Interactive effects of root diseases and drought on water use efficiency of wheat

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Abstract

A pot experiment was conducted to investigate the effects of fungal root diseases (*Pythium* and *Rhizoctonia*) and drought at either tillering or anthesis on the water-use efficiency (WUE), water relations, yield components and percentage of root lesion of two Australian bread-wheat cultivars (Mulgara and Janz). There were no significant differences between two pathogens. WUE did not differ between well-watered plants and those droughted at tillering but it was significantly reduced by drought at anthesis. Mulgara had slightly higher WUE than Janz. Drought at both growth stages significantly altered water relations for both cultivars. Uninfected plants of Janz droughted at tillering had higher total water potential (ψ) and osmotic potential (π) than diseased plants. However, osmotic potential of droughted controls was lower than diseased plants at anthesis. The number of heads, grain weight and grain number were significantly higher for well- watered than droughted plants and higher for Mulgara than Janz. The controls (38%) had significantly less lesioned roots than *Pythium* (53%) and *Rhizoctonia* (50%) and root lesion percentage in Janz was significantly higher than Mulgara except in the *Rhizoctonia* treatment. In conclusion, the pathogens affected water use during tillering but not at later stages when roots developed beyond the inoculation point.

Key Words

Drought, *Pythium*, *Rhizoctonia*, water relations, water use efficiency, root lesion

Introduction

Wheat is normally subjected to multiple simultaneous stresses. Water stress (drought) is the major abiotic stress limiting yield. Similarly, fungal root diseases (biotic stress) can affect productivity of wheat at almost any stage during plant growth and development. Infection with *Pythium* for example causes a decreases in root mass which leads to poor nutrient uptake, resulting in yield loss (Weller and Cook 1986). The yield of dryland crops can be considered in terms of water use, water-use efficiency (WUE), and harvest index (Fischer and Turner 1978). WUE or the ratio of grain yield to water use is considered an important determinant of yield under stress and even as a component of crop drought resistance (Blum 2009). It provides a simple means of assessing whether yield is limited by water supply or other factors **(**Angus and Herwaarden 2001). The effect of root diseases on physiological responses of wheat has been investigated for a limited number of diseases such as take-all and *Rhizoctonia* (Balota *et al*. 2005; Kirkegaard *et al*. 1999). However, little has been done on the interaction effects of drought and fungal diseases on WUE of wheat. This paper examines the effects of drought at tillering or anthesis and fungal root diseases (*Rhizoctonia solani* and *Pythium sp.*) on transpiration, WUE, water relations, yield components and root lesions of two Australian bread wheat cultivars.

Methods

A pot experiment was conducted in a glasshouse. *Rhizoctonia solani* and *Pythium* sp. were inoculated onto autoclaved millet seeds in Petri dishes and incubated at 25^0C for three weeks. Pots (20x20cm) were each filled with 3.5 kg of sandy loam soil mixed with peat (3:1) and pH was adjusted to 6.4 with agricultural lime. Two infested millet seeds were placed 2-3 cm beneath each of 3 wheat seeds per pot. Janz was used as a representative bread wheat cultivar, while Mulgara, which has a gene for osmoregulation (Wildermuth and Morgan 2004) was used as a cultivar expected to have a different drought response. Pots were watered to field capacity every 2-3 days. Droughts were imposed by

withholding watering for 7 days at tillering (GS 22; D1) or anthesis (GS 65; D2) on separate sets of plants, and compared with well-watered (WW) plants. There were 5 replicates. Transpiration was determined by subtracting water loss of unplanted pots from that of planted pots. A pressure chamber was used to measure total water potential (ψ) at the beginning and the end of each drought period. To determine osmotic potential (π), samples were thawed after freezing in liquid nitrogen, centrifuged and then π was measured using a vapour pressure osmometer. Relative water content (RWC) was calculated as percentage from the equation: RWC (%) = (Fresh weight - Dry weight)/(Turgid weight - Dry weight)*100. Percentage of root length with lesions was measured at harvest by the gridline intersect method.

Results

There were no significant differences between the two pathogen (*Rhizoctonia* and *Pythium*) treatments so data from these have been combined for presentation.

Water-use efficiency

Both wheat cultivars had higher total transpiration under well-watered (WW) conditions than drought treatments (Tables 1 and 2). However, total water use of both cultivars droughted at tillering (D1) was higher than when droughted at anthesis (D2). There was a disease effect at D1 on water use in Janz where controls transpired 2 1 more water than diseased plants but there was no significant effect in Mulgara. There was no difference between WUE of D1 and WW plants. However, WUE was decreased significantly in D2 for both cultivars. Mulgara had higher WUE (0.94 g/L) than Janz (0.87 g/L) but the effect was not significant. There was no disease effect on WUE.

Table 1. Effects of root diseases and drought period on WUE, water relations and yield components of Mulgara cultivar.

Water status	Water use (L)	Grain weight (g)	WUE (g/L)	No. heads	Grain number	Ψ (MPa	Π (MPa)	*P* (MPa)	RWC (%)
1st drought									
Diseases	13.8	17.8	1.29	29.0	546	-2.73	-2.27	-0.45	46.0
Control	12.7	14.7	1.16	27.0	431	-2.75	-2.20	-0.55	45.2
WW diseases						-0.81	-1.20	0.39	94.1
WW control						-1.20	-1.26	0.06	93.0
2nd drought									
Diseases	6.2	1.8	0.29	12.5	155	-6.67	-4.22	-2.45	42.7
Control	6.9	2.3	0.33	13.0	189	-5.99	-4.60	-1.39	35.8

WW diseases						-0.28	-1.34	1.06	95.5
WW control						-0.28	-1.40	1.12	93.3
Well-watered									
Diseases	17.5	22.1	1.26	29.5	623				
Control	17.0	21.9	1.29	28.0	594				
LSD (disease)	1.70	2.41	0.14	3.84	84	1.83	0.28	1.89	10.1
LSD (drought)	1.44	1.97	0.12	3.14	68	1.49	0.23	1.54	8.3

Table 2. Effects of root diseases and drought period on WUE, water relations and yield components of Janz cultivar.

Water status	Water use (L)	Grain weight (g)	WUE (g/L)	No. heads	Grain number	Ψ (MPa	Π (MPa)	*P* (MPa)	RWC (%)
1st drought									
Diseases	12.0	14.0	1.17	24.0	430	-3.75	-2.82	-0.94	47.5
Control	14.1	17.8	1.26	24.0	521	-2.10	-1.73	-0.37	56.1
WW diseases						-1.21	-1.22	0.01	89.8
WW control						-0.70	-1.10	0.40	94.7
2nd drought									
Diseases	6.4	1.55	0.24	9.5	97	-6.24	-4.14	-2.10	44.2
Control	6.4	1.80	0.28	10.0	111	-5.20	-4.60	-0.60	39.9
WW diseases						-0.25	-1.36	1.11	95.8

WW control						-0.27	-1.23	0.96	94.0
Well-watered									
Diseases	15.6	18.3	1.16	26.0	490				
Control	17.5	20.0	1.14	27.0	577				
LSD (disease)	2.05	4.47	0.27	4.37	145	1.44	0.88	1.51	10.2
LSD (drought)	1.68	3.65	0.22	3.56	119	1.18	0.72	1.23	8.3

Water Relations

Drought (water withheld for one week) at either tillering or anthesis altered water relations in both cultivars, with water stress being more severe in D2 than in D1 (Tables 1 and 2). The total leaf water potential (Ψ) and osmotic potential (π) were lower in droughted diseased plants of Janz (-3.75 and -2.82 MPa, respectively) than in controls (-2.1 and -1.73 MPa, respectively) in D1. Osmotic potential was lower in droughted control plants than diseased plants at D2, but this was significant only for Mulgara.

Yield Components

The number of heads, grains and grain weight were affected significantly by cultivars and drought. The yield components were higher for Mulgara than Janz and for well watered conditions than for either drought. Disease did not have a significant effect on yield components.

Lesion percentage

The variety ? fungus interaction had a significant effect on root lesion percentage (Figure 1). Root lesions on control plants (38%) were less than those inoculated with *Pythium* (53%) and *Rhizoctonia* (50%). *Rhizoctonia* resulted in more lesions on Mulgara than on Janz. Drought treatments had no significant effect on percentage of root lesioned.

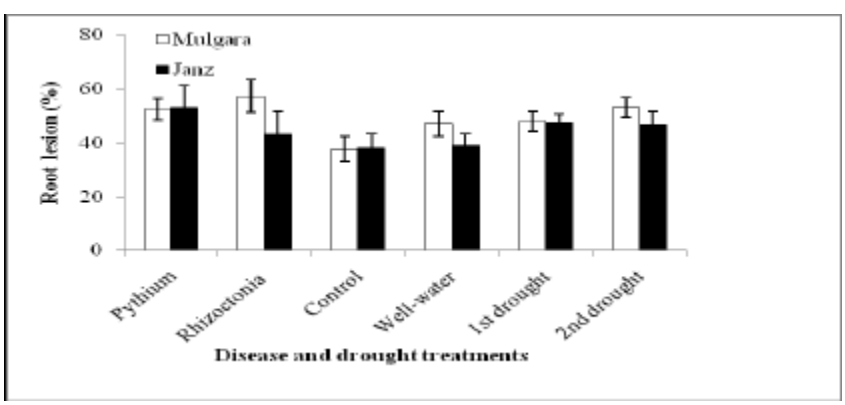

Figure 1. Effect of diseases and drought on lesion percentage of Mulgara and Janz cultivars

Discussion

Drought at tillering or anthesis reduced transpiration for both cultivars. Water use was reduced approximately 50% by drought at anthesis compared with drought at tillering. This study shows higher transpiration rates during anthesis than vegetative stages because the soil water supply is more rapidly exhausted at anthesis, which also results in reduction of leaf ψ (Morgan 1977). Wheat at anthesis has a large root system that may aid water uptake under drought. However, Ma *et al*. (2010) argued that a large root system can result in rapid soil-water consumption, which may not be favourable in arid and semiarid areas. Root diseases have been reported to affect transpiration of wheat. Although generally not significant, the healthy plants of Janz used more water than diseased and vice versa with Mulgara. That agrees with results of Martin *et al.* (1986) in which transpiration was decreased in all winter wheat genotypes infected by fungal disease except one genotype. WUE (g/l) was affected only by drought. There was no difference between WUE of D1 and WW because the ratio of yield: water use was almost the same in both treatments. Van den Boogaard *et al*. (1996) also found that WUE did not change with drought. WUE at D2 was reduced greatly depending on the reduction of grain yield. Zhang *et al*. (1999) found that WUE from stem elongation to milking is reduced when wheat exposed to stress.

Both drought treatments had significant effects on water relations. In this study, ψ and its components and RWC were reduced during D2 more than D1 due to higher transpiration rates during anthesis (Morgan 1977). Although there were no differences in transpiration rates between diseased and control plants during one week of drought at both tillering and anthesis (data not shown), total water and osmotic potentials of diseased Janz were reduced significantly more than controls at D1, showing that healthy plants resist drought more than diseased ones and it could be the pathogen itself had a major effect on the reduction. Osmotic potential of infected Mulgara was significantly higher than controls at D2 which indicated greater effect of drought than diseases on the plants at anthesis. Controls of both cultivars recovered faster after drought and their transpiration rates became higher than diseased ones. The reduction of ψ is not consistent with reduction of RWC possibly due to difference in time of ψ measurement (between 2 and 5 pm). It was suggested that RWC provides more accurate results as it estimates tissue water content and cell turgor.

The grain yield for both cultivars was greatly affected by drought, particularly at later stages of development (reproductive stage). Drought at this stage decreases grain set and loss of male fertility has been associated with accumulation of abscisic acid (ABA) in the spike (Morgan and King 1984). The disease had no effect on grain yield as the inoculum level in the soil was not adequate to reduce grain yield. The results also indicate that Mulgara had higher grain yield, water use and thus WUE than Janz because Mulgara is selected for high osmotic adjustment (OA) (Wildermuth and Morgan 2004). There was a relation between root pathogen inoculation and lesion percentage. The infected plants had higher lesion percentage than controls and lesioning of Janz was higher except for *Rhizoctonia*. It could be that the roots of Mulgara are more susceptible to *Rhizoctonia* than Janz.

Conclusion

Drought developed slowly at the tillering stage because of the large volume of soil in proportion to leaf area (Frank *et al*. 1973) and developed rapidly at anthesis stage (severe drought). Mulgara tolerated drought better than Janz. The diseases have minor effects on above-ground physiological parameters but have major effects at the underground level. The pathogens affect transpiration at tillering but not at anthesis when the roots had developed further below the inoculation point. There was no significant drought ? fungus interaction in this study. Further research is required to investigate the interaction between drought and disease at the whole plant level.

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