Differential responses to water regimes in triticale genotypes differing in aluminium tolerance

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ABSTRACT

Two triticale genotypes that differed in apparent aluminium tolerance were examined for differential responses to water availability regimes in an acid soil (in pot culture). A full watering (FW) regime resulted in higher dry matter and grain yield production than a half watering (HW) regime in both Al-tolerant and Al-sensitive genotypes. In the HW regime the Al-tolerant 19th ITSN 70-4 had an advantage in dry matter production and water use efficiency (WUE) over Al-sensitive 23rd ITYN 27. This advantage appeared to arise from a more developed and functional rooting system of the Al-tolerant genotype. These results suggest an association between apparent Al stress tolerance and tolerance to water deficit stress, and highlights the continuing need to develop and utilise Al-tolerant triticale genotypes in acid-stressed environments with limited water availability.

KEY WORDS

Acidity, aluminium stress/tolerance, dry matter production, root growth, water use efficiency, triticale.

INTRODUCTION

Drought and soil acidity are some major concerns of current crop production and breeding improvement research in Australia. Aluminium (Al) toxicity in a strongly acidic soil can result in reduced plant rooting depth by hampering root elongation, with a subsequent increase in the susceptibility to drought. Reduced root growth may intensify water deficit stress under drought conditions, although direct evidence of this interaction has been documented for only a small number of crops. In barley, water deficit stress differentially magnified the effects of Al stress on two cultivars differing in Al tolerance (4). Likewise in soybean, the combined effects of water deficit stress and Al stress on leaf water status exceeded predictions based on the additive effects of each independent stress factor (3). Intuitively, root systems impaired by Al stress may limit the ability of plants to withstand water deficit stress. Testing of a similar hypothesis is necessary in triticale. This experiment was designed to investigate the response to water regimes in plant dry matter production, particularly root growth, and to examine the relationship between tolerance to water deficit stress and tolerance to Al stress.

MATERIALS AND METHODS

Two genotypes, Al-tolerant 19th ITSN 70-4 and Al-sensitive 23rd ITYN 27, of similar phenology but with contrasting apparent Al tolerance response (7) were used. The experiment was conducted in a glasshouse at the University of New England, Armidale of NSW. Uniform UPVC tubes (15 ? 65 cm) were filled with acidic Coonabarabran soil to the level of 60 cm, with the top 5 cm surface left for ease of watering; this soil has a pH level (in 1:2 soil:$CaCl_2$) of 4.6 and 4.4 respectively for its topsoil and subsoil. Following experimental measurements, 8.430 kg subsoil and 4.832 kg topsoil (on an oven-dried basis) were respectively added to each tube to a bulk soil density of 1.591 g/cm? and 1.824 g/cm?.

Approximately 1000 ml of water was applied to each tube to moisten the soil, and then four germinated seeds were sown on 14 May 1998. The soil was maintained moist by frequent additions of a small amount of water until seedling emergence. Seedlings were thinned to two plants per tube on 25 May. Twenty-five days after sowing (i.e. on 9 June), each tube was watered sufficiently to allow free drainage, and adequate amounts of fertiliser Aquasol™ solution were applied to ensure that nutrient supply was not limiting to plant growth. Two days later (i.e. on 11 June) each tube was weighed to provide an initial measure of water content (W_0).

The experiment used a RCB layout with three replicates. Two water regime treatments (full watering, FW; and half watering as water deficit stress, HW) were assessed at three sampling dates (i.e. early-booting stage, heading stage and maturity). The early boot and heading samples were taken on the 28 July and 31 August (i.e. 75 and 109 days after seeding, respectively). Monitoring of water use was achieved by the regular addition of water to restore the tube to its original weight (W_0) for the FW regime, or by adding only 50% of water consumed in the HW regime. The amount of water use was determined by weekly weighing of each tube during the early seedling stage or by weighing twice weekly at later growth stages until harvest on 19 October 1998.

Tube positions were re-arranged six times during the experiment. Shoot samples were collected directly, whilst root samples were collected by dismantling the tube and then removing the soil and washing roots gently in tap water to ensure the bulk of the root system was recovered. Three plant growth parameters related to dry matter production and water use were recorded for all three sample times. At plant maturity, grain yield and cumulative water use were also recorded and the distribution of root dry weight at three soil depths was assessed. Shoot and root dry matter samples were dried in a force air heater at 75?C for 48 hr, and weighed. Harvest index (HI) was calculated as the ratio of grain yield to total aboveground dry matter production. Water use efficiency (WUE) was calculated as the ratio of grain yield produced per unit of water use (6). The effects of water deficit stress on plant performance were evaluated from the ratio of HW to FW.

RESULTS

Dry matter production at early boot and heading stages

Plants receiving FW management grew more vigorously than those receiving HW management, with greater plant height and more tillers irrespective of the genotype. In the early boot and heading samples, there were significant differences between the two water regimes in root, shoot, and total dry matter production (Table 1). The FW management generally produced higher dry matter than HW; however, HW management in Al-tolerant 19th ITSN 70-4 (in 1st sample) had a much higher root weight than FW (1.90 vs. 1.17).

Table 1. Comparison of booting and heading dry matter production (g/plant) of two varieties under two water regimes.

Variety	FW †			HW †			% of HW/FW		
	Shoot	Root	Total	Shoot	Root	Total	Shoot	Root	Total
1st sample stage/time (early boot)									
19th ITSN 70-4 *(Al-tolerant)*	8.07 ?0.54	1.17 ?0.10	9.24 ?0.46	5.64 ?0.18	1.90 ?0.33	7.54 ?0.16	69.9	162.4	81.6
23rd ITYN 27 *(Al-sensitive)*	8.14 ?0.45	0.85 ?0.13	8.99 ?0.52	6.63 ?0.48	0.80 ?0.20	7.43 ?0.49	81.4	94.1	82.6

2nd sample stage/time (heading)									
19th ITSN 70-4	22.13 ?0.80	2.43 ?0.10	24.56 ?0.88	17.70 ?0.56	2.30 ?0.04	20.00 ?0.56	80.0	94.7	81.4
23rd ITYN 27	23.52 ?0.25	1.79 ?0.18	25.31 ?0.29	18.17 ?0.84	1.48 ?0.10	19.64 ?0.85	77.3	82.7	77.6

† Mean ? s.e. (Tables 1 & 2)

Root dry weight was significantly higher in the Al-tolerant 19th ITSN 70-4 than in the Al-sensitive 23rd ITYN 27 for both water regimes and sample times. The higher root dry weights of the Al-tolerant genotype were not associated with higher shoot dry weight at these stages. Nevertheless, the Al-tolerant genotype performed much better than the Al-sensitive one in terms of relative root dry matter production; the ratio of HW to FW was 162.4% vs. 94.1% and 94.7% vs. 82.7% for the 1st and 2nd sample times, respectively.

Dry matter production and water use at plant maturity

At plant maturity significant differences occurred in shoot, root, and total dry matter production between varieties and between water regimes (data not shown). While significant differences in grain yield occurred between water regimes the Al-tolerant and Al-sensitive cultivars did not differ significantly. Total water use also differed between water regimes but not between varieties.

The FW regime used more water and produced higher dry matter and grain yield than the HW regime. Genotype comparisons indicated that the Al-tolerant 19th ITSN 70-4 produced significantly higher dry matter than Al-sensitive 23rd ITYN 27. The Al-sensitive genotype 23rd ITYN 27 produced a higher grain yield under FW regime than the Al-tolerant entry but was lower in grain yield under the HW regime. This contributed to the Al-tolerant 19th ITSN 70-4 having a much higher ratio of HW to FW in grain yield (95.6% vs. 59.2%) and HI (142.9% vs. 81.8%).

While total water use was similar in both genotypes, the Al-tolerant genotype (19th ITSN 70-4) achieved an especially high WUE (1.51 g/L) under the HW regime; this resulted in a much higher ratio of HW to FW (146.3%) in comparison with 23rd ITYN 27 (89.5%). This may imply that the Al-tolerant genotype was less sensitive to moderate water deficit stress than the Al-sensitive type under these experimental conditions.

Table 2. Comparison of dry matter production and water use† of two varieties under two water regimes.

Water regimes	Shoot (a)	Root (b)	Total (c = a+b)	Yield (d)	HI (e = d/a)	Water use (f)	WUE (d/f)
19th ITSN 70-4 (Al-tolerant)							
FW	44.12 ?1.76	2.35 ?0.13	46.47 ?2.16	12.49 ?1.84	0.28 ?0.05	12.133 ?0.146	1.03
HW	29.91 ?0.41	2.11 ?0.20	32.02 ?0.51	11.94 ?0.31	0.40 ?0.01	7.935 ?0.033	1.51

% of HW/FW	67.8	89.8	68.9	95.6	142.9	65.4	146.3
23rd ITYN 27 (Al-sensitive)							
FW	39.85 ?3.98	1.94 ?0.13	41.79 ?4.02	17.16 ?1.18	0.44 ?0.07	12.125 ?0.090	1.42
HW	27.98 ?0.77	1.68 ?0.18	29.66 ?0.70	10.15 ?0.85	0.36 ?0.02	8.010 ?0.124	1.27
% of HW/FW	70.2	86.6	71.0	59.2	81.8	66.1	89.5

† Dry matter and grain yield are reported as g/plant, water use as L/plant, and WUE as g/L

Distribution of relative root dry weight at plant maturity

The vertical distribution (Figure 1) of root dry weight at three soil depths indicated that the Al-tolerant 19th ITSN 70-4 had a higher proportion of roots at the 2nd (21−40 cm) and the 3rd soil depths (41−60 cm) than the Al-sensitive 23rd ITYN 27 for both FW and HW regimes. Moreover, for the Al-tolerant genotype, there was only a slight reduction in root weight in the 3rd soil depth, from FW (25.2%) to HW (22.0%); whilst for the Al-sensitive genotype, there was apparently a large decrease, from 20.3% (in FW) to 14.1% (in HW).

DISCUSSION

Acidic soil stress, which is dominated by low pH and/or high Al level, can severely decrease plant productivity of less tolerant crops through soil infertility, Al-induced reduction of plant rooting depth and/or intensified water deficit stress under drought conditions. This experiment examined the plant dry matter production and water use efficiency of two contrasting genotypes under two water regimes in an acid soil. Higher dry matter production and grain yields in both Al-tolerant and Al-sensitive genotypes resulted from continued maintenance and good supply of water over their complete life cycles (i.e. from the FW regime). In the HW regime the Al-tolerant genotype had an advantage in dry matter production and WUE over the Al-sensitive type, and this result is consistent with reports from other crop species (4). While the Al-sensitive 23rd ITYN 27 had the higher grain yield and HI under FW management, both of these productivity-related characters decreased sharply under HW management (Table 2). This suggests that Al sensitivity might be associated with sensitivity to water deficit stress, or Al tolerance might be associated with tolerance to water deficit stress. Similar results led Goldman et al. (3) to recommend that soybean breeders should select for Al tolerance when developing drought-tolerant cultivars because Al tolerance may impart some degree of drought tolerance in areas limited by low rainfall and subsoil acidity.

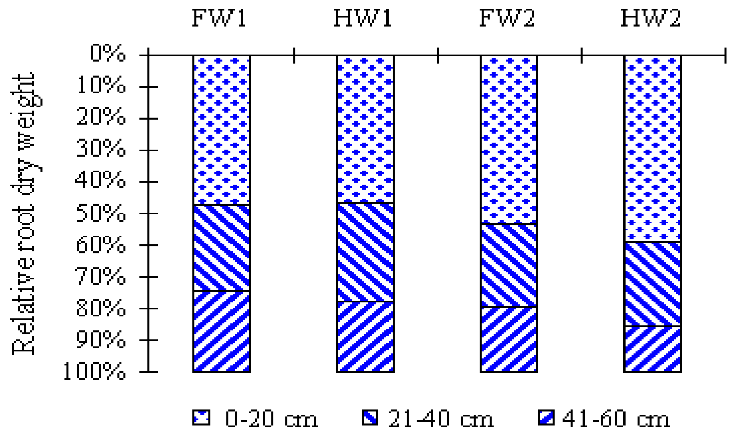

Figure 1. Vertical distribution (%) of root dry weights of two genotypes under two water regimes (FW and HW). FW1 and HW1 refer to Al-tolerant 19th ITSN 70-4, and FW2 and HW2 refer to Al-sensitive 23rd ITYN 27.

The advantage of Al-tolerant genotypes over Al-sensitive types subject to HW regime appears to arise from a more functional rooting system. The Al-tolerant 19th ITSN 70-4 produced higher root dry matter (Table 2) and had a higher proportion of root dry weight at deeper soil depths than the Al-sensitive genotype (Figure 1). A more developed rooting system may have enabled plants to gain access to more subsoil water and nutrients, or to extract water more efficiently from the Al-toxic subsoil layer. Turner (5) in his review highlighted the importance of, and the need for, a better understanding of the adaptation of roots and shoots to water deficits when dealing with the adaptation mechanisms of drought tolerance in crop plants. Similarly, an increased rooting depth and density has been identified as a putatively useful morpho-physiological trait for improved drought resistance in both intermittent and terminal stress environments (1, 2, 6). The results of the current experiment suggest that Al-tolerant triticale genotypes may achieve higher plant productivity in water-stressed acid soil environments. As total water use of Al-tolerant and Al-sensitive genotypes was similar, the advantage of Al-tolerant types relates mainly to a superior WUE for dry matter and grain production. Further comparative studies involving a larger set of genotypes of contrasting Al tolerance responses will be required to confirm these results.

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