GROWTH AND WATER USE OF IRRIGATED AND DRYLAND LENTILS AND WHEAT

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Abstract

Lentils are becoming an increasingly more important crop in Saskatchewan with over 230,000 ha planted in 1987. A large part of this acreage was in the Brown soil zone. To date lentil water relations and adaptation to water deficits are largely undescribed. This study was initiated to determine the drought tolerance characteristics of lentils and to compare them to those of wheat growing under the same weather conditions.

Dryland lentils exhibited considerable drought tolerance with large changes in osmotic potential in response to increasing soil water deficits. Despite maintaining high levels of turgor, values of stomatal conductance were very low. This behaviour enabled leaves to maintain high relative water contents and survive an extensive dry period. In contrast wheat displayed little drought tolerance. Consequently throughout the growing season the rates of dryland to irrigated aboveground dry matter was consistently higher for lentils than for wheat and at final harvest was 0.71 and 0.41 for the two crops, respectively.

Wheat and lentils had similar water use efficiencies but lentils used more water because of their greater dry matter production. Very high dry matter production in irrigated lentils did not translocate into high grain yields.

Introduction

Lentils have assumed significant economic important in Saskatchewan with over 230,000 ha grown in 1987. However little or no research has been conducted on their water relations, water use or responses to drought.

Jones (1983) has defined the ability of plants to survive drought as drought tolerance. Mechanisms that contribute to drought tolerance can be separated into three groups: (1) stress avoidance mechanisms that limit the occurrence of damaging water deficits; (2) stress tolerance mechanisms that maintain physiological activity as plant water deficits increase; and (3) efficiency mechanisms that optimize the use of limited resources such as water. One well documented stress tolerance mechanism is osmotic adjustment whereby cell turgor is maintained by means of increases in cell solute concentration (Hsaio et al., 1976; Livingston and Black, 1987). Recently it has been suggested that the main influence of osmotic adjustment is on leaf survival rather than turgor related processes such as leaf expansion (Turner, 1986; Flower and Ludlow, 1986; Ludlow, 1987). By maintaining a higher leaf water content as water deficits increase, leaves survive lower water potentials and over longer periods during drought. Consequently when the stress is relieved more leaves contribute to plant productivity.

Ludlow (1987) and Passioura (1986) have both questioned the role of turgor as a mediator of plant stress and furthermore have suggested that the water balance approach to understanding plant water relations might be more fruitful than the classic thermodynamic approach.

Leaf stomatal conductance (g_S) was measured hourly on 9 days during the growing season. Measurements of g_S were made with a transit-time diffusion porometer (Delta-T Instruments, Nottingham, U.K.) which was calibrated at the beginning and end of each day.

Plant growth: Approximately every two weeks throughout the growing season, 2 m^2 samples of aboveground biomass were harvested and immediately weighed. Subsamples were then taken for dry weight determination. These samples were separated into leaves and stems, and in the latter part of the season, into ears and grain (for wheat) or pods and grain (for lentils).

Growing season weather observations: Standard hourly average micrometeorological measurements were made from May until September. Global solar irradiance (R_S) was measured with a horizontally positioned pyranometer (Model LI-200S, Li-Cor Inc., Lincoln, NB, U.S.A.). Rainfall was measured with a tipping bucket rain gauge (Model RG2501, Sierra Misco, Inc., Berkeley, CA, U.S.A.). Relative humidity and air temperature were measured with a sulphonated polystyrene sensor (Phys-Chemical Research Corp., New York, NY, U.S.A.) and thermistor (Model UVT-51J1, Fenwal Electronics Corporation, Framingham, MA, U.S.A.), respectively. Wind speed was measured with a cup anemometer (Model 014A Met-one, Sunnyvale, CA, U.S.A.). Data were recorded as 1-hour averages or totals using a Model CR-21 data logger (Campbell Scientific, Logan, UT, U.S.A.) stored on audio cassette tape and later transferred to a microcomputer for processing.

Results and Discussion

Table 1 summarizes the rainfall data over the growing season at Outlook. During May and June only 65 mm of rain fell which is about 65% of the normal. Heavy rain fell after mid-July and in August so that by the end of the growing season the total rainfall exceeded the normal by 10%. During the dry period dryland lentils exhibited considerable osmotic adjustment in marked contrast to dryland wheat (Table 2). Neither the irrigated lentils nor the wheat exhibited a significant decrease in osmotic potential over this period which indicates that the osmotic adjustment in lentils was in response to environmental stress and not a seasonal response.

Table 1. Monthly rainfall and percent of normal between May and August 1988 at Outlook.

	Rain (mm)	% of normal
May	24	71
June	41	65
July	74	148
August	66	200
Total	205	110

Table 2. Osmotic potential (-MPa) of dryland lentils and wheat.

	May	June	July	August
Lentils	1.9	3.1	4.2	4.4
Wheat	0.9	1.2	1.8	1.9

Despite having very high levels of turgor dryland lentils exhibited considerable stomatal closure when measurements were made in early July (Figure 1). Irrigated lentils had similar turgor but maintained high stomatal conductances throughout the day. Measurements of pre-dawn water potential indicated that the average root zone soil water potential for the dryland lentils was -0.4 MPa which would indicate that g_S rather than being affected by ψ_p might be influenced directly by soil or root water status. This is in agreement with the work of Turner et al. (1985) and Gollan et al. (1985) who showed that both ψ_T and ψ_p were poorly correlated with g_S.

Dryland wheat exhibited some degree of stress tolerance so that despite very low values of turgor g_S remained relatively high (Figure 2). It is likely that the decrease in g_S in both dryland and irrigated treatments after mid-day was in response to the very high vapour pressure deficits (3-4 kPa). Figure 3 shows that the relative water content of dryland wheat leaves dropped considerably as a result of the high transpiration rates. It is likely that dehydration-sensitive cells such as those in the mesophyll might have been severely damaged thereby jeopardizing the survival of epidermal cells which have a higher tolerance of stress. In contrast lentil leaves maintained high levels of leaf hydration throughout the day.

Figure 4 shows that dryland lentils had very high g_S after heavy rain in mid-July had raised average soil water potentials in the root zone to -0.08 MPa. Dryland wheat, however, which had switched to reproduction growth and had exhibited considerable leaf senescence, had very low g_S compared to irrigated wheat (Figure 5).

Lentil, which is an indeterminant species, was able, because of ability to avoid stress, to take full advantage of the high soil water content in July and August. This is illustrated in Figure 6 which shows the ratio of aboveground dry matter production of non-irrigated to irrigated crops. During the dry period this ratio averaged 0.55 for lentils but rose to 0.71 by the end of the growing season. In contrast it decreased to 0.41 in wheat.

Table 3 gives the total dry matter production and grain yield for the two crops. The large amount of dry matter production in the irrigated lentils was not translated into correspondingly high grain yields. This is because the lentils, which were sprayed with Reglone in early September, did not have enough time to retranslocate assimilates from the leaves and stems to the pods. Dryland lentils and wheat had similar water use efficiencies (WUE) but lentils used almost 40% more water (Table 3) because of the greater dry matter production in the latter part of the growing season. Irrigated crops had slightly higher WUE. This reflects the fact that the irrigated crops had smaller root systems and diverted more assimilates to the shoots.

The objective of the paper is: (1) to describe the water relations of both irrigated and dryland lentils and to compare them to those of wheat, and (2) to relate the drought tolerance mechanisms of wheat and lentils to growth and harvestable yield.

Materials and Methods

Experimental Site and Design

The experimental site is located at the Irrigation Development Centre at Outlook, Saskatchewan. The experimental layout was a split plot design for both irrigated and non-irrigated treatments with species as the main plot treatment and nitrogen as the subplot treatment. Each subplot treatment was replicated four times. Three nitrogen rates were used: 10, 50 and 100 kg ha^{-1} applied as ammonium nitrate within one day of seeding. Irrigation was provided by a centre pivot system. Tensiometers in the irrigated plots indicated that the average soil water potential to a depth of 125 cm was never less than -0.06 MPa throughout the experiment.

Measurements

Soil water: Neutron access tubes were installed in each subplot and measurements of soil water content to a depth of 120 cm were made weekly in conjunction with measurements of soil water potential with tensiometers that were installed in eight subplots. Every two weeks throughout the growing season soil cores were extracted to a depth of 120 cm and gravimetric determinations of soil water content made.

Plant water measurements and stomatal conductance: Total leaf xylem water potential (ψ_T) was measured with a pressure chamber (PMS Inc., Corvallis, OR, U.S.A.) leaves were cut from plants, immediately sandwiched between two boards lined with soft foam covered with polyethylene and transported to the pressure chamber where measurements of ψ_T were obtained within 1-2 minutes of excision. Hourly measurements of ψ_T were made on selected days throughout the growing season.

Measurements of osmotic potential ψ_π and bulk modulus of elasticity were made every 2 to 3 weeks between late May and August using the technique described by Livingston and de Jong (1988). Discs, 6 mm in diameter, were punched out of hydrated leaves and weighed immediately on a precision balance. Each disc was then suspended above an unsaturated salt solution of known molality in a sealed test tube held at 5°C in a stirred water bath. Eighteen salt solutions were used whose water potential ranged from -0.09 to -4.67 MPa. After 12 hours the discs were reweighed and then oven dried at 65°C for 24 hours. Water release curves were obtained by plotting paired values of disc relative water content (RWC) and salt solution water potential. The turgor potential (ψ_p) was calculated by subtracting ψ_π from ψ_T.

Disc RWC was calculated as:

$$RWC = (M - M_d) / (M_t - M_d)$$

where M is the disc mass at a given ψ_T, M_d is the disc dry weight and M_t is the disc mass at full turgor.

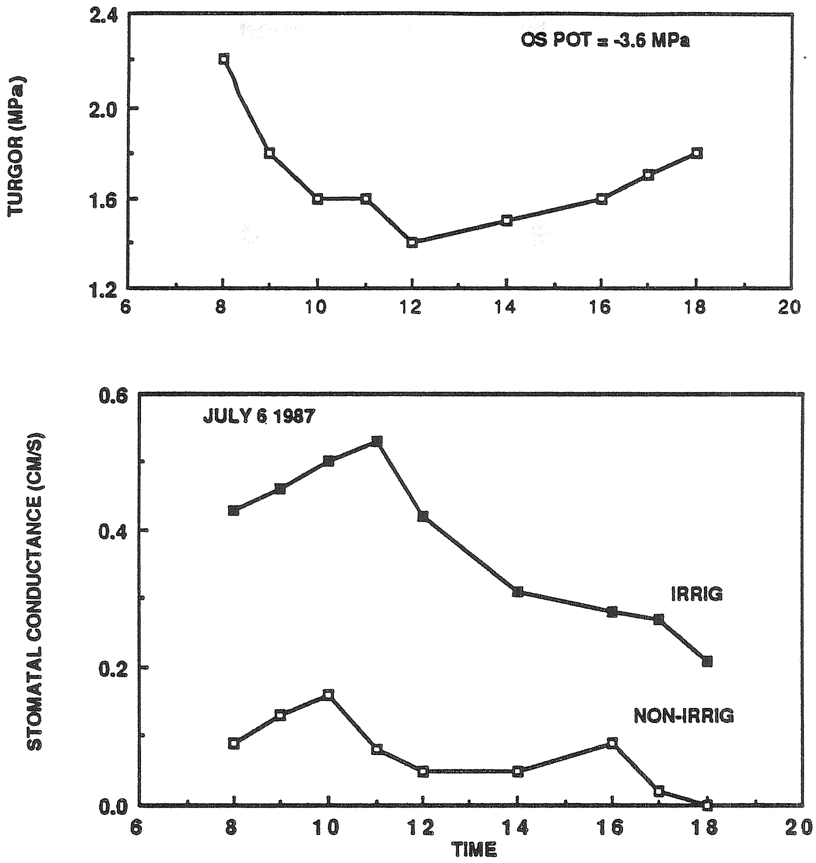

Figure 1. Stomatal Conductance and Turgor vs Time for Irrigated and Non-Irrigated Lentils

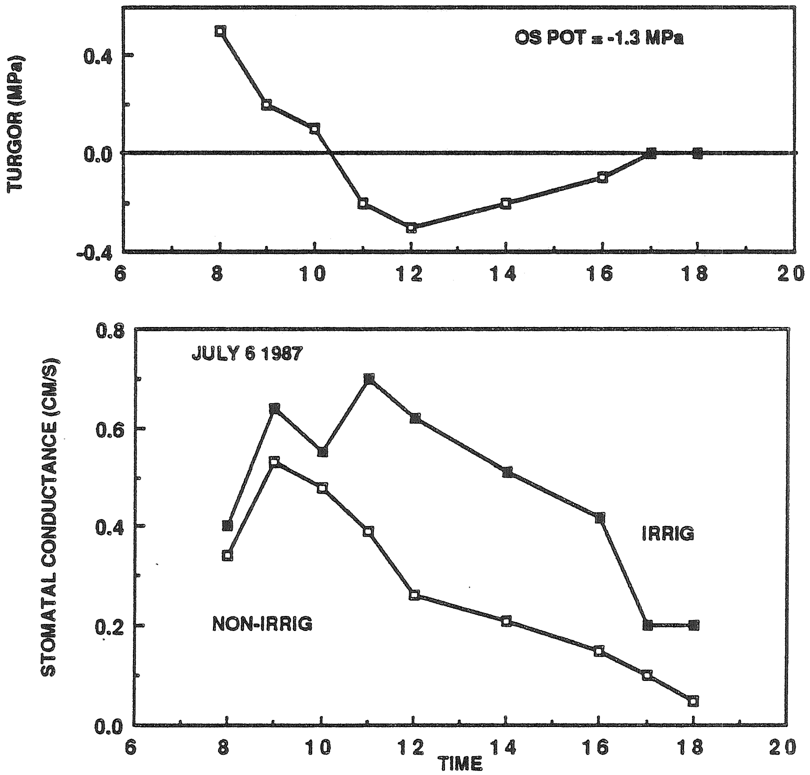

Figure 2. Stomatal Conductance and Turgor vs Time for Irrigated and Non-Irrigated Wheat

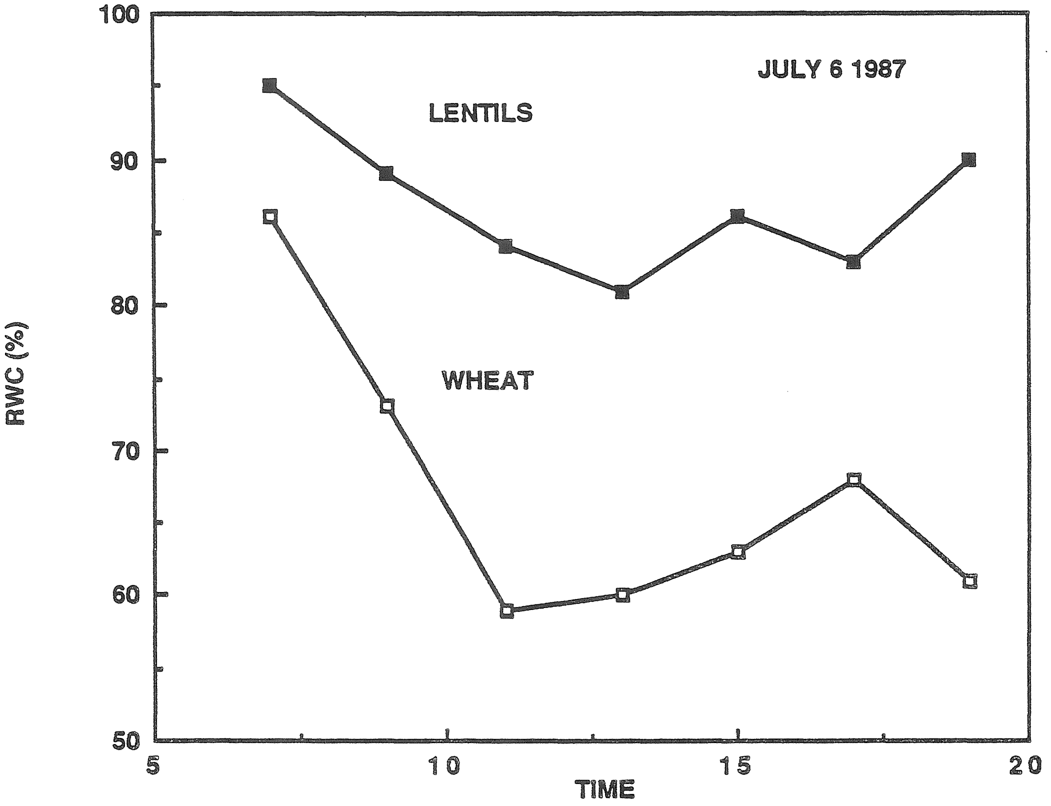

Figure 3. Leaf Relative Water Content vs Time for Non-Irrigated Lentils and Wheat

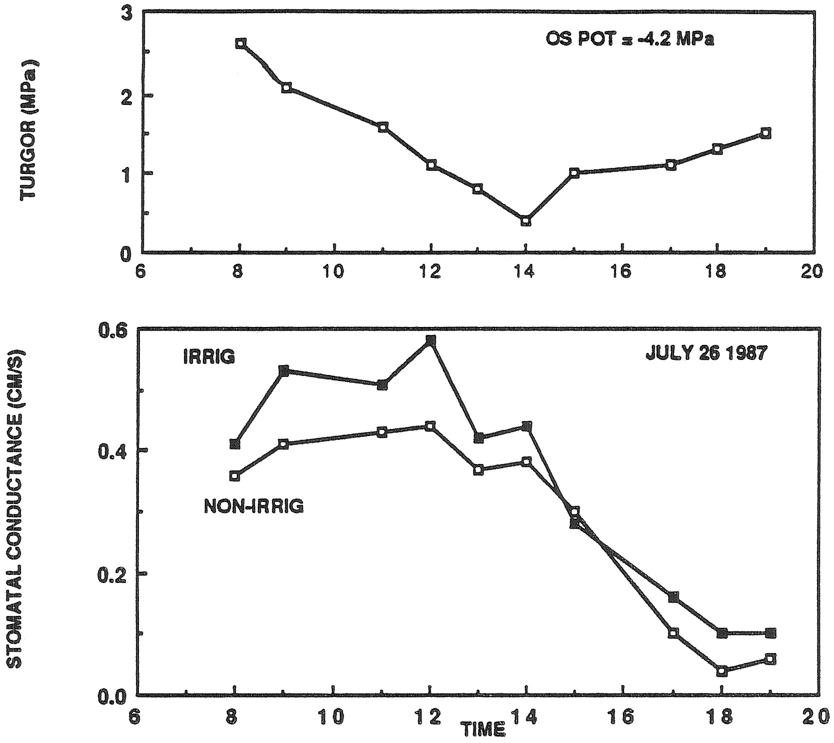

Figure 4. Stomatal Conductance and Turgor vs Time for Irrigated and Non-Irrigated Lentils

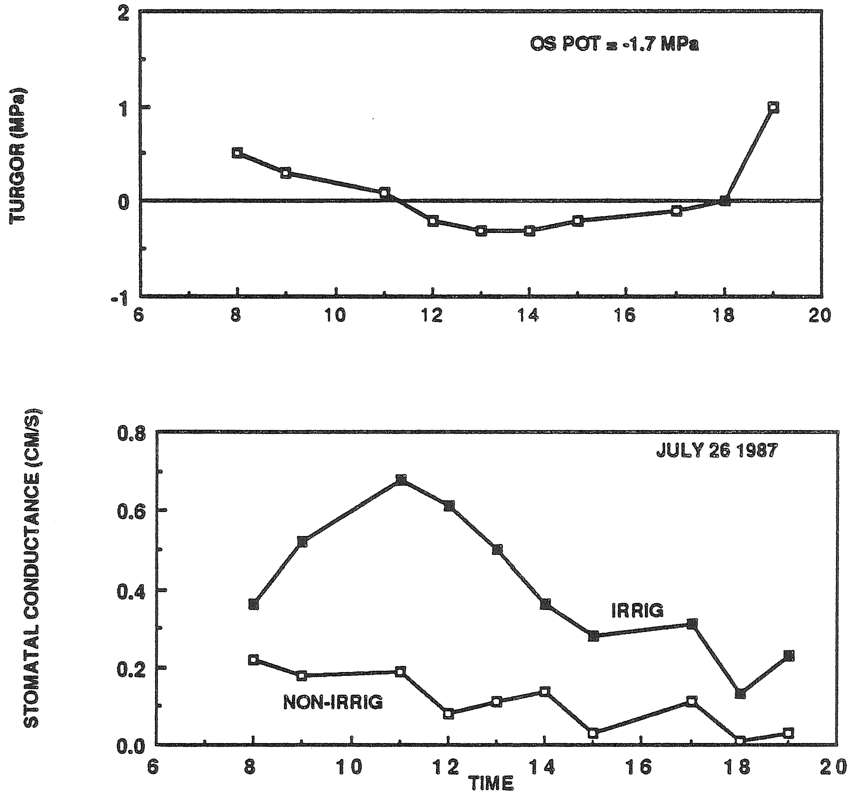

Figure 5. Stomatal Conductance and Turgor vs Time for Irrigated and Non-Irrigated Wheat

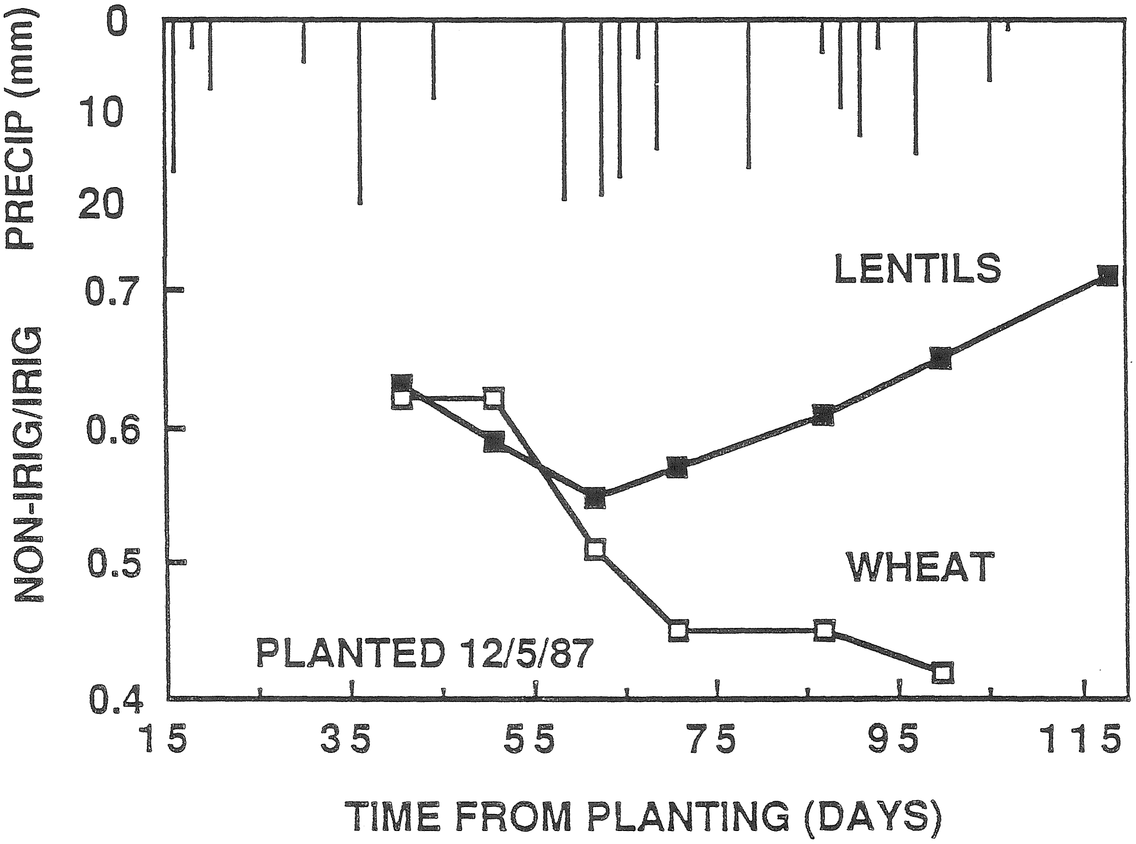

Figure 6. Ratio of aboveground dry matter production of non-irrigated to irrigated lentils and wheat.

Table 3. Yields (kg ha^{-1}), water used (mm) and water use efficiency (WUE) (kg ha^{-1} dry matter mm^{-1} water used) of irrigated and non-irrigated lentils and wheat.

	Non-irrigated		Irrigated	
	Wheat	Lentils	Wheat	Lentils
Yield				
Total	2918	4448	6678	6857
Grain	1321	1670	2725	1338
Harvest Index	0.45	0.38	0.41	0.20
Water Use				
Water used	179	244	327	361
WUE total	16.3	18.2	20.4	19.0
WUE grain	7.4	6.8	8.3	3.7

Conclusions

Lentils, in contrast to wheat, displayed considerable drought tolerance which was achieved through osmotic and stomatal adjustment. Despite maintaining high levels of turgor, g_s of dryland lentils were very low during a dry period early in the growing season. By maintaining high levels of leaf hydration during the period, lentils were able to take advantages of heavy rain in July and August so that by harvest total aboveground dry matter production of dryland lentils was over 70% of that of irrigated lentils. This compared to 41% for wheat.

The very high dry matter production in irrigated lentils did not translate into high grain yields and management strategies need to be developed to realize the full yield potential of this crop.

Wheat and lentils had similar WUE but lentils used more water over a growing season by virtue of their greater dry matter production.

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