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Full Length Research Paper

Impact of nitrogen nutrition and moisture deficits on growth, yield and radiation use efficiency of wheat (*Triticum aestivum* L.)

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Crop production in arid and semi arid areas is restricted by soil deficiencies in moisture and plant nutrients, especially nitrogen. In order to evaluate the impact of nitrogen nutrition and moisture deficits on growth, yield and radiation use efficiency of wheat (*Triticum aestivum* L.), a field experiment was conducted at Agronomic Research Area, University of Agriculture Faisalabad, during 2008 to 2009. The study comprised of four nitrogen levels, that is, N_0 = control, N_1 = 60, N_2 = 120 and N_3 = 180 kg N ha^{-1} and three water deficit levels, that is, I_1 = irrigation at 25 mm potential soil moisture deficit (PSMD), I_2 = irrigation at 50 mm potential soil moisture deficit (PSMD), I_3 = irrigation at 75 mm potential soil moisture deficit (PSMD). Results of the study revealed that maximum grain yield (6.72 t ha^{-1}) was obtained in the case of N_3 (180 kg N ha^{-1}) when I_2 = irrigation at 50 mm potential soil moisture deficit ($I_2 \times N_3$) was applied in contrast to lowest grain yield (2.00 t ha^{-1}) in response to I_3= irrigation at 75 mm potential soil moisture deficit × no nitrogen (control) ($I_3 \times N_0$). Highest plant height (86.27 cm), number of spike bearing tillers m^{-2} (320), grains per spike (49.73), 1000-grain weight (50.55 g), biological yield (15.48 t ha^{-1}), straw yield (8.76 t ha^{-1}) and harvest index (43.42%) increased with increasing levels of nitrogen. The maximum value of these parameters was also observed in I_2 where irrigation was applied at 50 mm potential soil moisture deficit. The maximum value of RUE for TDM (6.45 g MJ^{-1}) was observed in $I_2 \times N_3$ irrigation at 50 mm potential soil moisture deficit and nitrogen (180 kg ha^{-1}) treatment combination. Similarly, maximum RUE for grain yield (2.80 g MJ^{-1}) was observed for nitrogen (50 mm potential soil moisture deficit and 180 kg N ha^{-1}).

Key words: Wheat, nitrogen nutrition, moisture deficits, radiation use efficiency, yield, *Triticum aestivum* L.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most important and largest grain crop in Pakistan as it is called the king of cereals. It is the main staple food item of the country's population and thus occupies a central position in forming agricultural policies and dominates all agronomic crops in terms of acreage and production (Shehzad et al., 2012a, b). Wheat contributes 13.1% to the value added in agriculture and 2.7% to GDP. Wheat was cultivated on an area of 8.80 million hectares and production was 24.21 million tons and the yield was 2750 kg ha^{-1} (Government of Pakistan, 2011).

Despite higher yield potential, average grain yield of wheat is much lower in Pakistan as imbalance nutrition is one of the major challenges to crop production. Nitrogen plays a very important role in the plant metabolism and it increases the grain yield in cereals. In addition to the formation of proteins, nitrogen is an integral part of

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chlorophyll, which is the primary absorber of light energy for photosynthesis. An adequate supply of nitrogen is associated with high photosynthetic activity, vigorous vegetative growth and its supply influences the utilization of carbohydrates (Havlin, 1999). Addition of nitrogen fertilizer to wheat is required to ensure that nitrogen is available throughout the growing season due to its important role in promoting both vegetative and reproductive growth. High yielding wheat varieties need adequate and regular supply of nitrogen to develop high photosynthetic capacity and maintain the proper nitrogen concentration in the leaves so that CO_2 assimilation is not affected when large rates of nitrogen are required for ear growth and grain filling period (Lawlor, 1995). Plant height, flag leaf area, tillers number and dry weight per unit area of wheat are increased with increasing nitrogen level (Zahran et al., 1997). Numbers of tillers and spikes m^{-2}, plant height, spike length, number of spikelets per spike and grains per spike, grain and straw yields of wheat also increases with increasing nitrogen levels (Mostafa et al., 1997). Nitrogen application along with soil drying substantially increases grain filling period except in severe soil drying treatments as its higher rates can effectively balance the adverse effects of water stress (Ghani et al., 2000).

Wheat production is particularly dependent on mineral nutrition, especially nitrogen for its proper growth and development. Consequently, adequate levels of irrigation and nitrogen fertilizer are needed (Elsiddig et al., 1998). Grain development is a function of rate and duration of grain growth, determined by photosynthate supply and is affected by numerous environmental factors including water and nitrogen. Moisture deficits and nitrogen deficiency reduces photosynthate production because of stomatal closure and early senescence which ultimately affect grain development process (Singh and Wilkens, 1999). The effect of water and nitrogen on physiological responses in wheat indicates that supplemental water is needed for high rates of nitrogen to increase the rate and duration of leaf photosynthesis (Yang et al., 2001). Higher grain weight of plants which are frequently irrigated is associated with longer grain filling duration and faster grain filling rate (Li et al., 2000). Water scarcity induced after anthesis shortens the duration of grain filling by causing premature desiccation of the endosperm and by limiting embryo volume (Westage, 1994). The moisture stress reduces grain yield when applied at any physiological growth stage but the extent of damage varies from stage to stage as early grain development stage is more vulnerable to water stress than later grain development stage (Malik and Ahmad, 1993).

Water shortage in the country demands development of new technologies and methods of irrigation that can be helpful in utilizing this valuable input in an effective way. In addition, there is also a need to carry out practices of irrigation water management to achieve high water use efficiency. In Pakistan, wheat faces periods of drought due to shortage of water and seasonal canal closure during the months of December and January. This scarcity requires re-scheduling of irrigation which should not affect grain yield significantly, reducing the water applied to the crop (Balasubramaniyan and Palaniappan, 2001).

Considering the above view point, the present study was therefore planned to evaluate the growth and yield of wheat (*Triticum aestivum* L.) in response to different moisture regimes and nitrogen levels and determine nitrogen requirement under water deficit conditions.

MATERIALS AND METHODS

Site and soil description

The proposed study was conducted at Agronomic Research Area, University of Agriculture Faisalabad, Pakistan (31°.25' N, 73°.09' E) during the Rabi season 2008 to 2009 with the objective of studying the impact of nitrogen nutrition and moisture deficits on the growth, yield and radiation use efficiency of wheat. The experimental soil was analyzed for their physio-chemical characteristics. A composite and representative soil sample to a depth of 30 cm was obtained with soil auger prior to sowing of wheat crop. Analysis revealed that soil was sandy clay loam (sand 28%, silt 36% and clay 45%) with pH 7.6, 0.85% organic matter, 9.1 $cmol_c\ kg^{-1}$ cation exchange capacity (CEC), 1.79 $dS\ m^{-1}$ electrical conductivity (EC), 0.062% totals nitrogen, 13.1 ppm phosphorus and 179 ppm potassium. Seasonal rainfall, relative humidity and the prevailing air temperature (min and max) during the crop phase of crop growth and development are described in Table 1.

Experimental treatments and design

The randomized complete block design (RCBD) with split plot arrangement in a triplicate run using a net plot size of 1.5m × 6.0 m was outlined for layout of the experiment. The moisture deficit and nitrogen levels were randomized in main and sub-plots, respectively. Three moisture deficit levels (I_1 = 25 mm potential soil moisture deficit (PSMD), I_2 = 50 mm potential soil moisture deficit (PSMD) and I_3 = 75 mm potential soil moisture deficit (PSMD) and four nitrogen levels (N_0 = 0, N_1 = 60, N_2 = 120, N_3 = 180) kg ha^{-1} were applied depending on the treatments.

Crop husbandry

Wheat crop (Sahar-2006) was initiated in December, 2008 with the help of a single row hand drill in 25 cm apart rows using a seed rate of 100 kg seed ha^{-1}. Nitrogen was applied split doses as 1/2 nitrogen was applied at sowing, while the remaining 1/2 nitrogen was applied with first irrigation. The recommended dose of phosphorus and potassium was applied at the time of sowing. Maximum potential soil moisture deficit (D) was used as a criterion for irrigation application at 25, 50 and 75 mm moisture deficit. Daily Penman's potential evapotranspiration (PET) was calculated by using standard programme "CROPWAT" developed by FAO (1993). Daily summation of PET values over time gives a cumulative potential soil moisture deficit (D) as suggested by French and Legg (1979). The amount of water applied was equal to the difference between potential evapotranspiration (PET) and rainfall + irrigation [$D = \sum PET - \sum (I+R)$]. Then, PET was calculated by using the formula:

Table 1. Mean monthly temperature (minimum and maximum), rainfall and relative humidity during 2008 to 2009.

Month	Temperature (°C), minimum	Temperature (°C), maximum	Rainfall (mm)	R.H (%)
November	11.8	26.9	3.7	62.7
December	6	23.3	2.4	69.7
January	8	17.2	5.1	73.8
February	9.9	24	12.2	65.1
March	16.5	32.4	43.6	58.3
April	21.9	39.4	4.6	37.6

$PET = Kp.\ E_{pan}$

where, E_{pan} = Mean daily value of pan evaporation; Kp = Pan co-efficient.

A measured quantity of water was applied by manual labour. All other agronomic practices were kept normal and uniform for all the treatments except deficit levels. The crop was harvested manually at physiological maturity. This was done when the green colour from the glumes and kernels disappeared completely. Potential evapotranspiration (PET) was determined using pan evaporation method. Pan evaporation provides a measurement of all the integrated effects of radiation, temperature and wind on evaporation from a scientific open water space (evaporation pan).

Data recording

Observations concerning plant height, fertile tillers, number of grains per spike, 1000-grain weight, biological yield, grain yield, straw yield and harvest index were recorded using standard procedures. Radiation use efficiency for total dry matter (RUE_{TDM}) and grain yield (RUE_{GY}) was calculated as the ratio of total biomass and grain yield to cumulative intercepted PAR (∑Sa) (Khaliq et al., 2008):

$RUE_{TDM} = TDM / \sum Sa$
$RUE_{GY} = \text{Grain yield} / \sum Sa$

where, Sa is the amount of intercepted PAR (Sa); its value was determined by multiplying values of Fi with daily incident PAR (Si), during the season. Cumulative intercepted PAR (∑Sa) was calculated by adding all values of intercepted PAR (Sa) recorded at each 15 days interval:

$Sa = Fi \times Si$

where, Si is daily incident PAR and Fi is fraction of intercepted radiation and is calculated by Beer's law as follows:

$Fi = 1\text{-}\exp(-k \times LAI)$

where, k is an extinction coefficient for total solar radiation equal to 0.4 for wheat and LAI is the leaf area index.
Si is calculated by using the following formula:

$Si = \text{Total } Rs/2$

where, Rs is the solar radiation and it is calculated as follows:

$Rs = [a + b\ (n/N)] \times Ra$

where, a and b are constants and their values are 0.25 and 0.5, respectively, n/N is the ratio of actual (n) to maximum possible (N) sunshine hours and Ra is the extra terrestrial radiation expressed in equivalent evaporation in mm/day.

Statistical analysis

Data collected were analyzed statistically using Fisher's analysis of variance techniques. Differences among the treatments' means were compared using least significant difference (LSD) at 5% probability level (Steel et al., 1997).

RESULTS AND DISCUSSION

The data regarding the plant height as influenced by irrigation and nitrogen levels is presented in Table 3. Among irrigation levels, plant height increased significantly with the amount and timing of irrigations. In the case of I_2, where irrigation at 50 mm PSMD was applied, the plant height was maximum (76.27 cm) followed by 70.17 and 68.77 cm in (I_1) irrigation at 25 mm PSMD and (I_3) irrigation at 75 mm PSMD, respectively, which were statistically at par with each other. The maximum plant height at I_2 may be attributed to the adequate moisture supply through all plant growth stages. These results are quite in line with those of Warraich et al. (2007). As regarding nitrogen levels, maximum plant height (82.27) was observed in treatment N_3 (180 kg N ha^{-1}) followed by 77.16 in N_2 (120 kg N ha^{-1}), 69.04 in N_1 (60 kg N ha^{-1}) and minimum plant height (59.40 cm) was observed in N_0 (control). All treatments significantly enhanced the plant height over the control (N_0). The combined effect of ($I_2 \times N_3$) irrigation at 50 mm PSMD and N_3 (180 kg N ha^{-1}) also gave a maximum plant height (86.27 cm) with significant mean square values (Tables 2 and 4). These results are in conformity with those of Ali et al. (2003), Hussain et al. (2006),

Maqsood et al. (2002) and Khaliq et al. (1999) who also observed increase in plant height due to nitrogen fertilization. This tendency can be attributed to higher dose of nitrogen, which greatly help the plant to expose its potential to grow vigorously.

The importance of spike bearing tillers is evident from the fact that it influences directly the final grain yield. The data regarding the spike bearing tillers (m^{-2}) as influenced by irrigation and nitrogen levels is presented in Tables 2,

Table 2. The mean squares of moisture deficits and nitrogen treatments with regards to yield and yield components of wheat during 2008 to 2009.

Source of variation	df	Mean square									
		Plant height (cm)	Spike bearing tillers (m^{-2})	No. of grains $spike^{-1}$	1000-grain weight (g)	Biological yield ($t\ ha^{-1}$)	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Harvest index (%)	RUE_{TDM} ($g\ MJ^{-1}$)	RUE_{GY} ($g\ MJ^{-1}$)
Replication (r)	2	19.81	147.86	0.68	0.34	0.04	0.01	0.01	0.09	0.008	0.002
Irrigation (I)	2	21.88*	1089.53**	40.10**	209.29**	53.84*	11.80*	15.26*	36.01*	9.35*	2.05
Error a	4	10685	290.11	1.96	0.72	0.01	0.001	0.006	0.10	0.002	0.001
Nitrogen (N)	3	898.42**	6368.66**	53.13**	141.15**	67.64**	15.14*	19.10*	68.42**	11.74*	2.63*
I × N	6	15.25	1184.53**	5.77	2.60	1.99	0.43	1.12	6.64	0.35	0.07
Error b	18	2.58	271.99	0.45	0.15	0.01	0.001	0.001	0.04	0.001	0.001
Total	35										

** Indicates the significance at 5% level of probability.

Table 3. The response of yield and yield components of wheat to moisture deficits and nitrogen levels during 2008 to 2009.

Treatments	Plant height (cm)	Spike bearing tillers (m^{-2})	Number of grains $spike^{-1}$	1000-grain weight (g)	Biological yield ($t\ ha^{-1}$)	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Harvest index (%)	RUE_{TDM} ($g\ MJ^{-1}$)	RUE_{GY} ($g\ MJ^{-1}$)
Irrigation levels (I)										
I_1	70.17^b	263.3^b	40.72^b	40.03^b	9.88^b	3.67^b	6.21^b	36.64^b	4.12^b	1.53^b
I_2	76.27^a	283.1^a	44.47^a	45.52^a	13.02^a	5.09^a	7.93^a	38.48^a	5.42^a	2.11^a
I_3	68.77^b	224.0^c	39.95^b	37.33^c	8.98^c	3.18^c	5.80^c	35.01^c	3.74^c	1.32^c
LSD (*P*=0.05)	3.70	19.31	1.58	0.96	0.12	0.03	0.08	0.36	0.05	0.03
Nitrogen rates (N)										
N_0	59.40^d	221.2^c	39.06^c	36.55^d	7.03^d	2.37^d	4.65^d	33.68^d	2.93^d	0.99^d
N_1	69.04^c	262.1^b	40.80^c	39.10^c	10.23^c	3.61^c	6.62^c	35.23^c	4.26^c	1.50^c
N_2	77.16^b	258.1^b	42.18^b	42.60^b	11.77^b	4.53^b	7.24^b	38.17^b	4.90^b	1.89^b
N_3	82.27^a	285.6^a	44.81^a	45.60^a	13.48^a	5.40^a	8.07^a	39.76^a	5.61^a	2.25^a
LSD (*P*=0.05)	1.59	5.24	0.66	0.37	0.06	0.03	0.03	0.19	0.03	0.03

Means sharing same letters did not differ significantly at $P = 0.05$.

3 and 4. Among irrigation levels, maximum number of spike bearing tillers (m^{-2}) ($P \leq 0.05$) (283.1) was obtained in treatment I_2 (irrigation at 50 mm PSMD) followed by 263.3 in treatment I_1 (Irrigation at 25 mm PSMD) and I_3 (224.0). These results are similar to those of Bajwa et al. (1993) and Beher and Sharma (1991). They found that when irrigation at appropriate time was applied, it resulted in increase number of spike bearing tillers (m^{-2}). The treatment N_3 (180 kg ha^{-1}) produced the maximum number of tillers m^{-2} (285.6) followed by N_2 (258.2) and N_1 (262.1) which were significantly at par and N_0 (control) produced the minimum number of tillers (221.2). The interactive effect of ($I_2 \times N_3$) irrigation at 50 mm PSMD and N_3 (180 kg N ha^{-1}) also provided a maximum spike bearing tillers (320.00). These results are quite in line with those of Khaliq et al. (1999) who reported that

Table 4. The combined effect of moisture deficits and nitrogen levels on yield and yield components of wheat during 2008 to 2009.

Treatment	Plant height (cm)	Spike bearing tillers (m^{-2})	Number of grains $spike^{-1}$	1000-grain weight (g)	Biological yield (t ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)	RUE_{TDM} (g MJ^{-1})	RUE_{GY} (g MJ^{-1})
Interaction (I × N)										
$I_1 \times N_0$	56.67^{g}	232.0^{f}	39.23^{fg}	35.28^{j}	6.55^{k}	2.19^{k}	4.35^{j}	33.54^{i}	2.73^{k}	0.92^{j}
$I_1 \times N_1$	66.07^{f}	254.7^{de}	40.33e^{f}	37.63^{h}	8.95^{h}	3.24^{h}	5.71^{g}	36.20^{f}	3.73^{h}	1.35^{h}
$I_1 \times N_2$	76.27^{de}	264.0^{c}	40.73^{e}	42.09^{e}	10.60^{f}	4.00^{f}	6.59^{e}	37.80^{d}	4.42^{f}	1.67^{f}
$I_1 \times N_3$	81.67^{b}	302.3^{b}	42.57^{c}	45.14^{c}	13.45^{d}	5.25^{c}	8.20^{c}	39.03^{c}	5.60^{d}	2.19^{c}
$I_2 \times N_0$	67.67^{f}	247.7^{e}	40.67^{e}	40.39^{g}	8.45^{i}	2.93^{i}	5.52^{h}	34.63^{h}	3.52^{i}	1.22^{i}
$I_2 \times N_1$	74.13^{e}	269.7^{c}	42.93^{c}	43.46^{d}	13.58^{c}	4.77^{d}	8.81^{a}	35.12^{g}	5.66^{c}	1.98^{d}
$I_2 \times N_2$	79.80^{bc}	295.0^{b}	44.53^{b}	47.70^{b}	14.55^{b}	5.93^{b}	8.62^{b}	40.73^{b}	6.06^{b}	2.47^{b}
$I_2 \times N_3$	86.27^{a}	320.0^{a}	49.73^{a}	50.55^{a}	15.48^{a}	6.72^{a}	8.76^{a}	43.42^{a}	6.45^{a}	2.80^{a}
$I_3 \times N_0$	53.87^{h}	184.0^{h}	37.27^{h}	33.99^{k}	6.08^{l}	2.00^{l}	4.08^{k}	32.88^{j}	2.53^{l}	0.83^{k}
$I_3 \times N_1$	66.93^{f}	262.0^{cd}	39.13^{g}	36.22^{i}	8.16^{j}	2.81^{j}	5.36^{i}	34.37^{h}	3.40^{j}	1.17^{i}
$I_3 \times N_2$	75.40 ^{e}	215.7^{g}	41.23^{de}	38.00^{h}	10.17^{g}	3.65^{g}	6.51^{f}	35.97^{f}	4.24^{g}	1.52^{g}
$I_3 \times N_3$	78.87^{cd}	234.3^{f}	42.13^{cd}	41.10^{f}	11.50^{e}	4.24^{e}	7.26^{d}	36.84^{e}	4.79e	1.76^{e}
LSD (*P*=0.05)	2.75	9.07	1.15	0.65	0.11	0.05	0.05	0.34	0.05	0.05

Means sharing same letters do not differ significantly at *P* = 0.05.

number of spike bearing tillers (m^{-2}) increased with the increasing level of nitrogen.

Data regarding the number of grains per spike is presented in Tables 2 to 4. In the case of treatment I_2 (Irrigation at 50 mm PSMD), the number of grains per spike (44.47) were maximum ($P \leq 0.05$) followed by number of grains per spike (40.72) and 39.95 for treatments I_1 (Irrigation at 25 mm PSMD) and I_3 (Irrigation at 75 mm PSMD), respectively. These findings are in line with those of Maqsood et al. (2002). In the case of nitrogen application, the treatment N_3 (180 kg ha^{-1}) produced the highest number of grains (44.81) per spike followed by N_2 (120 kg N ha^{-1}) having 42.18 grains per spike, N_1 (60 kg N ha^{-1}) having 40.80 grains per spike and N_0 (control) having lowest number of grains (39.06) per spike. Maximum grains per spike (49.73) was attained in relation to ($I_2 \times N_3$) irrigation at 50 mm PSMD and N_3 (180 kg N ha^{-1}) interaction study. These finding are in agreement with those of Gab-alla et al. (1985) and Khaliq et al. (1999).

Statically analyzed data on 1000-grain weight as influenced by irrigation and nitrogen levels ($P \leq 0.05$) are shown in Tables 2 and 3. Among irrigation treatments, 1000-grain weight was the highest (45.52 g) in the case of I_2 (irrigation at 50 mm PSMD) which was followed by 40.03 and 37.33 g for treatment I_1 (irrigation at 25 mm PSMD) and I_3 (Irrigation at 75 mm PSMD), respectively. These results are similar with the findings of Maqsood et al. (2002) and Jin et al. (1999). 1000-grain weight also increased with the increasing level of nitrogen. The highest value of 1000-grain weight (45.60 g) was achieved in N_3 (180 kg N ha^{-1}) followed by 42.60 g in the case of N_2 (120 kg N ha^{-1}), 39.10 g in the case of N_1 (60 kg N ha^{-1}) and 36.55 g in case of N_0 (control), respectively. These findings are in conformity with those of Ali et al. (2003). Its interactive study also showed a maximum 1000-grain weight (50.55 g) in ($I_2 \times N_3$) irrigation at 50 mm PSMD and N_3 (180 kg N ha^{-1}) treated plots followed by ($I_2 \times N_2$) irrigation at 50 mm PSMD and N_3 (120 kg N ha^{-1}) (Table 4).

Biological yield is the total biomass produced by a crop from unit area. It is the combined contribution of yield components such as number of tillers per unit area, plant height, number of grains per spike and 1000-grain weight. Any factor causing change in these components will be reflected in the biological yield of a crop. The data regarding the biological yield as influenced by irrigation and nitrogen levels are shown in

Tables 2, 3 and 4. The analysis of variance for biological yield indicated highly significant difference among irrigation and nitrogen treatments ($P \leq 0.05$). Interactive study depicted that maximum biological yield (15.48 t ha^{-1}) was acquired by $I_2 \times N_3$ irrigation at 50 mm PSMD and N_3 (180 kg N ha^{-1}) treatment combination. Individually, the maximum biological yield (13.02 t ha^{-1}) was obtained in the case of treatment I_2 followed by 9.88 t ha^{-1} in case of I_1 (irrigation at 25 mm PSMD). Minimum biological yield (8.98 t ha^{-1}) was produced by treatment I_3 (Irrigation at 75 mm PSMD). Ghuman and Mauraya (1986) and Thompson and Chase (1992) also reported that biological yield was significantly different under different deficit irrigations. In the case of nitrogen, maximum value of biological yield (13.48 t ha^{-1}) was obtained with the treatment N_3 (180 kg N ha^{-1}) which was followed by 11.77 t ha^{-1} in the case of N_2 (120 kg N ha^{-1}), 10.23 t ha^{-1} in the case of N_1 (60 kg N ha^{-1}) and minimum biological yield (7.03 t ha^{-1}) was obtained in N_0 (control). These findings are in line with those of Hussain et al. (2006), Ali et al. (2009) and Zahran et al. (1997). They observed that increasing nitrogen levels increase the biological yield of the crop.

The efficiency and effectiveness of a package of technology is ultimately reflected by the level of grain yield ha^{-1} which is a function of cumulative behavior of yield components such as number of fertile tillers per unit area, plant height, number of grains per spike and 1000-grain weight. The data regarding grain yield in wheat is influenced by irrigation and nitrogen levels. The analysis of variance for grain yield indicating highly significant results were obtained from irrigation and nitrogen treatments ($P \leq 0.05$). Among the irrigation levels, maximum grain yield (5.09 t ha^{-1}) was achieved in I_2 (Irrigation at 50 mm PSMD) followed by grain yield (3.67 t ha^{-1} and 3.18 t ha^{-1}) for treatment I_1 (irrigation at 25 mm PSMD) and I_3 (Irrigation at 75 mm PSMD), respectively. These findings are supported by Kang et al. (2002) and Zhang et al. (2008). They found that grain yield increased with application of irrigation at specific time and in appropriate amount. In the case of nitrogen, the highest value for grain yield (5.40 t ha^{-1}) was obtained for treatment N_3 (180 kg N ha^{-1}), this value of grain yield is significantly different from the grain yield of 4.53, 3.61 and 2.37 t ha^{-1} for treatments N_2 (120 kg N ha^{-1}), N_1 (60 kg N ha^{-1}) and N_0 (control), respectively. Interactive study illustrated that maximum grain yield (6.72 t ha^{-1}) was attained with $I_2 \times N_3$ irrigation at 50 mm PSMD and N_3 (180 kg N ha^{-1}) treatment combinations (Table 4). These results are quite in line with those of Hussain et al. (2006), Haskett et al. (2000) and Ali et al. (2009). They observed that grain yield was increased by increasing nitrogen levels.

The analysis of variance in Tables 2 to 4 for straw yield is shown with significant differences for both irrigation and nitrogen treatment means ($P \leq 0.05$). Combined effect of $I_2 \times N_3$ irrigation at 50 mm PSMD and N_3 (180 kg N ha^{-1}) treatment showed the maximum straw yield (8.76 t ha^{-1}). Highest straw yield (7.93 t ha^{-1}) was recorded in the case of I_2 (Irrigation at 50 mm PSMD) which was followed by 6.21 t ha^{-1} in I_1 (irrigation at 25 mm PSMD) and 5.80 t ha^{-1} in I_3 (Irrigation at 75 mm PSMD), respectively. These results are in conformity with those of El-Kholy et al. (2005). Highest straw yield (8.07 t ha^{-1}) was observed in treatment N_3 (180 kg N ha^{-1}) among the nitrogen treatment means which was statistically different from N_2 (7.24 t ha^{-1}), N_1 (6.62 t ha^{-1}) and N_0 (4.65 t ha^{-1}), respectively. Iqbal et al. (2007) also observed that straw yield was increased by increasing levels of nitrogen.

The physiological efficiency of wheat plants to convert dry matter into the grain yield is measured in terms of harvest index (HI). The more the HI value, the more will be the physiological efficiency of plant to convert dry matter into grain yield. The data regarding the HI as influenced by irrigation and nitrogen levels is given in Tables 2, 3 and 4. The analysis of variance for grain yield indicated highly significant difference among irrigation and nitrogen treatments ($P \leq 0.05$). With the comparison of treatment means in the case of irrigation, the highest value (38.48%) for harvest index HI was achieved in I_2 (Irrigation at 50 mm PSMD) followed by 36.64% in the case of I_1 (irrigation at 25 mm PSMD) and 35.01% in the case of I_3 (irrigation at 75 mm PSMD). These findings are in line with those of Khan et al. (2002). Among the nitrogen levels, the highest value (39.76 %) was recorded in treatment N_3 (180 kg N ha^{-1}) followed by 38.17, 35.23 and 33.68% of HI in treatments N_2 (120 kg N ha^{-1}), N_1 (60 kg N ha^{-1}) and N_0 (control), respectively. Significant increase in harvest index was also achieved through ($I_2 \times N_3$) irrigation at 50 mm PSMD and N_3 (180 kg N ha^{-1}) treatment combination. The results of Ali et al. (2009) and Maqsood et al. (2002) collaborate the results obtained.

Radiation use efficiency (RUE) for total dry matter (TDM) was significant among different irrigation treatments. The highest value of RUE for TDM was achieved in I_2 (irrigation at 50 mm PSMD) and this value was 5.42 g MJ^{-1} of intercepted radiation. The RUE of treatment I_1 (irrigation at 25 mm PSMD) was 4.12 g MJ^{-1} of intercepted radiation ($P \leq 0.05$). The lowest radiation use efficiency was observed in I_3 (irrigation at 75 mm PSMD) and its value was 3.74 g MJ^{-1}. The RUE among different irrigation treatments was 3.74 to 5.42 g MJ^{-1}. With the comparison of the treatments in case of nitrogen, the value of RUE varied from 2.93 to 5.61 g MJ^{-1}. The highest value of RUE (5.61 g MJ^{-1}) was observed in N_3 where nitrogen was applied at the rate of 180 kg ha^{-1}, followed by 4.90 g MJ^{-1} in case of N_2 (120 kg N ha^{-1}), 4.26 g MJ^{-1} in the case of N_1 (60 kg ha^{-1}) and lowest RUE was achieved in N_0 (control) 2.93 g MJ^{-1}. $I_2 \times N_3$ irrigation at 50 mm PSMD and N_3 (180 kg N ha^{-1}) treatment provided greater RUE for total dry matter than other treatment combinations (Tables 2, 3 and 4).

Radiation use efficiency (RUE) for grain yield (GY) was significant among different irrigation treatments ($P \leq 0.05$). Individual effect showed that the highest value of RUE for GY was achieved in I_2 (irrigation at 50 mm PSMD) and this value was 2.12 g MJ^{-1} of intercepted radiation (Tables 2, 3 and 4). The radiation use efficiency (RUE) of treatment I_1 (irrigation at 25 mm PSMD) was 1.53 g MJ^{-1} of intercepted radiation. The lowest radiation use efficiency was observed in I_3 (irrigation at 75 mm PSMD) and its value was 1.32 g MJ^{-1}. The RUE among different irrigation treatments varied from 1.32 to 2.12 g MJ^{-1}. These findings are similar to those of Whitfield and Smith (1989) who found that deficit irrigation decreased the RUE of wheat. Comparing the means in case of nitrogen, the value of radiation use efficiency (RUE) varied from 2.25 to 0.99 g MJ^{-1}. The highest value of radiation use efficiency (2.25 g MJ^{-1}) was observed in N_3 where nitrogen was applied at the rate of 180 kg ha^{-1}, followed by 1.90 g MJ^{-1} in the case of N_2 (120 kg N ha^{-1}), 1.50 g MJ^{-1} in the case of N_1 (60 kg ha^{-1}) and lowest RUE was achieved in N_0 (control) 0.99 g MJ^{-1}. Interaction ($I_2 \times N_3$) irrigation at 50 mm PSMD and N_3 (180 kg N ha^{-1}) also has significant impact on RUE for grain yield (2.80 g MJ^{-1}). These results are similar to those of Calvigia and Sadras (2001) who reported that radiation use efficiency increases with increasing levels of nitrogen.

Conclusions

In this investigation, it can be concluded that the highest wheat grain yield (6.72 t ha^{-1}) was attained at interaction effect of $I_2 \times N_3$ irrigation at 50 mm PSMD and N_3 (180 kg N ha^{-1}). Hence, we can say that nitrogen rate (180 kg N ha^{-1}) has more potential to produce maximum yield at 50 mm potential soil moisture deficit (PSMD). In addition, maximum radiation use efficiency was also attained from nitrogen (180 kg N ha^{-1}) and its response to irrigation at 50 mm PSMD was also positive.

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