NITROGEN NUTRITION AND WATER STRESS EFFECTS ON GROWTH, YIELD AND WATER USE EFFICIENCY OF WHEAT (*Triticum aestivum* L.)

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Field experiments were conducted on a sandy loam soil in 2002-03 and 2003-04 growing seasons to determine the effect of nitrogen nutrition on growth, yield and water use efficiency of wheat under adequate and limited water supply conditions. The treatments comprised of four levels of irrigation (I_1, one irrigation at tillering stage; I_2, two irrigations, each at tillering and anthesis stages; I_3, three irrigations, each at tillering, anthesis and grain development stages and I_4, four irrigations, each at tillering, stem elongation, anthesis and grain development stages) in main plots and four N levels (0, 50, 100 and 150 kg N ha^{-1}) in sub-plots of a split plot design and were replicated three times. Increase in number of irrigations from 1 to 4 and nitrogen levels from 0 to 150 kg N ha^{-1}, significantly ($p \leq 0.05$) increased the average leaf area index (LAI), crop growth rate (CGR), yield attributes, and grain yield over the control (I_0 and N_0), in both the seasons. The maximum LAI and CGR were commensurate with highest levels of irrigation as well as nitrogen observed on an average during the 73-88 days after sowing (DAS) period of growth. The regression analysis revealed that LAI estimates with biological yield were 92% and 38% during the year 2002-03 and 2003-04, respectively. Mean grain yield in four, three and two irrigation treatments compared with that in one irrigation treatment increased by 47, 23 and 9 % during 2002-03 and by 91, 84 and 23 % in 2003-04, respectively. Water deficit reduced spikes m^{-2}. In both years, the average reduction in spikes m^{-2} at maximum irrigation deficit (one irrigation) at all N levels was 24%. Similar reduction occurred in grains $spike^{-1}$ where water deficit decreased this component on an average of 36 %. Mean water use efficiency (WUE) at all nitrogen levels was 41% higher in one irrigation treatment compared with four irrigations treatment. Significantly higher WUE was observed with 150 kg N ha^{-1} at all irrigation treatments. The water use efficiency (WUE), decreased with increasing number of irrigations, whereas nitrogen application significantly improved WUE.

Keywords: Wheat; crop growth rate; leaf area index; water use efficiency; yield; irrigation; nitrogen

INTRODUCTION

Precipitation and irrigation water are limited during the growth period of wheat, so it is very important for the growth of crop and the formation of grain yield to fertilize and irrigate in the dry-period (Li *et al.*, 2001a & b; Zizhen and Hong, 1997; Zizhen and Hong, 1998), Despite the importance of fertilization in maintaining the current productivity in dry-land agriculture, the role of fertilizer application seems to be limited because of shortage of usable water. Over the last decades, a number of studies have been conducted on the regulation of water and fertilizers in arid and semi-arid regions, an attempt to increase crop yield (Aase and Pikul, 2000; Li *et al.*, 2001a & b). When evaluating dry matter production, expansive growth deserves special attention, since it is the means for developing leaf area for intercepting light and carrying out photosynthesis (Davis, 1994). Maximum leaf area index (LAI) for wheat is generally observed at anthesis, a time that falls just after maximum growth rate of crop. LAI at flowering is mainly used for forecasting wheat yields, with the prime assumption that there is no stress in the subsequent stages of crop growth. The response of wheat growth rates varies with time of growth, availability of added inputs and environment and is limited by the inherent genetic potential of the crop (Singh *et al.*, 1987 and Zhang *et al.*, 1999)

Yield and yield components of wheat such as number of tillers per unit area, spike bearing tillers, grain weight per spike, 1000-grain weight, grain and straw yield were affected significantly by different levels of irrigation and nitrogen (Bellido *et al.*, 2000; Halepyati 2001; Jan *et al.*, 2002). Increasing irrigation and fertilizer rates increase spikes m^{-2}, spike weight, number and weight of grains $spike^{-1}$ and number of fertile spike lets per spikes (Beher and Sherma, 1991). Bellido *et al.* (1996) reported that N fertilizer rate applied to wheat under rain-fed conditions is a function of rainfall and wheat did not respond to N fertilizer when rainfall was below 450 mm during the growing season. Increase in grain yield with increasing irrigation frequency and N rate have also been reported (Loveras *et al.*, 2001). The moisture stress reduces grain yield when applied at any physiological growth stage, but the extent of damage varies from stage to stage (Malik and Ahmad, 1993; Angadi *et al.*, 1991). Irrigation applied at sensitive stage of the crop thus would be a valuable management practice for improving yield.

Water use efficiency (WUE) can be described on various scales from the leaf to the field. In its simplest terms, it refers to the ratio of grain yield (GY) to the water used during crop growth (Ehdaeie, 1995). Water use efficiency provides a simplest mean of assessing whether yield is limited by water supply or other factors and is considered an important component of adaptation to water deficit conditions (Edhaie and Waines, 1993). As the amount of water used is strongly affected by crop management, a good understanding of crop management effects on WUE may provide researchers opportunities to identify and select appropriate crop management practices for improved water use efficiency. Some studies (Li *et al.*, 2001 a & b; Persand and Khosla, 1999; Stephens and Hess, 1999) suggest that limited supplemental irrigation and fertilization during the growth season can significantly increase WUE and wheat yield. The objective of this study was to determine the effect of differential irrigation water and nitrogen supply on the growth, yield and WUE of wheat.

MATERIALS AND METHODS

A field experiment was conducted during November-April 2002-03 and 2003-04 on a sandy loam soil at the farm of Department of Crop Physiology, University of Agriculture, Faisalabad, Pakistan (31.25°N latitude, 73.09°E longitude and 184 m altitude). The climate of the experimental site is semi-arid. Mean maximum temperature for the wheat-growing season was 26°C in 2002-03 and 29°C in 2003-04 (Fig. 1 and 2). Soil was analyzed for different physical/chemical properties by following the methods described by US Salinity Lab. Staff (1954) except available P and soil texture, which were determined by methods described by Watanabe and Olsen, (1965) and Moodie *et al.* (1959), respectively. A brief description of different physical/ chemical properties is given in Table 1.

Table 1. Physical/chemical properties of soil

Characteristic	Unit	Value
pH		8.05
Electrical conductivity	dS m^{-1}	1.55
Total soluble salts	%	0.10
CO_3	me L^{-1}	0
HCO_3	me L^{-1}	4.80
Cl	me L^{-1}	7.60
SO_4	me L^{-1}	3.30
Ca + Mg	me L^{-}	7.03
OM	%	0.67
Available P	mg kg^{-1}	5.30
Available K	mg kg^{-1}	168
Total N	%	0.03
Texture		Sandy loam

Wheat (*Triticum aestivum*, cv. Inqlab-91) was sown on 14 November 2002 and 3rd December 2003 at a seed rate of 100 kg ha^{-1} with 25 cm row spacing. Four irrigation and nitrogen treatments were applied for the study. Irrigation treatments included: One irrigation at tillering stage (I_1); two irrigations each at tillering and anthesis stages (I_2); three irrigations each at tillering, stem elongation and grain development stages (I_3); four irrigations each at tillering, stem elongation, anthesis and grain development stages (I_4). Irrigation water was applied by flooding at a rate of 76.4 mm/irrigation using cut-throat flume (90 cm x 20 cm). Four nitrogen rates (0, 50, 100, 150 kg ha^{-1}) were applied to each irrigation treatment through urea. Half nitrogen was applied as side dressing with the help of a single row hand drill at the time of sowing and remaining half was applied with first irrigation. Phosphorus in the form of triple super phosphate @ 100 kg ha^{-1} was applied to all plots at the time of sowing. The experiment was laid out in randomized complete block design in a split-plot arrangement with irrigation in main plots while nitrogen in sub plots. Every treatment was replicated three times for a total of 48 plots of 1.5 m x 6m (9 m^2). All other cultural practices were standard and uniform for all treatments. Leaf area index from each plot was recorded directly in the field with the help of a PAR Ceptometer (AccuPAR, Decagon Inc). Crop growth rate was calculated after determining the plant dry matter accumulation over time. Twenty-five cm row segments from each sub plot were harvested at 15 days interval, and the dry weight was recorded after drying at 70°C to a constant weight. The crop growth rate was calculated using the following formula (Hunt, 1978).

$$CGR\ (gm^{-2}d^{-1}) = \frac{W_2 - W_1}{T_2 - T_1}$$

At maturity, one meter square area selected randomly from each plot was used to determine the number of spikes per unit area. Ten spikes from each plot were randomly sampled, threshed manually for recording No. of grains per spike and grain weight. An area of 6 m^2 (4 rows) in both years was harvested manually from the center of each plot for the measurement of grain yield. Water use efficiency was calculated as the ratio of the grain yield (kg ha^{-1}) to the total water applied in mm (Hussain and Al-Jaloud, 1995) which includes water applied as irrigation and rainfall during the crop growing season. The data were subjected to analysis of variance technique (Steel and Torrie, 1984) and the Duncan's New Multiple Range (DMR) test at 5% probability level to test the difference among the significant means.

RESULTS

Effect of irrigation and nitrogen on growth and development

Leaf area index (LAI) is the main physiological determinant of crop yield. It describes the surface growth and light use in crop growth periods (Zizhen and Hong, 1998), whereas crop growth rate (CGR) determines the gain in weight of crop per unit area over a time period. The effect of irrigation and nitrogen on LAI and CGR during both the seasons is shown in Fig. 3 and 4. Increasing number of irrigations significantly ($P \leq 0.01$) increased LAI and CGR. The differences in LAI and CGR for irrigation treatments at early growth stages were lower than the differences observed at latter growth stages. LAI and CGR values in four irrigations treatment at all harvests were significantly higher than all other irrigation treatments. The maximum LAI values of 3.98 and 4.04 were recorded at 87 and 88 days after sowing in the treatment where four irrigations were applied during 2002-03 and 2003-04, respectively. The maximum CGR reached at 26.29 g m^{-2} day^{-1} and 24.45 g m^{-2} day^{-1} for the growth period of 72-87 and 73-88 days after sowing during 2002-03 and 2003-04, respectively. Nitrogen application also significantly affected ($P \leq 0.01$) LAI and CGR at all irrigation levels throughout the season. LAI and CGR increased significantly with increasing levels of nitrogen at all harvesting times. The maximum LAI values of 3.87 and 3.77 were recorded under the nitrogen treatment of 150 kg N ha^{-1} at 87 - 88 days of sowing in 2002-03 and 2003-04, respectively. Similarly the maximum CGR values of 22.93 g m^{-2} day^{-1} and 22.18 g m^{-2} day^{-1} for the growth period of 72-87 and 73-88 days after sowing during 2002-03 and 2003-04, respectively, were recorded under the nitrogen treatment of 150 kg N ha^{-1}. In general, the maximum LAI and CGR values were observed in the treatment combination of four irrigations and N @150 kg ha^{-1} whereas the minimum LAI and CGR were recorded for one irrigation and N @ 0 kg ha^{-1} treatment combination.

Effect of irrigation and nitrogèn on yield and water use efficiency

Grain yield response varied with the season and yield was higher in 2002-03 season than 2003-04. In general, grain yield reduced in each season by withholding irrigation at various growth stages at all nitrogen rates. In both seasons, the average mean grain yield for four, three and two irrigation treatments were 1.68, 1.53 and 1.16 times, respectively, of that for one irrigation treatment. The highest yields of 4548.5 and 4988.8 kg ha^{-1} in 2002-03 and 2003-04 growing seasons, respectively, were achieved for 150 kg N ha^{-1} rate. The average grain yield for both seasons were increased by 38, 25 and 13 % with high (150 kg N ha^{-1}), moderate (100 kg N ha^{-1}), and low (50 kg N ha^{-1}) nitrogen application compared with 0 kg N ha^{-1} treatment.

Different irrigation and nitrogen treatments significantly affected the yield components in both years (Table 2 and 3). In both years, response of all yield components studied was more obvious with treatment where four irrigations were applied. Number of spikes m^{-2} and grains $spike^{-1}$ were affected more by irrigation and nitrogen than grain weight, spike length and spikelets $spike^{-1}$. Water deficit reduced spikes m^{-2}. The reduction in spikes m^{-2} at maximum irrigation deficit (one irrigation) was 20 and 47 % in 2002-03 and 2003-04, respectively. Similar reduction occurred in grains $spike^{-1}$ where water deficit decreased this component on an average of 26 and 85 % in 2002-03 and 2003-04, respectively.

The response of harvest index (HI) to irrigation varied from 33 to 36 % in 2002-03 and 36 to 44 % in 2003-04. Mean harvest index in 2003-04 in water deficit plots (one irrigation) was 22 % higher than non-water deficit plots (four irrigations). Nitrogen application improved HI in both years with maximum values of 37 and 42 % observed with 150 kg ha^{-1} in 2002-03 and 2003-03, respectively.

Water use efficiency is the grain yield per unit of water applied. The WUE was generally higher in 2003-04 than in 2002-03 (Table 4). Under different irrigation treatments the WUE varied from 10.97 to 15.88 kg ha^{-1} mm^{-1} in 2002-03 and 15.36 to 21.19 kg ha^{-1} mm^{-1} in 2003-04. In both years, average WUE was 41% higher in one irrigation treatment compared with four irrigations treatment. Nitrogen application also affected WUE and increasing rate of N application increased WUE. In both years, significantly higher WUE values were observed under N application rate of 150 kg ha^{-1}.

Effect of irrigation and nitrogen on crude protein of grain and leaf

In both seasons (2002-03 and 2003-04), the irrigation treatments significantly ($P<0.01$) affected the grain and leaf crude protein percentage (Table 1 and 2). Crude protein percentage decreased with increasing level of irrigation. The maximum grain and leaf crude protein decreased with increasing level of irrigation. The maximum grain and leaf crude protein (13.63 and 11.92% during 2002-03 and 12.62 and 10.83 % in 2003-04, respectively) was recorded under the treatment where one (at tillering) irrigation was applied. The minimum grain and leaf crude protein percentage (8.92 and 7.41 during 2002-03 while 8.43 and 6.91 in

Table 2. Grain yield and its components of wheat under different levels of irrigation and nitrogen in the year 2002-03

Treatments	Grain yield (kg ha^{-1})	1000-grain weight (g)	Spike length (cm)	Spikelets spike^{-1}	No. of grains spike^{-1}	Spike m^{-2}	Harvest index (%)	Grain Protein (%)	Leaf Protein (%)
Irrigation levels									
I_1	3208.25 d	42.01 d	9.93 c	16.72 b	43.17 c	570.25 b	33.00 c	13.63 A	11.92 A
I_2	3527.75 c	42.66 c	10.66 b	17.03 b	48.08 b	537.42 b	34.00 bc	12.55 B	9.55 B
I_3	3952.83 b	43.31 b	10.91 ab	17.29 ab	50.58 ab	568.00 b	35.00 ab	11.92 C	7.41 C
I_4	4729.25 a	44.04 a	11.35 a	17.78 a	54.50 a	714.67 a	36.00 a	8.92 D	7.41 C
Nitrogen levels									
N_0	3093.75 d	42.01 b	9.24 c	15.75 b	39.25 d	503.42 c	32.00 b	10.79	8.80 B
N_1	3619.58 c	42.86 ab	10.61 b	17.05 a	47.08 c	564.08 b	34.00 b	11.42	8.54 B
N_2	4156.25 b	43.29 a	11.20 ab	17.74 a	53.00 b	643.42 a	35.00 a	11.42	8.54 B
N_3	4548.50 a	43.60 a	11.80 a	18.29 a	57.00 a	679.42 a	37.00 a	13.38 A	10.42 A
Irrigation X Nitrogen level									
IxN	NS	NS	NS	NS	NS	NS	NS	NS	NS

Data within columns followed by different letters are significantly different at $P < 0.05$.

I_1 = One irrigation at tillering stage

I_2 = Irrigations at tillering and anthesis stages.

I_3 = Irrigations at tillering , anthesis and grain development stages

I_4 = Irrigations at tillering, stem elongation, anthesis and grain development stages

Table 3. Grain yield and its components of wheat under different levels of irrigation and nitrogen in the year 2003-04

Treatments	Grain yield (kg ha^{-1})	1000-grain weight (g)	Spike length (cm)	Spikelets spike^{-1}	No. of grains spike^{-1}	Spike m^{-2}	Harvest index (%)	Grain Protein (%)	Leaf Protein (%)
Irrigations levels									
I_1	2970.68 d	40.12 c	9.44 c	13.75 c	32.50 d	465.50 d	44.00 a	12.62 A	10.83 A
I_2	3664.13 c	40.74 bc	10.50 b	15.75 b	40.25 c	525.75 c	39.00 b	11.53 B	8.52 B
I_3	5461.34 b	42.00 b	10.76 ab	16.75 b	48.75 b	587.50 b	39.00 b	11.52 B	8.54 B
I_4	5672.58a	45.50 a	11.36 a	18.75 a	60.00 a	687.00 a	36.00 c	8.43 C	6.91 C
Nitrogen levels									
N_0	3939.54 d	41.25 b	9.07 d	15.25 b	42.75 c	488.75 d	38.00 c	9.87 C	8.39 B
N_1	4293.49 c	42.12 ab	10.15 c	16.50 a	45.50 bc	520.25 c	39.00 bc	10.63 B	7.93 B
N_2	4546.93 b	42.25 ab	11.13 b	16.50 a	46.75 ab	594.25 b	40.00 ab	11.04 B	8.19 B
N_3	4988.76 a	42.75 a	11.71 a	16.75 a	49.50 a	662.50 a	42.00 a	12.62 A	10.28 A
Irrigation X Nitrogen level									
IxN	NS	NS	NS	NS	NS	NS	NS	NS	NS

Data within columns followed by different letters are significantly different at $P < 0.05$.

I_1 = One irrigation at tillering stage

I_2 = Irrigations at tillering and anthesis stages.

I_3 = Irrigations at tillering , anthesis and grain development stages

I_4 = Irrigations at tillering, stem elongation, anthesis and grain development stages

2003-04) was recorded under the treatment where four irrigations (irrigation at tillering, stem elongation, anthesis and grain development) were applied.

Nitrogen application during the year 2002-03 and 2003-04 had significant ($P<0.01$) effect on grain and leaf crude protein percentage. Maximum grain and leaf crude protein percentage (13.38 and 10.42 during 2002-03, whereas 12.62 and 10.28 in 2003-04) was recorded under the nitrogen treatment of 150 kg N ha^{-1}. The minimum grain and leaf crude protein percentage

(10.79 and 8.80 during 2002-03 and 9.87 and 8.39 in 2003-04) was recorded under the treatment where no nitrogen was applied.

Table 4. Water use efficiency (WUE) of wheat under different levels of irrigation and nitrogen (kg ha^{-1} mm^{-1})

Treatments	WUE (kg ha^{-1} mm^{-1})	
Irrigations	2002-03	2003-04
I_1	15.88 a	21.19 a
I_2	12.67 b	18.64 b
I_3	11.12 c	16.92 c
I_4	10.97 c	15.36 d
Nitrogen		
N_0	10.01 d	15.96 d
N_{50}	11.90 c	17.40 c
N_{100}	13.6 b	18.35 b
N_{150}	15.08 a	20.39 a
Irrigation X Nitrogen level		
IxN	NS	NS

Data within columns followed by different letters are significantly different at $P < 0.05$.
I_1 = One irrigation at tillering stage
I_2 = Irrigations at tillering and anthesis stages.
I_3 = Irrigations at tillering, anthesis and grain development stages
I_4 = Irrigations at tillering, stem elongation, anthesis and grain development stages

The interaction between irrigation and nitrogen levels (IxN) for both seasons (2002-03 and 2003-04) were non-significant.

DISCUSSION

Leaf area index and CGR improved with nitrogen nutrition and increasing availability of water applied as irrigation. Maximum irrigation (four irrigations) and 150 kg N ha^{-1} resulted in more LAI and CGR of wheat in this study. Irrigation and fertilization improved availability, uptake and utilization of N which ultimately influenced plant growth and development through better utilization of photosynthates, increased root biomass and LAI (Li *et al.*, 2001a; Li *et al.*, 2003). Under higher N-fertilization, more dry matter was also partitioned into leaves, which expanded rapidly, enhanced crop coefficient (Pal *et al.*, 1996), intercepted more radiation and resulted in higher photosynthetic activity and biomass (Davis, 1994). Frederick and Camberato (1995) reported higher LAI under irrigated than under non-irrigated conditions with increasing spring N rates. Ahmed *et al* (1990) have also reported significant increases in LAI and NAR at low and medium levels of N with increasing P. Grain yield in wheat is the result of number of effective tillers, number of grains per spike and grain weight (Ahmad *et al.*, 1988). Responses to irrigation vary among the yield components because of the differences in soil water conditions during the growing season (Frederic and Camberato, 1995). The grain number and weight in spike are determined after anthesis and are strongly influenced by environmental factors and availability of photosynthates. Assimilation and partitioning of photosynthates in relation to grain growth are therefore of vital importance. Irrigation from the beginning of tillering to anthesis in this study resulted in the production of a more number of effective spikes and higher grain yield. Matsunaka *et al.* (1992) also reported increased grain yield of wheat with the increase in number of effective spikes per unit area, which was more affected by irrigation than single grain weight, or number of grains per spike. They attributed the beneficial effects of irrigation from tillering to heading to promotion of N absorption by the crop, increase in the number of tillers and increase in the number of effective spikes. Increase in grain yield with increasing frequency of irrigation have also been reported by Pratibha (1992); Bhoi *et al.* (1993); Frizzone *et al.* (1996); Karim *et al.* (1997) and Gill and Singh (1999). In present study increasing levels of nitrogen fertilizer improved grain yield, which seems to be the result of enhanced tiller production and increased kernel number per spike. Similar results have also been reported by Fredrick and Camberato (1995). The possible reason of increased grain yield with adequate nitrogen supply may be the result of delayed leaf senescence, sustained leaf photosynthesis during the grain filling period, and extended duration of grain fill (Fredrick and Camberato, 1995). Limited irrigation in present study improved mean grain protein percentage. Overall a significant increase (30-35%) in grain protein contents was recorded for limited irrigation treatments as compared to control.

Water use efficiency indicates the performance of a crop growing under any environmental condition. Many studies about the effects of supplemental irrigation on yield performance and water use efficiency have shown that proper supplemental irrigation can increase crop yield by improving soil water conditions and their WUE significantly (Ehdaie, 1995, Li *et al.*, 1999, HoWell *et al.*, 1998; Deng *et al.*, 2002 and Zhang *et al.*, 2004).

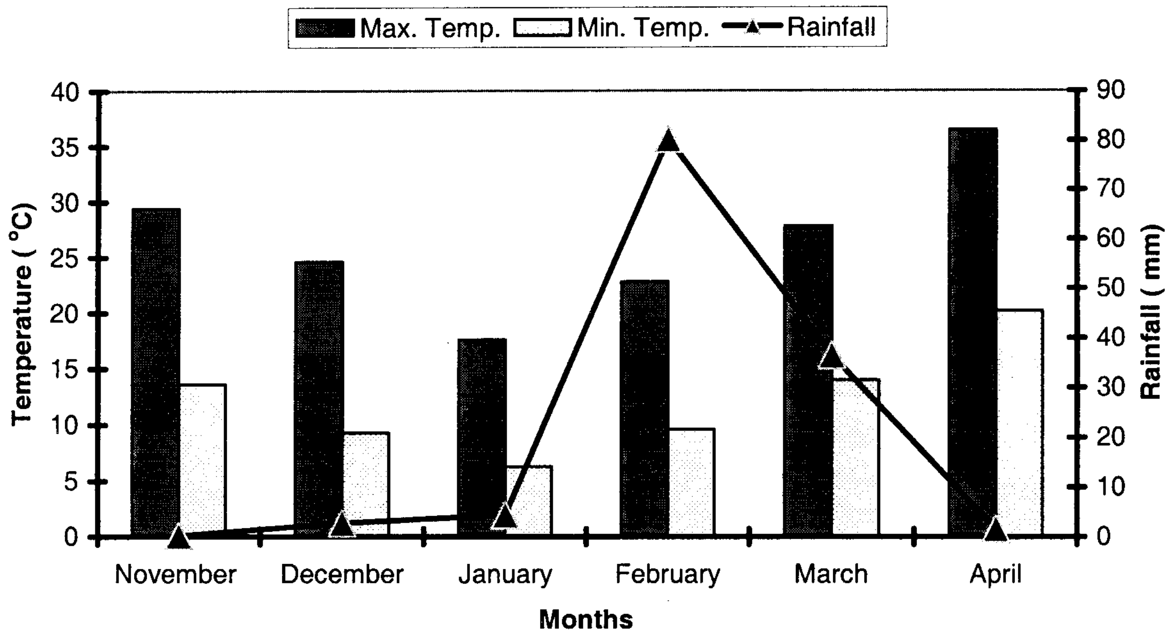

Fig. 1. Meteorological data for the year 2002-03

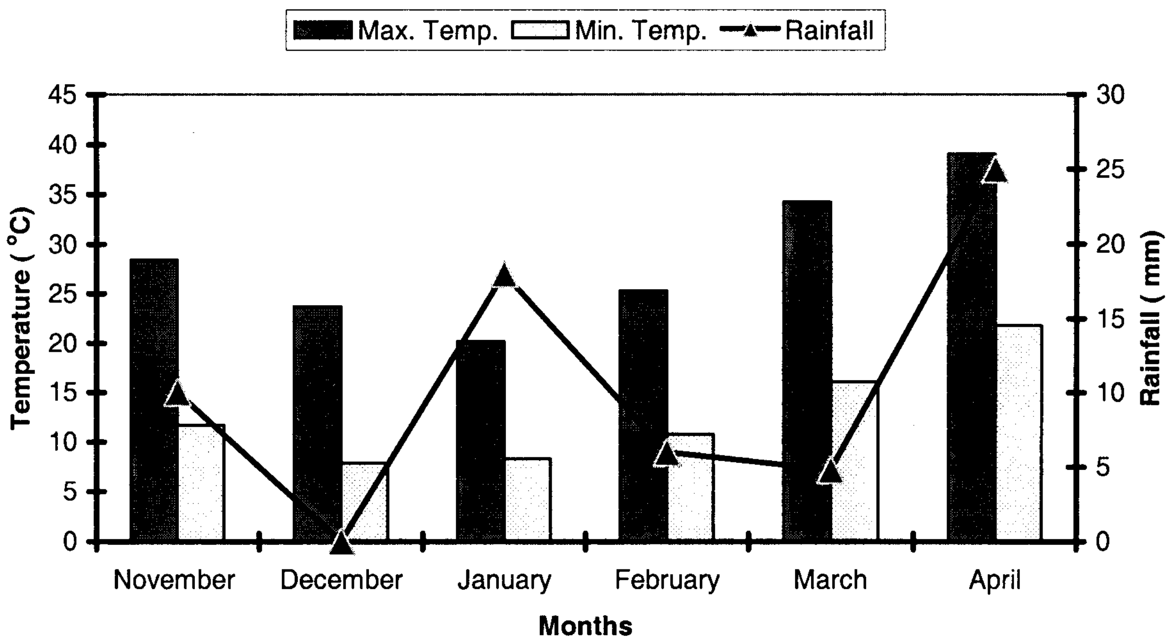

Fig. 2. Meteorological data for the year 2003-04

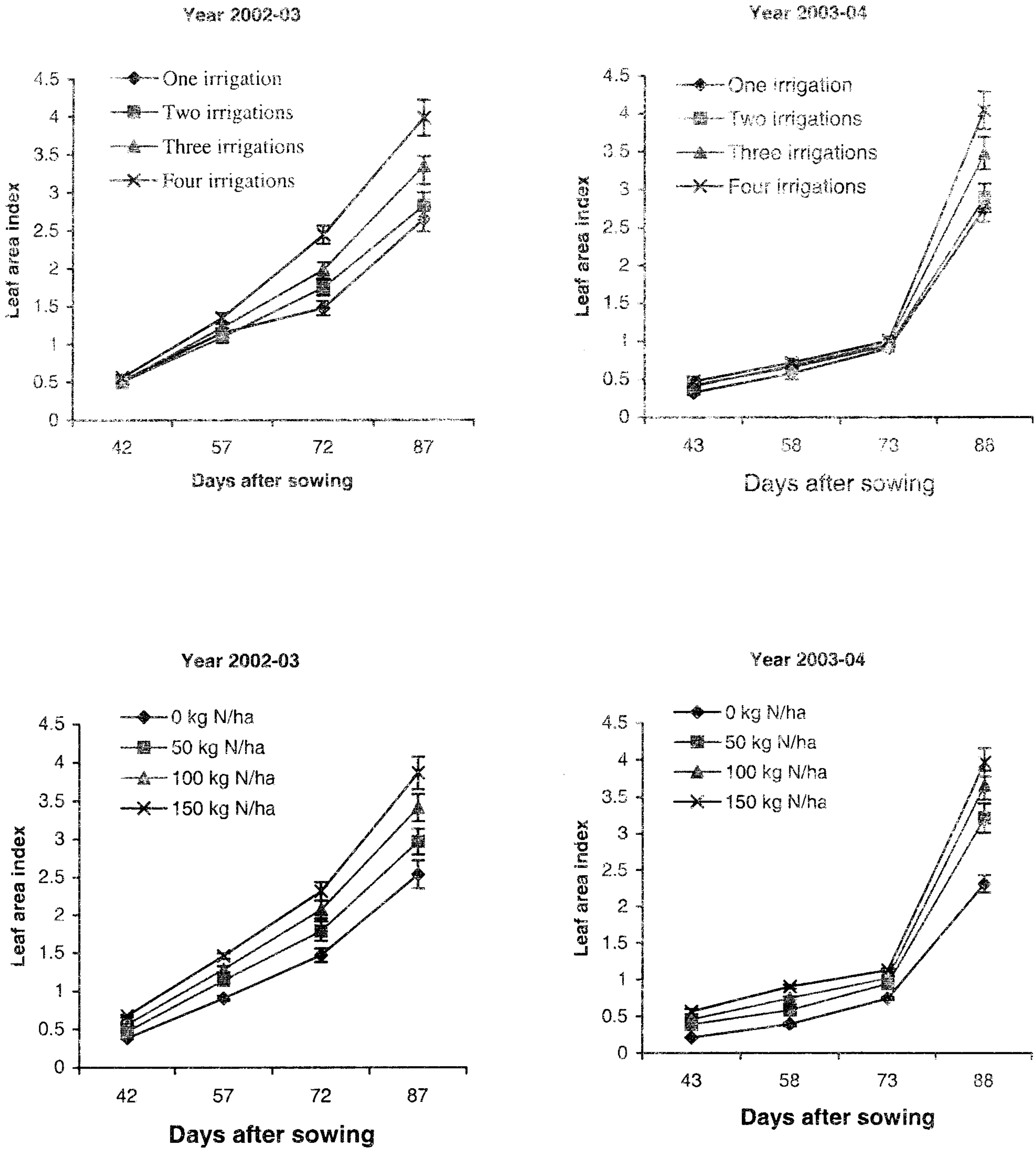

Fig. 3. Effect of different levels of irrigation and nitrogen on leaf area index of wheat.

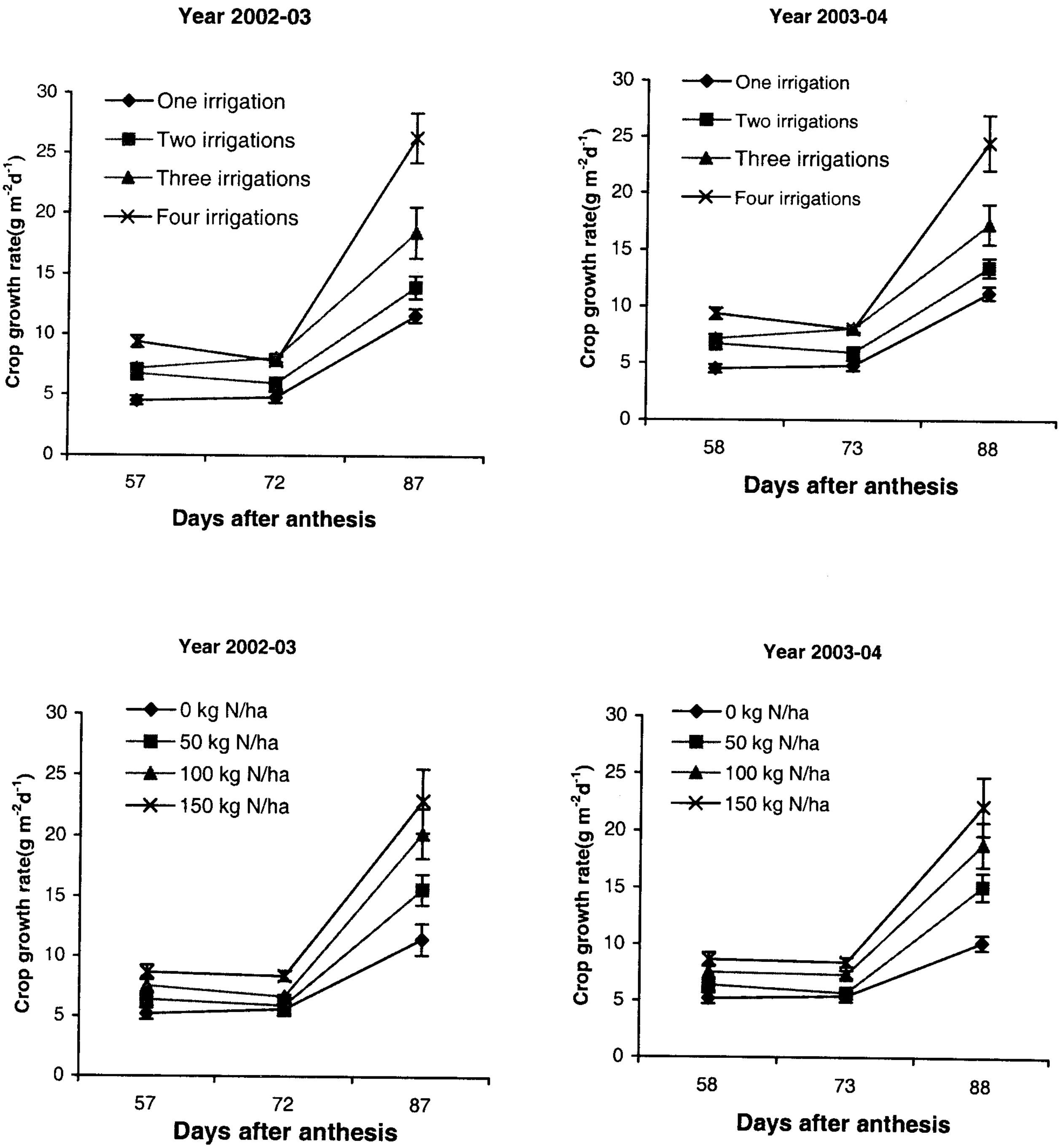

Fig. 4. Effect of different levels of irrigation and nitrogen on crop growth rate of wheat

Fertilization in dry-land can increase the usage of soil water, and improve crop yields to some extent. However, owing to the shortage of usable water, the effect of fertilization is limited. The key to increased crop yield lies to a large extent, in the increase of usable water. Some researchers (Li *et al.,* 2001a & b; Persand and Khosla, 1999; Stephens and Hess, 1999) focused on determining the relationship between yields of spring wheat and water use. These studies suggest that limited supplemental irrigation and fertilization during the growth season can significantly increase water use efficiency (WUE) and wheat yields. Nitrogen application in this study improved WUE suggesting that fertilizer application can promote the absorption of soil moisture and has a beneficial role for promoting WUE. Both irrigation and nitrogen application have positive effect on grain yield increase. The WUE, however, decreased with increasing number of irrigations, whereas nitrogen application significantly improved WUE at all irrigation levels.

CONCLUSIONS

Increasing irrigation and nitrogen supplies in wheat enhanced LAI, crop growth rates and yield components, which consequently resulted into higher above ground dry matter production and grain yields. The maximum LAI and CGR in wheat were commensurate with highest levels of irrigation (Four irrigations) as well as nitrogen application (150 kg N ha^{-1}) during 72-88 days period of growth in both seasons. The water use efficiency in wheat decreased with increasing number of irrigations, whereas increasing N supplies significantly improved WUE.

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