Water use efficiency of wheat in a semi-arid environment

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Abstract

Components of the crop water balance were studied for a calcareous soil typical of a large proportion of the dryland cropping areas of South Australia. Soil water content was measured at intervals during the growing season in 2000 for wheat after a series of alternate crops (canola, medic pasture, vetch, barley and wheat) in 1999. There were no observed changes in total soil water content below 70 cm soil depth, indicating the limit for extraction of water by crop roots. Drainage below this depth was not detectable. Plant available water in the root zone at sowing was significantly greater after canola (40 mm) than the other treatments but the difference was no longer evident 57 days after sowing. Total evapotranspiration (ET) was not significantly different for any of the treatments (mean ET=315 mm). Nevertheless yield (t/ha), and hence grain water use efficiency (WUE, kg/ha/mm), were significantly greater for wheat after canola (2.5; 8.0), barley (2.5; 7.9) and continuous wheat (2.4; 7.6) than after medic (2.2; 7.0) or vetch (2.1; 6.8). These values for WUE fall within the 25th percentile of WUE values recently obtained in a farm survey across the Mallee regions of NSW, SA and Victoria. Estimated loss of water via soil evaporation in 2000 averaged 101 mm whereas for the 2001 season it was considerably lower (64 mm). The major influence of rainfall and effective rooting depth on the dynamics of plant available water in soil is highlighted by the study. However, additional edaphic and environmental factors, including timing of rainfall events, soil fertility and phenological development of the crop are also critical when evaluating crop WUE, particularly in a semi-arid environment.

Keywords

Grain yield, evaporation, neutron moisture meter, rotation.

Introduction

In the semi-arid region of the Upper Eyre Peninsula (South Australia), where available water is considered the most limiting factor for crop production, wheat represents the principal crop and is generally grown in rotation with barley, legume pastures or an opportunity crop of canola. Water use efficiency (WUE), estimated from grain yield and growing season rainfall (GSR) minus a nominal value for soil evaporation, is commonly used as a measure to assess the productive capacity of crops in these environments (1). Recent estimates of WUE for the low rainfall areas of the Eyre Peninsula vary considerably from 8-12 kg grain yield/ha/mm and are considered relatively inefficient compared to other cropping regions in Australia (2). However, these estimates of WUE have been derived without actual regional data for soil evaporation or depth of water extraction from the soil profile and do not account for drainage of water below the root zone. The following study was therefore carried out to provide a more comprehensive assessment of the components of the soil water balance for a soil type typical of a large area of the region, in order to better define the actual proportion of GSR available for plant production, and thus allow better evaluation of crop WUE.

Methods

The research reported here was conducted at a site15 km west of Rudall (Lat. 33.69?S, Long. 136.27?E) on the eastern Upper Eyre Peninsula, from 1999 to 2001. The soil at the site is classified as a Lithocalcic Calcarosol with little or no slope and is representative of a large proportion of cropped land in the region. Characteristically the soil is acidic in the sandy top layer, becoming extremely alkaline below 20 cm; and there is a clay layer (>30%) in the soil profile between 10 and 40 cm that re-appears below 80 cm (Table 1).

The experiment was designed as a randomised complete block with four replicates to facilitate statistical analysis using Genstat. Each plot was 19 m ? 95 m and the rotation treatments were: barley-wheat (BW); canola-wheat (CW); medic pasture-wheat (MW); vetch-wheat (VW) and wheat-wheat (WW). The alternate crops were sown in 1999 and 2001 and in 2000 the entire site was sown to wheat (variety Excalibur) on 19 April with fertiliser (DAP at 70 kg/ha; 13 kg N/ha and 14 kg P/ha at 18:20:0) drilled with the seed. Soil water

Table 1. Profile distribution of selected properties for the soil at Rudall on eastern Upper Eyre Peninsula.

Soil layer depth (m)	Sand %	Silt %	Clay %	Water content (mm)* -1500KPa	-10KPa	PH $CaCl_2$	$\rho^{\#}$ g/cm^3
0.0-0.1	87	2	11	8	18	5.9	1.40
0.1-0.2	64	4	32	21	29	7.3	1.54
0.2-0.4	63	7	30	36	54	8.2	1.46
0.4-0.6	71	9	20	26	52	8.5	1.44
0.6-0.8	64	13	23	27	58	8.7	1.46
0.8-1.0	54	17	29	18	57	8.9	1.42
1.0-1.4	48	18	34	36	124	8.9	1.58
1.4-1.8	51	7	42	44	144	8.8	1.69

All water content data determined from intact cores on pressure plates at –10 kPa and –1500 kPa.
[#] Dry bulk density.

content to a depth of 1.8 metres was measured periodically throughout the season at 57, 90, 107, 142 and 218 days after sowing (DAS), using a neutron moisture meter (NMM). Values represent the mean of 8 readings for each treatment (2 per plot). The values for soil water contents at field capacity (FC), and for wilting point (WP) at the lower depths only, were determined for intact cores in pressure chambers at –10 kPa and –1500 kPa respectively. Plant available water (PAW) was determined as the sum of the difference between the WP value and the measured total soil water content for each depth down to 70 cm. Evapotranspiration (ET) was calculated from mean data using the water balance equation (3). Dry matter was sampled from each plot at tillering, anthesis and harvest and grain yields were measured using a plot harvester and weigh trailer. Soil evaporation (Es) was taken as the x-intercept of the linear relationship between cumulative ET (x-axis) and dry matter production (y-axis).

Results

The results reported here relate to the 2000 season with occasional reference to relevant data collected in the other seasons. GSR in 2000 was 301 mm compared to an average GSR of 254 mm. The distribution of rainfall throughout the season varied from the long-term rainfall pattern with rainfall in April-May (83 mm) exceeding the average by 70%, June was drier than average (35 mm), rainfall in July, August and October (52, 61 and 32 mm) was greater than average, September rainfall was average (38 mm) and there was 10 mm prior to harvest in November. During the growing season there were only eight daily rainfall events that exceeded 10 mm.

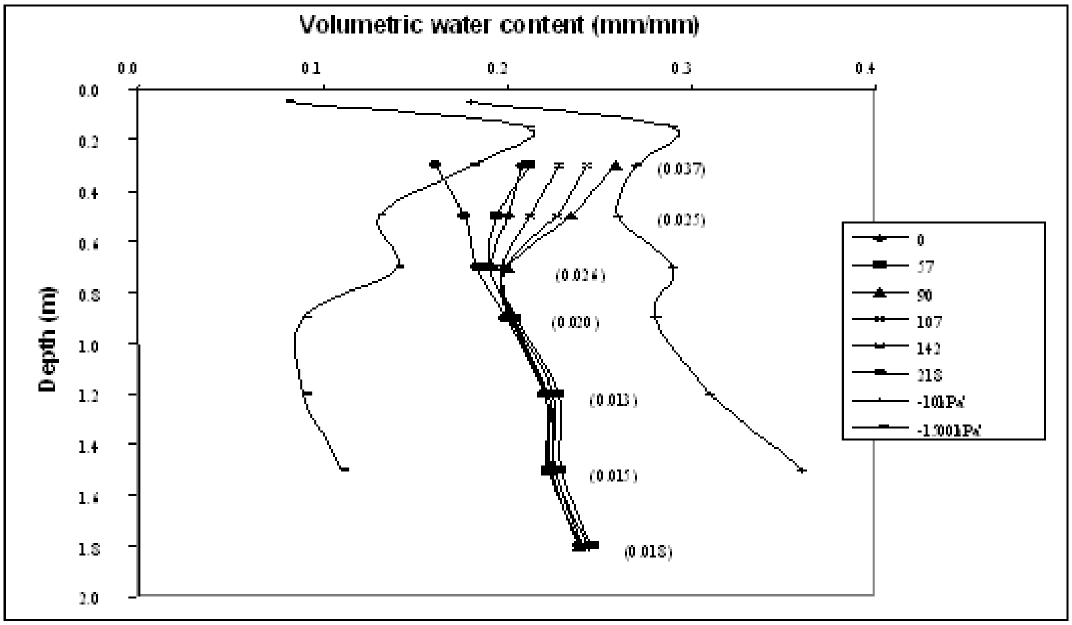

Figure 1. Total volumetric water content (mean of all treatments) for the Rudall soil profile, measured at sowing (0) and at intervals (57, 90, 107,142 and 218 days after sowing) during 2000. Values in parenthesis are standard deviations for each depth. Data for FC and WP determined as described for Table 1.

Total soil water content, extraction depth, drainage and PAW

There were no observed changes in total soil water content below 70 cm in the soil profile in any of the treatments throughout the season, illustrated by plotting overall mean data for the site (Figure 1). Furthermore, the maximum profile water content recorded at 90 DAS did not approach –10 kPa (theoretical field capacity) at any point in the profile (Figure 1). Volumetric water content data for 15 cm was not included in Figure 1 due to unreliable estimates from neutron probes at this depth, and incomplete gravimetric measurements.

There were some initial treatment differences in PAW to 70 cm at sowing (Figure 2), with the plots after medic being significantly ($P<0.05$) drier than the other treatments. Canola plots were significantly wetter than vetch and medic pasture plots, probably due to the fact that the canola plots were the only treatment where summer weeds did not germinate following a 58 mm rainfall event over three days in February 2000. However, by 57 DAS there were no significant differences in PAW for any treatments.

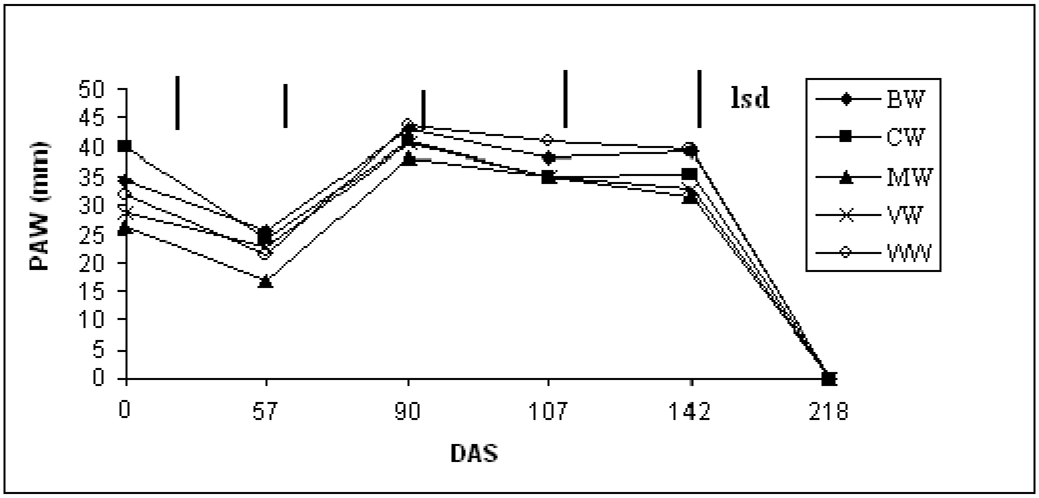

Figure 2. Calculated plant available water (PAW) (0-70 cm soil depth) against days after sowing (DAS) during 2000 under wheat grown following barley, canola, medic pasture, vetch or wheat.

Yield, ET, E_s and WUE

Wheat yield, and hence WUE, for the different rotation treatments differed significantly (Table 2), with lower yields for wheat after vetch or medic and higher yields for wheat after canola and the continuous cereals. However, there were no significant differences in ET or in Es, for the rotation treatments (Table 2). Estimated Es in 2000 was slightly less than the value of 110 mm commonly applied for wheat in semi-arid regions, but was much larger than Es estimates for wheat in 2001 (data not shown) where the range was 54 to 73 mm. The values for WUE are relatively poor and fall within the 25th percentile of WUE values recently obtained in a farm survey across the Mallee regions of NSW, SA and Victoria (4).

Maximum water extraction depth for the soil at this site was 70 cm, probably due to the hostile nature of the soil for root penetration and function. Further, there was no apparent drainage below the root zone even in a wetter than average year and indeed the capacity for the soil to store water did not appear to be met under these climatic conditions. Admittedly, there is some disagreement concerning the application of empirical soil parameters to field situations. However, some preliminary NMM data obtained following saturation of the soil in the field ('ponding') suggest that for this soil profile there is some correlation between theoretical and observed FC under field conditions – further work establishing these relationships is on going.

Table 2. Yield, estimated ET, Es, transpiration (Ep) and WUE for wheat in 2000 grown following barley, canola, medic pasture, vetch or wheat. Values within a column followed by different letters are significantly different (P<0.05).

1999	2000	Yield t/ha	ET Mm	Ep Mm	Es[1] Mm	WUE[2] kg/ha/mm
Barley	Wheat	2.52a	319	219	100	7.8a
Canola	Wheat	2.52a	317	215	102	8.0a

Medic	Wheat	2.23bc	317	214	103	6.7b
Vetch	Wheat	2.10c	310	209	102	6.8b
Wheat	Wheat	2.39ab	313	214	99	7.8a

[1] Es - taken as x-intercept from linear plot of cumulative mean ET and DM production.
[2] WUE = Yield (kg/ha)/ET(mm).

Conclusion

Despite the fact that previous crops had no effect on ET for the subsequent wheat crop there was an influence on yield, and hence WUE of that subsequent crop. Clearly, other influences of rotation on factors such as soil fertility, and hence crop phenological development, are important in determining final yield. The values for WUE are relatively low. Although not influenced by rotation, loss of water via evaporation from the soil is certainly a dynamic factor dependent on season and other less well-defined parameters. Further data correlating Es with patterns of rainfall and crop canopy development parameters such as leaf area index (LAI) is required for these semi-arid regions.

Acknowledgements

The authors thank Matt, Mignon and Peter Dunn for generous access to land, equipment and their time. Able assistance was provided by Penny Day from Roseworthy Campus and staff at SARDI Minnipa Ag Centre. D. Adcock is supported by a GRDC postgraduate scholarship and the research is part of the Eyre Peninsula Farming Systems Project, a GRDC funded initiative.

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