Soil exploration by sorghum root systems in wide row cropping systems

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Abstract

Wide and 'skip row' row configurations have been used as a means to improve yield reliability in grain sorghum production. However, there has been little effort put to design of these systems in relation to optimal combinations of root system characteristics and row configuration, largely because little is known about root system characteristics. The studies reported here aimed to determine the potential extent of root system exploration in skip row systems. Field experiments were conducted under rain-out shelters and the extent of water extraction and root system growth measured. One experiment was conducted using widely-spaced twin rows grown in the soil. The other experiment involved the use of specially constructed large root observation chambers for single plants. It was found that the potential extent of root system exploration in sorghum was beyond 2m from the planted rows using conventional hybrids and that root exploration continued during grain filling. Preliminary data suggested that the extent of water extraction throughout this region depended on root length density and the balance between demand for, and supply of, water. The results to date suggest that simultaneous genetic and management manipulation of wide row production systems might lead to more effective and reliable production in specific environments. Further study of variation in root-shoot dynamics and root system characteristics is required to exploit possible opportunities.

Media summary

Root systems of sorghum crops grow beyond 2m in search of water, but this depends on genetic, management and environmental factors.Can we design improved production systems for water-limited environments using this understanding?

Key words

Sorghum, roots, water extraction, skip rows, root chambers.

Introduction

Grain sorghum production in the more marginal dry land cropping areas of NE Australia has been characterised by poor yield reliability. In seasons with low in-crop rainfall, soil moisture reserves are often fully utilised by anthesis and low yields or total crop failure can result. In recent years 'skip row' configurations have been tried as a means to improve yield reliability (Butler et al., 2001). A common skip row configuration is double skip (DS), where two rows are planted and two not planted. A base row spacing of 1.0 m, which is commonly used in the solid planted (SP) configuration is also used for DS. Skip row configurations are thought to improve yield reliability by delaying utilisation of soil moisture in the centre of the skip area until late in the growing season when the soil water extraction front extends into this area. As a result, soil moisture in the centre of the skip is more likely to be available during the grain filling stage allowing higher yield and increased harvest index in moisture limited growing conditions.

A series of linked field and modelling studies have been conducted to quantify the production risks associated with DS and SP systems for a range of soil and climatic conditions (Routley et al. 2003; McLean et al. 2003). These studies indicated that ‘skip row’ systems have good potential to improve reliability of sorghum production and perhaps extend the environmental range supporting crop production. However, there has been little effort put to design of these systems in relation to optimal combinations of root system characteristics and row configuration, largely because little is known about root system characteristics.The studies reported here aimed to determine the potential extent of root system exploration in skip row systems. The intent was to learn enough to initiate informed research on improving system design by considering genetic and management manipulation simultaneously.

Methods

Two field experiments were conducted under rain-out shelters at Hermitage Research Station (Lat. 28° 12’ S, Long. 152°06’ E 470m above sea level) in south eastern Queensland.

Experiment 1 – Root exploration in soil

Experiment 1 was sown 14th October 2002 using two rainout shelters. The soil was a strongly cracking and self-mulching alluvial clay with a high montmorillonitic clay content that was well drained and about 120cm deep. The experimental area was fertilised to provide non-limiting nutrient conditions and irrigated prior to sowing to fill the soil profile. No further water was added throughout the crop life cycle and rain was excluded. Sorghum hybrids were planted in twin 1m rows separated by 6m. In the first rainout shelter early (Pacer) and late (Buster) maturity hybrids were grown at a density of 10 plants/m row. In the second rainout shelter, the late maturing hybrid was grown at high (20 plants/m) and low densities (5 plants/m). There were 3 replicates arranged in a randomised block in each rainout shelter (Fig.1). Neutron access tubes were installed every 50 cm across the row configuration (starting in the middle of the two rows) and soil water monitored every 4-5 days at 20cm depth increments in all plots. Soil cores were taken on four occasions through the crop cycle and roots extracted. Cores were taken every 100cm across the row configuration and cut into 20cm depth increments in all plots. Samples were soaked and washed and all root material collected, scanned for root length, and weighed after drying. Plant samples were taken at flowering and maturity and separated into leaf, stem, head and grain fractions for determination of biomass. Tagged plants were monitored in each plot for leaf area production and senescence and timing of developmental stages.

Experiment 2 – Root exploration in large root chambers

Experiment 2 was sown into specially constructed root observation chambers on 15 October 2003. The chambers were 240cm wide, 120cm deep and 10cm thick with removable clear perspex sides attached to a rigid steel frame. These dimensions were chosen to reflect the soil volume available to a sorghum plant in a ‘skip row’ configuration. The chambers were filled with a mixture of the local alluvial clay soil and sandy loam. Fertiliser was incorporated so that nutrition would not limit plant growth. The soil was wetted completely and allowed to settle and drain. Three of the chambers (one per replicate) were opened and the soil cut into 20cm square sections to determine moisture content and its distribution prior to planting. These chambers were re-filled and re-watered. In each of the 12 chambers used, a single plant was allowed to establish from 5 seeds planted 50cm from one end. Three replicates of four treatments were arranged in a randomised block design above the ground under a rainout shelter. The perspex sides were covered with insulating, light-excluding material and shades were installed at the ground level of the chambers to minimise heating from direct radiation (Fig. 1).

The four treatments consisted of sorghum hybrid 'Buster' with 2 tillers permitted to develop, the same hybrid with tillers removed, the experimental triple dwarf hybrid '23171/31945-2-2' and its taller double dwarf mutant, both with tillers removed. Plant height, phenology, and leaf appearance, size and senescence were monitored regularly and biomass components were determined at harvest at maturity. The position of roots intersecting the perspex was noted each week. At harvest the chambers were opened and the soil cut into 20cm square sections. A sample was removed to determine gravimetric soil moisture for each location and the block was then soaked and washed to remove all roots.

Figure 1. Rain-out shelter experiments 1 (2002-03, left panel) and 2 (2003-04, right panel).

Results and Discussion

In experiment 1, neither hybrid maturity nor density affected grain yield, which was close to 2 t/ha despite the extremely wide row system employed (Table 1). There was only 3 days difference in maturity between early and late hybrids and tillering compensated for low plant density in the density experiment.

Table 1. Growth and yield in hybrid maturity and density experiments (Experiment 1)

	Maturity Experiment			Density Experiment		
	Early	Late		High	Low	
Yield (g m^{-2})	209	189	ns	189	192	ns
LAI at anthesis	0.81	0.91	ns	1.12	0.89	ns
Days to anthesis	61	64	*	63	64	ns
Fertile tiller no (m^{-2})	2.9	1.9	ns	0.9	3.0	**
Density (m^{-2})	3.0	2.9	ns	6.0	1.4	**

Possibly as a consequence of the small differences among treatments above ground, there were also only slight differences among treatments in ability of root systems to explore the soil profile (data not shown). The rate of exploration of the soil profile was about 2 cm/day in all directions continuing well into the grain-filling period (Fig. 2), which was consistent with previous studies (Routley et al. 2003; Robertson et al. 1993). Greater differences in maturity are required to test the effect of crop duration on root system exploration. While roots were recorded up to 2m from the base of the plants in any row, their density diminished below 0.1 cm cm^{-3} beyond distances of about 1m. This root length density represents a threshold level required for complete extraction of soil water (Robertson et al. 1993). These data suggest that although root system exploration was expansive, there remained incomplete extraction of water at depth and in the wide inter-row spaces. In this experiment, this likely reflected the interaction of the potential root system exploration of the crop and the generally low demand for water given the low LAI (Table 1).

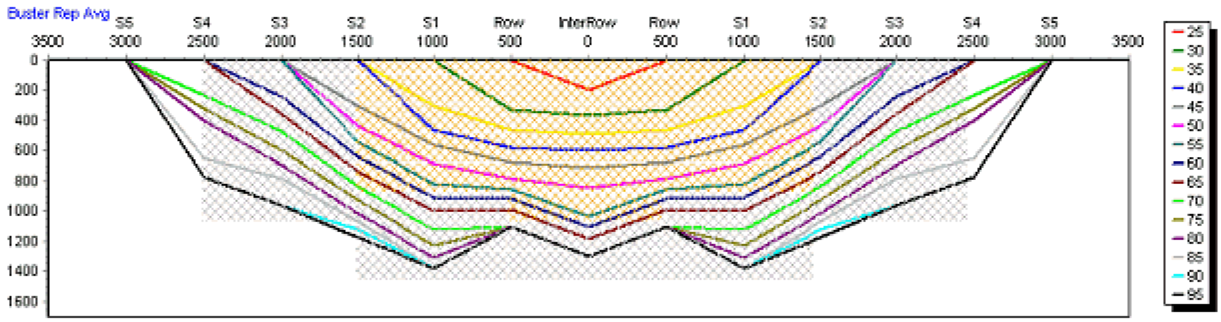

Figure 2. Limit of water extraction every 5 days through the crop cycle and root length density at maturity for hybrid Buster grown in twin wide rows. The coloured lines indicate the extent of water extraction measured at the associated days after sowing. The hatching indicates root length densities at maturity, either >0.1 (yellow) or <0.1 cm cm^{-3} (blue). Soil depth to decomposing rock was about 120cm. Data are average values over 3 replicates for hybrid 'Buster' in experiment 1.

In experiment 2, the spatial distribution of roots (Fig. 3; length data not yet available) and water use at maturity (Fig. 4) suggested there may be some differences in ability to extract water associated with root-shoot balance. The root chambers with the hybrid 'Buster' with tillers retained showed extensive root exploration and water extraction. The shallower soil depths at greatest distance from the plant appeared to have fewer fine roots (Fig. 3) and there was less water extraction from this area (Fig. 4). Observations for treatments with tillers removed (data not shown) suggested reduced exploration and water use, although final data analyses are yet to be undertaken. This likely reflects the enhanced demand for water associated with the tillering plant and its possibly larger root system. However, it also suggests that such manipulation provides a logical basis for balancing the genotype and management system adopted with the prevailing environment in a manner most suited to effective and reliable production. There may be opportunities to further advance this interaction by exploiting genetic variation in root-shoot dynamics and root system characteristics.

Figure 3. Composite image showing distribution of roots at maturity for sorghum hybrid 'Buster' grown with tillers in experiment 2. The root chamber was 240cm wide, 120cm deep and 10cm thick. The thick nodal roots converge at the position of the plant. Note that vertical and horizontal scales differ.

9	9	11	8	9	10	12	13	17	20	20	19
11	12	12	12	12	12	12	12	16	21	23	22
11	12	12	12	11	11	12	12	12	14	20	23
12	12	12	12	12	12	13	12	12	14	17	21
11	11	12	11	12	11	12	12	12	13	17	21
12	12	12	11	11	12	12	13	12	13	17	21

Figure 4. Volumetric soil water content for 20 x 20cm sections of soil taken at maturity averaged for the three root chambers from the treatment shown in Figure 3. The shading shows sections that were either completely dry (approx 12%; orange), at or below half full (approx 21%; yellow), or above half full (21-30%; blue-green).

Conclusion

The potential extent of root system exploration in skip row sorghum systems is beyond 2m from the planted rows using conventional hybrids. The extent of water extraction throughout this region depends on root length density and the balance between demand for, and supply of, water. The results to date suggest that simultaneous genetic and management manipulation might lead to more effective and reliable production in specific environments. Further study of variation in root-shoot dynamics and root system characteristics is required to exploit possible opportunities.

References

Butler, G., Cawthray, S., Castor, M.,Yeates, S. and Christian, T. (2001) Improving the reliability of sorghum production in the farming system. Proceedings of the 10th Australian Agronomy Conference, Hobart. Australian Society of Agronomy. www.regional.org.au/au/asa/2001/3/a/butler.htm

McLean, G., Whish, J., Routley, R.A., Broad, I. and Hammer, G.L. (2003) The effect of row configuration on yield reliability in grain sorghum. II. Modelling the effects of row configuration. Proceedings of the 11th Australian Agronomy Conference, Geelong. The Australian Society of Agronomy. www.regional.org.au/au/asa/2003/c/9/mclean.htm

Robertson, M.J., Fukai, F., Ludlow, M.M. and Hammer, G.L. (1993) Water extraction by grain sorghum in a sub-humid environment. I. Analysis of the water extraction pattern. Field Crops Research, 33:81-97.

Routley, R.A., Broad, I., McLean, G., Whish, J. and Hammer, G.L. (2003) The effect of row configuration on yield reliability in grain sorghum. I. Yield, water use efficiency and soil water extraction. Proceedings of the 11th Australian Agronomy Conference, Geelong. The Australian Society of Agronomy. www.regional.org.au/au/asa/2003/c/9/routley.htm