthesis than the untreated plants (Figures 3 and 6). In the 2006-2007 growing season, Nicknejad cultivar had the highest LAI (2.19) and dry matter accumulation (318.23 g m^{-2}) at anthesis in the treatment consisting of CCC and 80 kg N ha^{-1}. In the next season, the highest LAI (1.66) and dry matter accumulation (247.10 g m^{-2}) at anthesis was

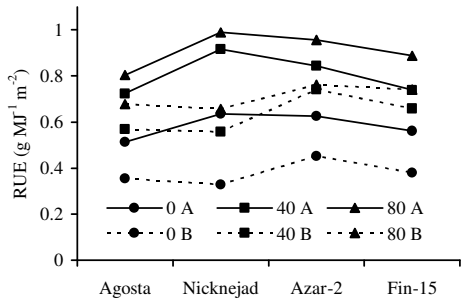

Figure 8. Effects of different levels of N (0, 40 and 80 kg ha-1) on RUE of four dry land wheat cultivars in 2006-2007 (A) and 2007-2008 (B).

obtained from Azar-2 cultivar under similar conditions. Increases in dry matter accumulation and LAI at anthesis were associated with increased biomass yield. In fact, the increase in source size (i.e. leaf area of the treated plants) or photosynthesis rate with the CCC treatments might be an explanation for the yield enhancement achieved by CCC applications (Singh *et al*., 1987; Ma and Smith, 1992; Emam and Karimi, 1997; and Emam and Moaied, 2000). It might, therefore, be concluded that CCC could effectively increase resistance of wheat to drought stress and change the rate of photosynthesis and photo-assimilate partitioning to the grain (Singh *et al*., 1987; Ma and Smith, 1992; Emam and Karimi, 1997). Further investigation is required for better understanding of the mechanism of beneficial effects of CCC on wheat dryland cultivars under different N rates (Emam and Karimi, 1997; Emam and Moaied, 2000).

In our study, N application had significant effects on biomass yield, with 80 kg N ha^{-1} having the greatest effect (Table 5). Indeed, N application improved growth rate and crop canopy at earlier stages, when moisture supply was not limited, and it increased radiation interception. This supports the idea that nitrogen is associated with both the green area (Caviglia and Sadras, 2001; Salvagiotti and Miralles, 2008) of the wheat canopy and with the dry matter component. The higher biomass production sustained a large fertile spike population that increased the grain

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number per unit area and, consequently, the grain yield. Similar results have been reported by others (Salvagiotti and Miralles, 2008). It is reported that wheat grain yield, photosynthesis, and accumulation of dry matter would decrease with over-fertilization of nitrogen (Nielsen *et al*, 2002). Therefore, determination of the appropriate amount of nitrogen for dryland wheat is important so that the growers can optimize yields and improve their grain quality without over-fertilization with N that might increase N leaching potential (Halvorson *et al*., 2004).

Nitrogen fertilization also improved RUE (Caviglia and Sadras, 2001). The balance between N fertilization and the available seasonal moisture supplies seems to be important (Halvorson *et al*., 2004). The improved RUE appeared to be mainly due to the changes in LAI and accumulation of dry matter before anthesis. Indeed, in our study, the effects of the precipitation and N application were to increase PAR interception (Figure 9) as reported by others (Muurinen and Peltonen-Sainio, 2006; Quanqi *et al*., 2008).

With regard to precipitation distribution (Table 2), during anthesis and late season drought stress, less grain could be formed and leaf senescence might be the main reason for both lower total biomass and grain yield (Wilson and Jamieson, 1985; Gallo *et al*., 1993; Wajid *et al*, 2007). For improving biomass production in dryland conditions, IPAR or RUE should be enhanced by increasing LAI at earlier growth stages (Brancourt-Hulmel *et al*., 2003; Acreche *et al*., 2009). In our study, crop yield was positively related to RUE (Figure 9), a finding in agreement with the results reported by others (Abbate *et al*, 1995; Chen *et al*., 2003; Li *et al*., 2006).

After anthesis, yield capacity is mainly determined by photosynthesis of the green flag leaves and spikes. PAR does not seem to be a limiting factor (Fang *et al*., 2006). Therefore, the improved ability of these plant parts to transform light into dry matter might be very important for increased dry matter production (Monteith, 1977; Sinclair and Muchow, 1999). In fact, in dryland conditions, the most important factor

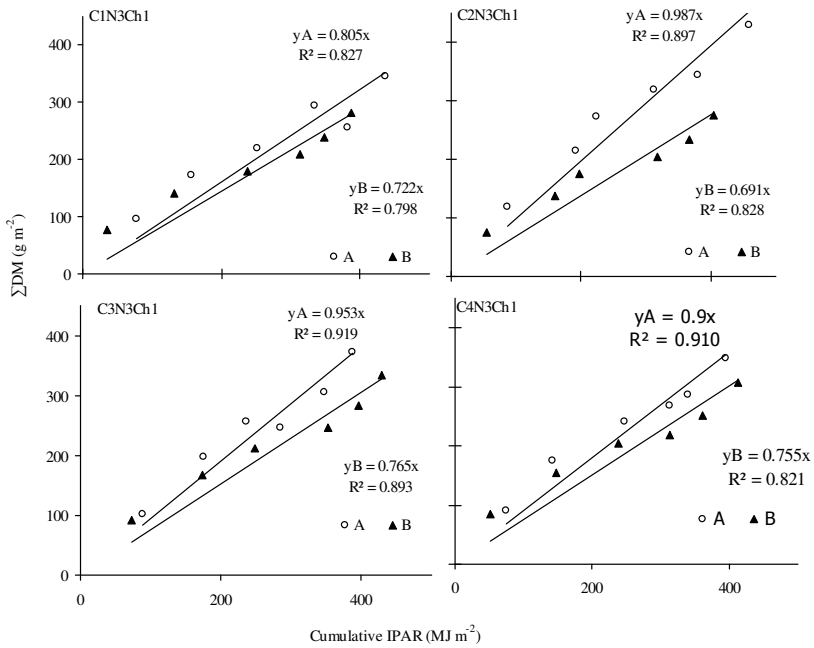

Figure 9. Relationship between dry matter (DM) and cumulative IPAR at six developmental stages of four dryland wheat cultivars (C1= Agosta; C2= Nicknejad; C3= Azar-2; C4= Fin15; N3 =80 kg N ha^{-1}, Ch1= CCC application) for year 2006-2007 (A) and 2007-2008 (B).

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responsible for high photosynthetic efficiency after anthesis might be increased duration of leaf area and greater remobilization to sinks. In dryland conditions, photosynthesis is restricted by moisture supply (Uhart and Andrade, 1995; O'Connell *et al*., 2004) and depends primarily on the amount of light intercepted by photosynthetic tissues (Monteith, 1977), which is determined by the canopy size and the ability for N uptake (Muurinen and Peltonen-Sainio, 2006; Quanqi *et al*., 2008).

Lower RUE values obtained in our study could be explained in many ways. RUE may change due to environmental conditions such as light saturation, moisture deficit, nutrient stress, low and high temperature and low density of planting in dryland conditions. Variation in RUE can arise from differences in partitioning between root and shoot, or from differences in PAR interception (O'Connell *et al*., 2004). The relatively small year-to year variation in RUE appears to be due to precipitation amount and its distribution. RUE reductions due to water stress are known to occur in barley (Legg *et al*., 1979). The RUE obtained in our study showed differences among the dryland wheat cultivars (Figure 9) that are consistent with the results reported for other environments, which could reflect a genotype-by-environment interaction (O'Connell *et al*., 2004).

Data are now required to test the relative benefits of high and low RUE in semi-arid environments. In such water-limited situations, the higher RUE 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 canopy cover (Figures 1 and 2). This should be an area for further investigations. Agronomic management strategies aimed at maximizing the opportunity for dryland wheat to intercept PAR include timely/early sowing, adequate plant densities to achieve early canopy expansion and maximum ground cover, tactical fallowing for soil water conservation to minimize post-anthesis water stress, provision of adequate plant nutrition, and using appropriate cultivars. Results obtained in the present study suggest that Nicknejad and Azar-2 are the bread wheat cultivars appropriate for dryland production under dry and wet years, respectively.

CONCLUSIONS

Our results showed that differences between cultivars for LAI, biomass, and RUE were significant. In the 2006-2007 growing season, the highest biomass production and RUE (431.2 g m^{-2} and 0.99 g MJ^{-1} m^{-2}, respectively) were obtained from Nicknejad cultivar in the treatment consisting of CCC application and using 80 kg N ha^{-1}. In 2007-2008, however, the corresponding results belonged to Azar-2 cultivar (333.5 g m^{-2} and 0.76 g MJ^{-1} m^{-2}, respectively). The highest LAI (2.19 and 1.66, respectively, in the first and the second season) and dry matter during anthesis (318.23 and 247.10 g m^{-2}, respectively) were obtained from the same treatments. It appeared that RUE was dependent on LAI and that total biomass yield increased by N application rates and precipitation during the growth stages. It might be recommended that application of N and selection of cultivars resistant to late season drought stress should be considered for improving RUE and biomass production under dryland conditions. Also, future studies should consider RUE in pre and post anthesis separately; because of the many major physiological changes occurring in these periods.

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کارآیی عملکرد و استفاده از تابش در چهار رقم گندم دیم تحت سطوح مختلف کود نیتروژن و کلرمکوات کلرید

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چکیده

در دهه های آینده تاثیر تغییرات اقلیمی ریسک تولید را در شرایط خشک افزایش می دهد. بنابراین، انتخاب ارقامی از گندم (*Triticum aestivum* L.) که بتوانند در اقلیم های آتی عملکرد مطلوبی داشته باشد، از اهمیت زیادی بر خوردار است. کارآیی استفاده از تابش (RUE) فاکتور کلیدی جهت تعیین عملکرد محصول، و در ارتباط با زیست توده و شاخص سطح برگ (LAI) است. برای دستیابی به عملکرد بالای ارقام دیم افزایش کارآیی استفاده از تابش امری ضروری می باشد. در این پژوهش، تاثیرات سطوح مختلف کود نیتروژن و یک ماده کند کننده رشد (کلرمکوات کلرید) بر شاخص سطح برگ، تجمع ماده خشک، عملکرد زیست توده و کارآیی استفاده از تابش چهار رقم گندم دیم مورد مطالعه قرار گرفت. این پژوهش مزرعه ای در دو سال زراعی ۸۶-۱۳۸۵ و۸۷-۱۳۸۶ در مزرعه تحقیقاتی دانشکده کشاورزی دانشگاه شیراز انجام شد. نتایج نشان داد که بین ارقام مختلف از نظر شاخص سطح برگ، زیست توده و کارآیی استفاده از تابش تفاوت معنی‌داری در شرایط مشابه وجود دارد و مشخص شد کارآیی استفاده از تابش در ارتباط با شاخص سطح برگ و عملکرد زیست توده است. بیشینه تولید زیست توده در سال ۸۶-۱۳۸۵ (۴۳۱/۲ گرم بر متر مربع) و کارآیی استفاده از تابش (۰/۹۹ گرم برمگاژول بر متر مربع) از رقم نیک نژاد و در سال ۸۷-۱۳۸۶ از رقم آذر ۲ (به ترتیب، ۳۳۳/۵ گرم بر متر مربع و ۰/۷۶ گرم برمگاژول بر متر مربع) با تیمار کلرمکوات کلرید و کاربرد ۸۰ کیلوگرم نیتروژن در هکتار بدست آمد. با توجه به نتایج این پژوهش به نظر می‌رسد مصرف کود نیتروژن و انتخاب ارقام مقاوم به تنش خشکی دیررس اثر بارزی در بهبود کارآیی استفاده از تابش در شرایط دیم داشته باشد.

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