Spring Wheat Productivity under Increased Temperatures in Çukurova

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1. Introduction

Çukurova plain in the East-Mediterranean region is one of the most productive and important agricultural regions of the Turkey. In Çukurova, wheat is grown from November to June by using high yielding spring or facultative type cultivars.

There is increasing evidence that the climate is changing. Expected temperature increases over the entire Mediterranean region reported by Rosenzweig, and Tubiello (1996) varied in the range 3.9-6.6 °C for a doubling of atmospheric CO_2 content. Moreover a widening of current seasonal precipitation is indicated.

A subtle review of wheat responses to climatic change has been given by Lawlor and Mitchell (2000). Production of wheat will be affected adversely by the increases in mean temperatures. Within temperate regions, current cultivars will mature earlier, and hence yields will be decline in response to warmer temperatures. Nevertheless, this negative effect of warmer temperatures should be countered by the increased rate of crop growth at elevated atmospheric CO_2 concentrations, at least when there is sufficient water and Nitrogen. Of more importance for the yield of wheat may be changes in frequency of hot (or cold) temperatures. Grain yields are particularly sensitive to brief episodes of hot temperatures if these coincide with critical stages of crop development (Wheeler et al., 2000). Wheat yield projections for Mediterranean regions showed generally yield decreases depending upon projected temperature increases (Iglesias and Minguez, 1997; Tubiello et al., 2000; Guerena et al., 2001). Thus anticipated temperature changes are likely to cause new problems in wheat production, which would need to be solved to improve wheat productivity.

There is a need for greater understanding of how plants respond to increased temperatures. Understanding the responses of yield determinant processes to temperature (and underlying causes) will be essential to develop technologies that mitigate the negative effects of high temperature.

The objective of this study was to evaluate the response of wheat to increased temperatures in Çukurova region, which represents agro-climatic conditions, typical of those prevailing Mediterranean region. Two temperature regimes were obtained by using of two sowing dates. To eliminate the effect of drought from high temperature, experiments were conducted under rain-fed and irrigated conditions.

2. Material and Methods

Field experiments were conducted at the experimental area of the Department of Irrigation and Agricultural Structures of the Faculty of Agriculture of the University of Çukurova at Balcalı, Adana (36°59′ N and 35°18′ E, 21 m above sea level), Turkey, during 2003/2004 growing season. The area has a typical Mediterranean climate, with cool, rainy winters and hot, dry summers. Longterm average rainfall in the area is 650 mm. Soil of the research area was classified as a Palexerollic Chromoxerert with heavy clay texture and slightly alkaline. A well adapted spring wheat cultivar, Adana-99 was evaluated under amply nutrient with two temperature regimes as described below:

NT: normal temperature regime, sowing at the current sowing date

HT: high temperature regime, sowing at a later date when the main air temperature is increasing in spring.

Experiments were conducted under non irrigated (rainfed, RF) and irrigated (IR) conditions, to distinguish the effect of drought and high temperature. Thus the treatments used in the study were as given below:

NTRF: Normal temperature regime without irrigation
NTIR: Normal temperature regime with irrigation
HTRF: High temperature regime without irrigation
HTIR: High temperature regime with irrigation

Two fields with the sowing dates of 17. November 2003 and 4 March 2004 were seeded in the large (100x50m and 50x25 m respectively) side by side. In both fields, Phosphorus (80 kg ha^{-1}), Potassium (80 kg ha^{-1}), Zinc (1 kg ha^{-1}) and the first rate of Nitrogen (80 kg ha^{-1} of a total of 200 kg ha^{-1}) were applied before sowing. The second (80 kg ha^{-1}), and third (40 kg ha^{-1}) rates of Nitrogen were applied at Zadoks growth stages (ZGS's, Zadoks et al., 1974) 21 and 30, respectively. Sowing rate was 500 viable seeds per m^2. Rows were spaced 13 cm apart. Treatments were conducted in a two factor strip-plots arrangement with four replicates of temperature regimes (sowing dates) as the main plots and irrigation regimes as the subplots. Each subplot consists of 25x10 m.

Crop growth and development, changes of PAR in the canopy, LAI, biomass, leaf photosynthetic gas exchange traits (A_n, E, g_s, C_i, WUE_{Ph}), were measured through growing period. At maturity, biological yield, distribution of dry matter, grain yield and yield components were determined. Here in this study, we reported only the results related to biological and grain yield and yield components.

3. Results and Discussion

Growing conditions

To eliminate the adverse effect of drought from the effect of heat, experiments were carried out under irrigated and not irrigated conditions in both temperature regimes. The soil water content, which was measured previous to each irrigation during the growing season, is illustrated in Figure 1. The minimal level of water under rain-fed conditions was generally and especially under HT lower than the water level at wilting point. Under irrigated conditions however was the level in both of the temperature regimes never under the level of wilting points. Thus the elimination of drought effect seems to be obtained under irrigated conditions, as it was planned. Two temperature regimes, which were attained with two sowing date were given in Table 2. As foresighted, daily mean temperatures during whole plant development after plant emergence were higher in late sowing date than in current sowing date. Temperature difference between two treatments was 4.4 °C between emergence and beginning of tillering. This difference was nearly 6 °C during later growth stages until anthesis. During the grain growth period, mean temperature difference between high and normal temperature regime was on average 3.2 °C. Warmer air temperatures accelerated plant development, reducing the number of days in IR from sowing to anthesis by 48% and from anthesis to physiological maturity by 26%. Declining of pre anthesis growth period was more pronounced (56%) under RF conditions. Shortening of plant developmental period under warm conditions is a well known response of wheat (Lawlor and Mitchell, 2000) and is well integrated to the simulation models (Wheeler et al., 2000).

Biological Yield, Grain Yield and Harvest Index

The effect of HT on biological yield and grain yield was similar (Figure 2). Both biological yield and grain yield were reduced significantly by HT. In RF plots biological yield was reduced from 1769 g m^{-2} to 1302 g m^{-2}, in IR plots however from 1668 g m^{-2} to 1559 g m^{-2}, which corresponds to 26.4% and 6.5%, respectively. In a similar manner, grain yield was reduced from 647 g m^{-2} to 465 g m^{-2} (28.1%) in RF and from 564 g m^{-2} to 533 g m^{-2} (5.5%) in IR plots. The adverse effect was pronounced under RF conditions. This was attributable to drought conditions in late planted crops. As shown in Figure 1, soil water in IR conditions was never limiting. Thus the reductions in these conditions could be attributed to the adverse effect of increased temperatures. The effect of HT in IR was not obvious. HT reduced biological yield and grain yield only 6.5% and 5.5%, respectively. Increases in mean temperature over the whole season would decrease yield mainly due to shorter duration of crop growth (Wheeler et al.,1996; Lawlor and Mitchell, 2000). In our study, the effect of increased temperatures on growth duration was greater in extent than that of on grain yield. Thus shortening of growth period seem to be countered in same degree by the enhancement of the growth rate.

As biological yield and grain yield were affected similarly by temperature regime, irrigation and interaction of these factors, harvest index was not effected by treatments (data not shown). Harvest index averaged over treatments was 0.35.

These results suggested that, water and temperature will be important factors influencing wheat growth and yield in Çukurova region. In future, combined effects of decreased precipitation and increased temperatures would depress grain yields below present levels even under well fertilized conditions, depending how increased CO_2 offset grain yield reduction. For the maintaining crop yields at current levels management practices are to be changed. Irrigation and more fertilizer would be required.

Yield Components, Grain Number and Grain Weight

Number of grains per unit area was reduced significantly by HT under both rain-fed and irrigated conditions (Figure 3). The extent of the reduction was greater in rain- fed plots than in irrigated plots, with reductions of 35% and 15%, respectively. Although in greater extent, these reductions showed very similar trends as the grain yield reductions. Grain weight was the only component, which was increased by HT (Figure 3). Increases were similar in RF and IR conditions. Average grain weight increase was 10.9%. This increase was not sufficient to compensate for the reduced grain number.

Spikelets and Grain Setting

Ear density showed a reduction of 17% by heat only under RF conditions (data not shown).
But this reduction was not significant at 0.05 probability level. Thus differences in grain number were resulted more in the number of grains per ear than in the ear number per unit area.

Number of grains per ear was reduced significantly by HT both under RF and IR conditions (Figure 4). The average reduction was 18% (from 37.3 grains per ear to 30.6 grains per ear).

The number of spikelets per ear showed also reductions of 12% and 5% under high temperature regime without and with irrigation, respectively (Figure 4). In addition to the decreased number of the spikelets, a grain per grain bearing (fertile) spikelet was also decreased by 11% (from 1.80 to 1.60) in rainfed and 9% (from 1.76 to 1.59 in irrigated conditions.

These result showed that reductions in grain yield were resulted mostly in reduced number of grains per ear due to the reduced spikelets per ear and grains per grain bearing spikelets as well.

Agronomic measures other than irrigation were kept similar in both temperature regimes. Thus the decline of grain number under RF conditions could be related to the drought and higher temperatures. Under IR conditions, however grain number decrease seem to be related more to the high temperatures, as plots under IR conditions were never water stressed.

These results indicate that wheat in Çukurova is more responsive to high temperatures during the spikelet formation and especially grain set than during the grain filling period. The temperature sensitivity of spikelet formation and grain set in wheat has been reported repeatedly in earlier studies (Al-Khatib and Paulsen, 1984; Entz and Fowler, 1988; Wardlaw et al., 1989; Shlafer and Savin, 1991; Mitchell et al., 1993; Gibson and Paulsen, 1999).

An adverse effect of high temperatures is also guessed on grain growth, as grain weight increase was not sufficient to nullify the effect of reduced grain number. A 50% thinning treatment of the rows after grain set (not reported here) caused further increases in grain weight. This indicate that grain weight potential was not limited

4. Conclusions

The first results of this study showed that ear growth and grain set characteristics are more adversely affected by high temperatures than the grain growth. Grain set seem to be most sensitive processes to high temperatures. Thus, as underlined by Wheeler et al. (2000) for annual seed crops, brief episodes of high temperatures, rather than increased mean temperatures may adversely affect ear fertility and hence future wheat productivity in Çukurova, if they coincides with time of temperature sensible ear developmental stages.

Future research has to concentrate on how episodes of hot temperatures affect the grain yield components of wheat and how the impact of these events may be predicted.

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Table 2. Daily mean temperatures (ºC) during different growth stages of wheat in two temperature regimes, NT (Normal temperature regime, current sowing date) and HT (High temperature regime, late sowing date) during 2003/2004 growing season in Çukurova.

ZADOKS GROWTH STAGE	IRRIGATION	CURRENTSOWING DATE TEMP.	DAYS	LATE SOWING DATE TEMP.	DAYS	TEMP. DİFFER
ZGS 00-10	RF,IR	14.2	13	13.2	11	-1.0
ZGS 10-21	RF,IR	11.3	24	15.6	14	4.4
ZGS 21-31	RF,IR	10.6	42	16.9	27	6.3
ZGS 31-50	RF,IR	13.0	54	19.4	11	6.4
ZGS 50-65						
	RF	15.5	11	22.0	6	6.5
	IR	15.5	11	21.1	12	5.6
ZGS 65-86 (grain filling)						
	RF	19.2	33	22.1	28	2.9
	IR	19.4	38	23.0	27	3.6
First 10 days of grain filling						
	RF	17.9		20.4		2.5
	IR	17.9			21.5	3.6
Second 10 days of grain filling						
	RF	18.8				3.7
	IR	18.8				4.5

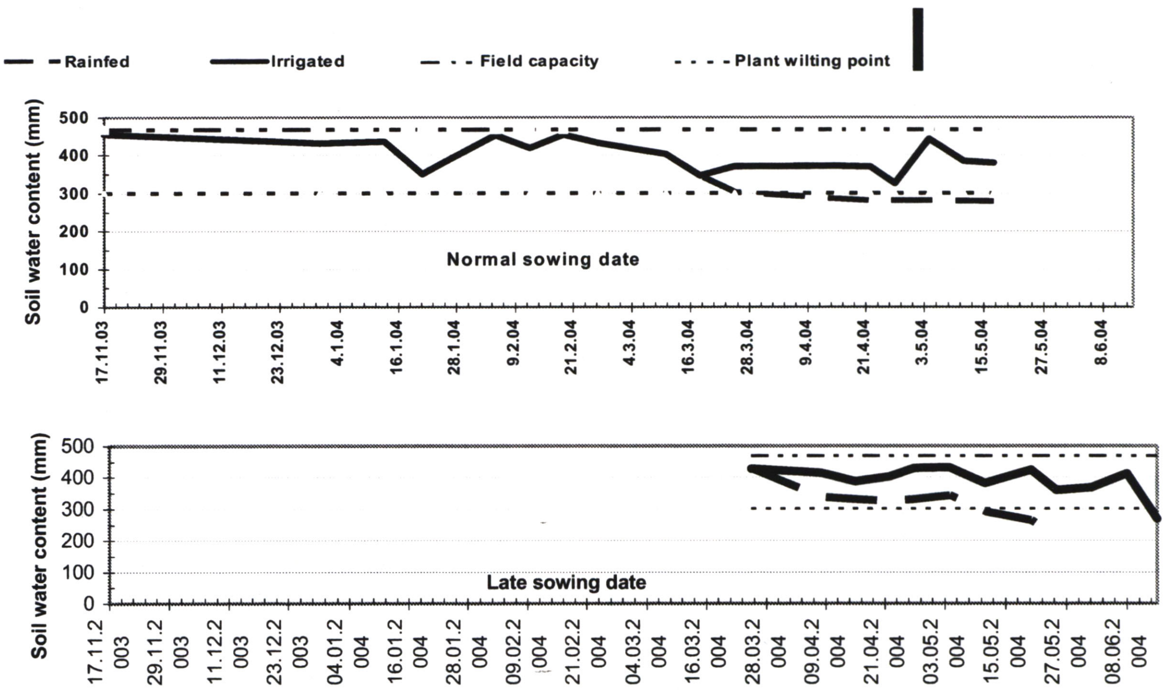

Figure 1. The soil water content previous to each irrigation in two temperature regimes, NT (Normal temperature regime, current sowing date) and HT (High temperature regime, late sowing date) during 2003/2004 growing season in Çukurova

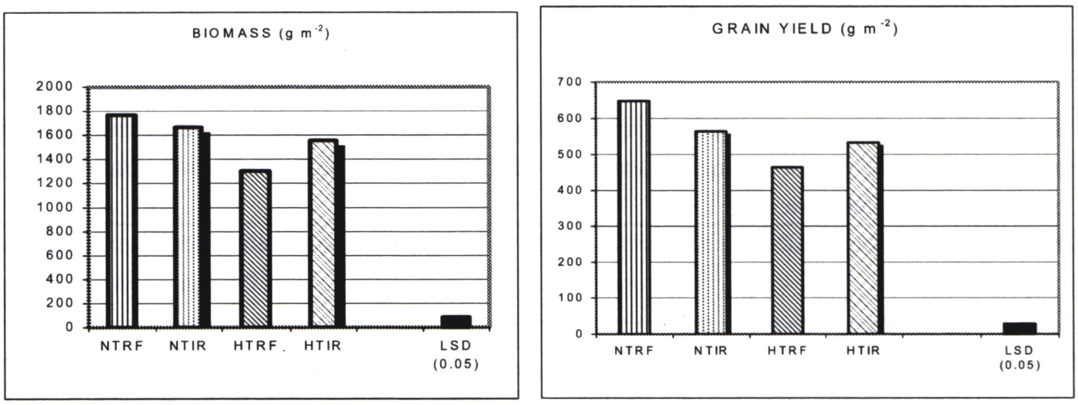

Figure 2. Biological and grain yield of bread wheat cultivar Adana-99 under two temperature (NT,Normal temperature; HT, High temperature) and two irrigation (RF, Rain-fed; IR, irrigated) regimes during 2003/2004 growing season in Çukurova.

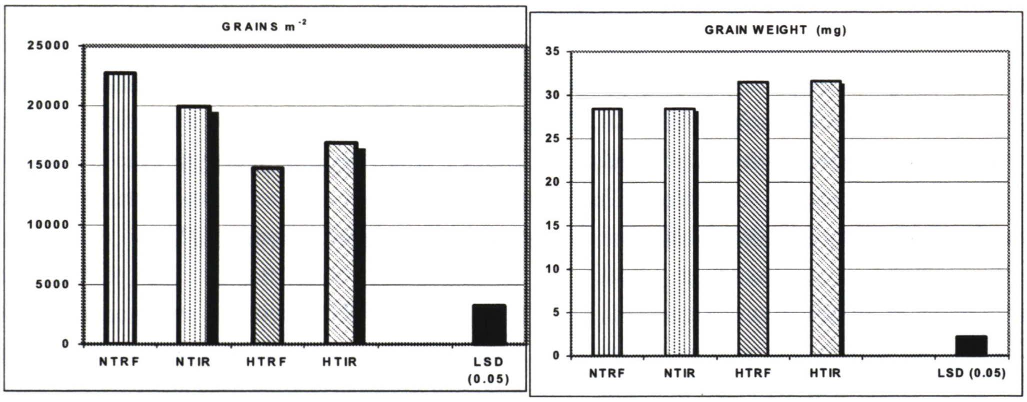

Figure 3. Grain Number and grain weight of bread wheat cultivar Adana-99 under two temperature(NT, Normal temperature; HT, High temperature) and two irrigation (RF, Rain-fed; IR, irrigated) regimes during 2003/2004 growing season in Çukurova

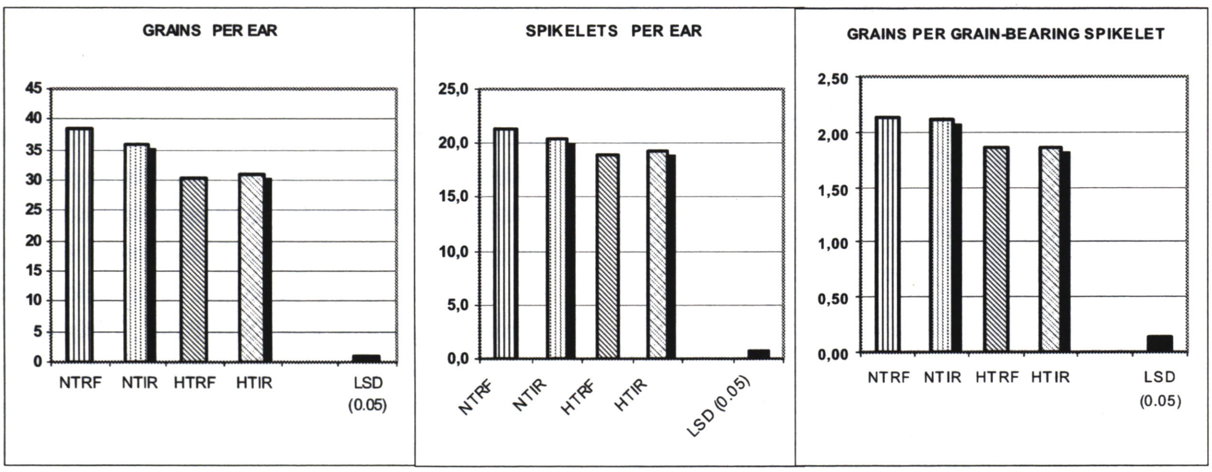

Figure 4. Grains and Spikelets per ear and grains per spikelet of bread wheat cultivar Adana-99 under two temperature (NT, Normal temperature; HT, High temperature) and two irrigation (RF,Rain-fed; IR, irrigated) regimes during 2003/2004 growing season in Çukurova