

Temperature, Vapour Pressure Deficit and Water Stress Interaction on Transpiration in Wheat



Physiology

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ABSTRACT

Hartog, semi dwarf spring wheat with little response to vernalisation and photoperiod, was grown in naturally lit glasshouses with two temperature regimes of 30/25oC and 21/ 16oC from sowing to flag leaf ligule emergence. The plants were subjected to two water regimes of well watered and limited water supply. At flag leaf ligule emergence these plants were transferred to a growth cabinet maintained at high temperature (35/ 20oC) to study the rate of water loss. The most visible effect of temperature and water stress was the reduction in leaf area before flag leaf ligule emergence. In growth cabinet, after flag leaf ligule emergence pots with two plants lost water more quickly than those with one plant after exposure to high temperature (35/20oC), suggesting that leaf area plays a primary role in rate of water loss. Pre-treatments of high temperature and water stress at low temperature reduced the degree of damage during later period of high temperature. High temperature was associated with increase in vapor pressure deficit which governed the rate of transpiration.

Introduction

High temperature and water stress poses a serious problem to cereals, pulses and oil seeds in tropical environments. At high temperatures, the rate of plant development is increased (Midmore et al., 1984), thus reducing the potential for biomass accumulation. Wheat yields can be severely reduced in moisture-stressed environments (Morris et al., 1991), which affect at least 15 million ha of spring wheat alone in the developing world. Over 7 million ha of spring wheat are grown under continual heat stress, namely environments with mean daily temperatures of greater than 17.5°C in the coolest month (Fischer and Byerlee, 1991). There is a continuous requirement for identification of improved genotypes resistant to heat and water stress. In field studies it is difficult to separate the detrimental effects of high temperature on plants from the detrimental effects of soil water and high vapour pressure deficits (VPD). Consequently, the purported negative impact on growth of high temperature may be due to other associated environmental factors. Even in studies that enclosed and heated section of field crop and demonstrated yield reductions (e.g. Fischer and Maurer, 1976) it could not be concluded that the effects were solely due to temperature, as VPD was also changed. VPD has major effects on water-use efficiency through changing the amount of water lost by plants per unit of radiation intercepted. Indirectly, via its effects on transpiration rate, VPD can also alter the rate and degree of water stress suffered by plants. Perhaps the only way to examine the effect of high temperature alone is to use controlled environments which control VPD as well as temperature. The present study aimed to test whether high transpiration rate at high temperature is a major component of high temperature damage to wheat plants. In these studies, transpiration rate was varied by varying leaf area per pot either by water stress and temperature pre-treatment or by having either one or two plants per pot. Whether pre-treatment of temperature and water stress affect the rate of transpiration and degree of damage during later periods of high temperature. Whether transpiration rate at different temperatures is associated with VPD when water is plentiful?

Material and Methods

There were two temperature regimes of 30/ 25oC and 21/ 16oC from sowing to leaf ligule emergence during which plants were grown in naturally lit glasshouses in the phytotron at Canberra. The glasshouses were not controlled for humidity. There were two water regimes of 20 pots in each temperature regime. In the first water regime plants were watered daily. In the second, plants had limited water after emergence of second tiller (four leaves). Four seeds of Hartog, semi dwarf spring wheat with little response to vernalisation and photoperiod, were planted in 500 mm x 90 mm pots filled with composted soil. Planting was done at 18 days interval in the 21/ 16oC and 30/ 25oC regime. The eighteen days difference was used so that both regimes would reach heading at the same time. A duplicate set was planted eve-

ry 10 days after until there were four sets of each temperature treatment. Plants were thinned to two per pot when they had two leaves. Limited water treatment was achieved by withholding water. Soil water contents were allowed to drop below 50% of field capacity which took one week and then brought back to it by replenishing the losses on alternate days. A pot without a plant was kept to estimate soil water evaporation. Leaf area was estimated non-destructively by summing up lamina length x maximum width of each leaf and multiplying by a factor of 0.72 at the beginning of water stress treatments.

After one week of water stress two plants were harvested from irrigated as well as stress treatment and leaf area was measured by leaf area meter. The rate of transpiration per unit leaf area was calculated from water loss and these leaf area measurements. These measurements were made in both temperature regimes to analyze the differences in rate of transpiration per unit of leaf area at two different vapour pressure deficits. Vapor pressure deficit and temperature in the glasshouses (Figure 1 & 2) was measured by a dew point hygrometer and copper constantan thermocouple linked to a data - logger. The data - logger recorded the data every 15 seconds and data were downloaded to the computer every two days during the stress treatments. Dew point for day was used in calculations of transpiration. Vapour pressure deficit was calculated by subtracting saturation vapour pressure (SVP) for dew point from SVP for dry bulb temperature (Standard table for SVP at different dew points was used for this purpose).

Figure 1 Air temperature and dew point temperature in cooler glasshouse regime

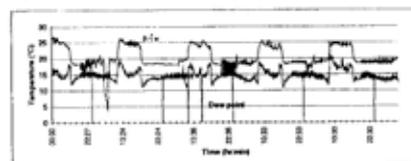
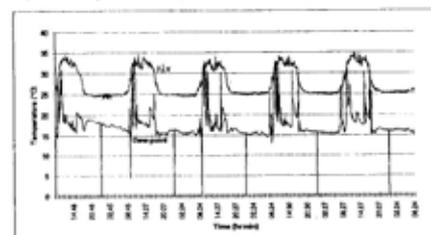


Figure 2 Air temperature and dew point temperature in hotter glasshouse regime



In the second part of the study, plants which had been pre-treated as described above were transferred to a growth cabinet at flag leaf ligule emergence which approximates the stage of pollen meiosis. High temperature (35/ 20oC) treatment was given

for five days to all plants. Up to this stage there had been two plants in every pot. In half the pots of each treatment, one plant was removed, to halve the leaf area and potential water loss per pot during this five day period of high temperature. Pot weight was taken in the beginning, next day and then after two days to determine transpiration rates during the high temperature treatment. Water was supplied at the beginning and end of the treatment. One plant from each pot of two water regime (Five pots each) was used for leaf area measurements.

Results and Discussion

Transpiration and growth before flag leaf ligule emergence

It is evident (Table 1) that mean vapor pressure deficit was higher in glasshouse maintained at 30/ 25oC than that at 21/ 16oC. This is because the same air enters into all the glasshouses and they are not controlled for humidity. The warm air can hold more water vapour so the relative amount of vapour is low in glasshouse maintained at 30/ 25oC. In the high-temperature glasshouse (30/25oC), at 17 days after sowing (DAS) the rate of transpiration was high (0.49 µg cm-2 sec-1 vpd-1). At 25 days after sowing the rate of transpiration (Table 2) was lower (0.29 µg cm-2 sec-1 vpd-1). The lower rate of transpiration may have been due to stomatal closure at high vapor pressure deficit at high temperature (Table 1). The most visible effect of temperature and water stress was the reduction in leaf area in consequence of smaller leaves. At the time of leaf ligule emergence total leaf area were 606 cm2 and 224 cm2 in low temperature pre-treatment as compared to 287 cm2 and 161 cm2 under high temperature pre-treatment in irrigated and stressed plants, respectively. Cyclic drought is a frequent event in field crops, occurring during pre-anthesis, post-anthesis, and the grain-filling period. Under severe drought stress, plants with the ability to adjust osmotically can maintain turgor when leaf water potential is reduced, sustained leaf gas exchange, sustained cellular membrane and protein function, as well as chloroplast volume and function (Morgon, 1980; Morgon and Condon, 1986; Blum, 1988; Zhang et al. 1999; Santosh Kumari, 2010). The reduction in leaf size results in a smaller transpiring leaf area is an adaptive response to water deficit (Tardieu, 2005). In the longer term, a reduced leaf area can save soil water for the later stages of plant development via a reduction in transpiration.

Table 1 Mean relative humidity (%) and vapor pressure deficit (millibar-mb) during day and night in two glasshouses-collected over five days during period as shown in table-3

Temperature	Day RH VPD	Night RH VPD	Mean RH VPD
21/16 °C	74 6.77	90 2.28	82 4.52
30/25 °C	48 18.76	70 12.54	59 15.65

Table 2 Rate of transpiration (µg cm-2 sec-1 and µg cm-2 sec-1 vpd-1) and water loss(g) pot-1 day-1 of water stressed Hartog at two temperature regime at different days after sowing (DAS)

17 DAS		25 DAS	
Temperature	LA	WL	TRa TRv
21/16 °C	168.5	35.5	1.78 0.26
30/25 °C	233.0	93.0	9.25 0.49

LA= Leaf Area
 WL= Water Loss
 TRa= Transpiration per leaf area basis ((µg cm-2 sec-1)
 TRv= Transpiration per leaf area per vpd (µg cm-2 sec-1 vpd-1)

Transpiration after flag leaf ligule emergence

Exposure to high temperature (35/ 20oC) in the growth cabinet resulted in the well watered plants from the 21/16oC regime losing more water after first day of treatment than between 2-4 days of treatment (Table 4). These plants died soon after being exposed to high temperature; therefore, the water lost was the lowest in these treatments. Where there were one or two pre-stressed plants per pot they remained green except slight burning on the leaves. In plants grown at 30/ 25oC regime, water loss was high at the end of the treatment i.e. 4th day (Table

3). Plants from high temperature and irrigation pre-treatments died in the last day of treatment because they had used all available water. It is evident (Table 3) that the pots with two plants lost more water than those with one plant after one day. This suggests that leaf area plays a primary role in water loss. Irrigated plants grown at 21/ 16oC died rapidly (Table 4) at the end of the treatment (four days of exposure to higher temperature). Pre-exposure to high temperature and water stress may result in decreased sensitivity to subsequent stress (Vassiliev and Vassiliev, 1936). The leaf temperature during pre-stressed conditions was probably close to 35/ 20oC. These plants were not exposed to the high temperature suddenly. As they were already grown under high temperature, they adapted to that condition. Pre-irrigated plants with higher leaf area were not able to transpire to match the evaporative demand. Leaf temperature was raised due to the stomatal closure and leaves were burnt on exposure to high temperature treatment. Deposition of wax another characteristic of the hardened plants was noticed in plants grown at high temperature and water stress. It is speculated that the thick cuticle helped the leaves to maintain water contents. However, plants receiving high temperature pre-treatment performed better than low temperature pre-treatment (Table 4). The better survival of the pre-stressed plants may be due to the hardening of these plants. An important function of leaf waxiness is to increase the efficiency of stomatal control by reducing water loss after stomatal closure (Clarke and Richards, 1988) contribute to heat stress avoidance, by reducing radiation absorbed by the plant (Blum, 1988). Whilst waxiness increases radiation reflectance, and thereby reduces leaf and spike temperature it increases leaf and floret survival (Johnson et. al., 1983; Richards et. al, 1986) in wheat.

Table 3 Water loss (g) per pot and total water use (g) of wheat plants after earlier growth at two temperatures and two water regimes

Previously Irrigated		Previously Stressed	
1 Plant	2 Plants	1 Plant	2 Plants
After 1 Day at 35/20 °C			
Temperature	Water Loss	Water Loss	Water Loss
21/16 °C	208	192	80
30/25 °C	212	332	120
After 2-4 Day at 35/20 °C			
21/16 °C	135	52	279
30/25 °C	336	202	403
Total water use for 1-4 days			
21/16 °C	343	244 (606)*	279
30/25 °C	548	534 (287)*	523

Table 4 Performance of wheat plants in terms of percentage of greenness (recovery) under natural environment with irrigation treatment after 5 days exposure to high temperature (35/20°C) in growth cabinet, pretreated at two temperatures and water regimes

Percentage Greenness		Pretreatments Irrigated Stressed	
	1 Plant	2 Plants	1 Plant
21/16 °C	died	died	70
30/25 °C	10	10	90

Note: * Values of Leaf Area under irrigated and pre-stress treatments

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