Root development of rice under flooded and aerobic conditions

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Abstract

To maximise grain yield of rice, water management in lowland systems traditionally aim to keep fields continuously flooded. However, water availability for rice production is being threatened in many regions of the world because of climate change and environmental concerns, population growth and increase in industry demand. To save water, aerobic rice production has been advocated as one potential alternative to the flooded irrigation system. This paper examines the root architecture of three genotypes (Lemont, Tachiminori, and PSBRc-9) grown in root chambers under flooded and aerobic conditions in a glasshouse experiment. No significant treatment difference existed in above ground plant (mean 3.25 g/plant) or root (mean 1.04 g/plant) dry weights. However, image analysis with WinRhizo revealed that plants grown under aerobic conditions produced significantly more total root length (830 cm) than those grown under flooded (398 cm) conditions. Aerobic grown plants had significantly greater branching (139 %) and root tips (322 %) than flooded (900 forks and 613 tips per plant) with the total surface area being greater in aerobic (135.3 cm^2) than flooded (75.1 cm^2) conditions. PSBRc-9 produced significantly greater above ground plant and root dry weights than Lemont and Tachiminori which behaved similarly. While total root length was not significantly different among genotypes, the branching, surface area and rooting depth from the crown were all significantly greater in PSBRc-9 than Lemont and Tachiminori. Provided adapted genetic material is utilised there appears to be no reduction in above ground growth under aerobic conditions. The reduction in water supply is possibly offset by the greater potential exploitation of the soil volume due to greater root development under aerobic conditions.

Introduction

The availability of water for agriculture particularly rice production in most parts of the world is becoming scarce (Gleick 1993). As rice is considered particularly susceptible to water deficit, conventional water management in lowland rice aims at keeping the fields continuously flooded to maximise grain yield (Fukai and Inthapan, 1988; Kondo et al 2000). Aerobic rice production is a relatively new water saving production system in which the rice is grown under non-flooded lowland conditions (Bouman et al 2002). In field trials on aerobic and flooded rice production systems, Kato et al. (2009) observed similar or higher grain yield under aerobic conditions. In a water use efficiency pot experiment, Nguyen et al. (2009) reported that different water systems (including aerobic rice) reduced water use by 28–16% compared to the continuously flooded system and improved water use efficiency by up to 20%.

Rice has a considerably compact and shallow root system compared with other crops (Yoshida and Hasegawa 1982; Angus et al., 1983). Variation in root development and architecture is critical in determining water and nutrient acquisition and the ability of rice to tolerate periods of water deficit. Root system architecture in rice is a function of adventitious root growth (from the base of the stem) and of lateral root branching on each adventitious root (Rebouillat et al., 2009). While upland-adapted cultivars tend to have deeper root systems than lowland-adapted cultivars (Chang and Vergara, 1975; Angus et al., 1983), many of the aerobic environments in which lines have been tested have been relatively severe water stress conditions. In this paper we examine variation in a number of root traits in response to flooded and aerobic conditions of three genotypes where the aerobic conditions are maintained at around field capacity and identify whether genotypic differences exist.

Materials and methods

A root chamber experiment was conducted in a glasshouse at the University of Queensland, Gatton in February 2010. One lowland (Lemont) and two upland (Tachiminori and PSBRc-9) rice varieties were utilised. Two water treatments, flooded and aerobic, were imposed on the root chambers, which all had small holes at the bottom to allow for water drainage/flow. The chambers were made with perspex plates fitted with screws on both sides. The root chambers, 60 cm high, 40 cm wide and 3 cm thick were filled with 10.8 kg of sandy loam air dry soil, which was mixed with 20 g Osmocote slow release fertilizer to each chamber. Once filled, the chambers were wrapped with black plastic sheets to prevent exposure of roots to light. The 42 root chambers, consisted of 7 replications, 3 genotypes and two water treatments were all placed upright inside a tub measuring 30 cm high and 45 cm wide (six chambers per tub) in a randomised complete block design.

For the aerobic treatment (21 chambers), the chambers were placed inside the tubs which were filled with water to a height of 25 cm, thus maintaining a constant water table at 30cm below the soil surface. The root chambers were watered to field capacity before sowing, and on a few occasions after sowing to ensure that all soil was well watered. For the flooded treatment (21 chambers) the tubs were immersed in water by placing them inside a large water tank measuring 100 cm high and 90 cm wide, water was maintained at a height 4 cm above the soil surface of the chambers for the duration of the experiment. Four seeds were planted in each chamber. The seedlings were thinned to one plant in each chamber when they were 6 days old. Treatment started 8 days after sowing (DAS). All chambers were harvested 41 DAS. The total dry matter (TDM) was determined at the end of experiment at 33 days after treatment imposed. At harvest, the plant was cut at the base of the stem and samples were oven dried at 65 °C for 4 days and weighed to determine the above ground dry matter (AGDM). After harvesting above ground biomass, each chamber was laid flat, unscrewed and the top perspex plate removed. A pinboard with dimensions similar to the chamber was placed on top of the exposed soil. The pinboard consisted of 3 cm long nails, positioned in a 3×3 cm grid on a plywood base that was painted black (Singh et al. 2010). The pinboard was pushed into the soil block and the soil with root system was upturned ensuring that the root system architecture was undisturbed. The soil was then washed from the pinboard using a low pressure water spray to minimise disturbance and the intact washed root system was imaged with a digital camera mounted on a tripod. The images were converted to high-contrast black and white images using Adobe Photoshop Version 10 software. Various root measurements on the images were made using WinRHIZO Pro V2007a (Regent Instruments Inc.) software. Using a ruler, the rooting depth from the crown and also the spread or width of root at 9cm depth was measured. The root material was placed in a separate bag after photographing and root dry matter (RDM) determined after oven drying.

Results and Discussion

For most traits there was no significant interaction effect and consequently only main effects of water supply treatments and genotype effect were presented here.

Effect of aerobic and flooded water supply

There was no effect of reducing water supply from flooded to aerobic conditions on the above-ground dry matter, root dry matter and consequently total dry matter producing an average of 3.25, 1.04, and 4.28 g/plant respectively (Table 1a). However, there were significant treatment differences in many root traits. The length of the roots under the aerobic (830 cm/plant) treatment was significantly longer than that produced under the flooded (398 cm/plant) and this equated to a 133% greater root length density in the aerobic treatment compared to flooded (0.14 vs 0.06 cm/cm^3).

The surface area of roots produced under the aerobic (135 cm^2) treatment was 80% greater than that produced under the flooded (75 cm^2) treatment. There was significantly greater branching under aerobic treatment as indicated by the 139% greater number of root forks. While average root diameter was not different, there were significantly more fine roots with 2589 root tips produced under aerobic treatment compared to that produced under the flooded (613) treatment. The specific root length under aerobic conditions (929 cm/ g) was double that of flooded (456 cm/g) conditions. While not measured here arenchyma development in the flooded treatment is likely to have contributed to differences in root morphology including root diameter, and this may explain similar root biomass.

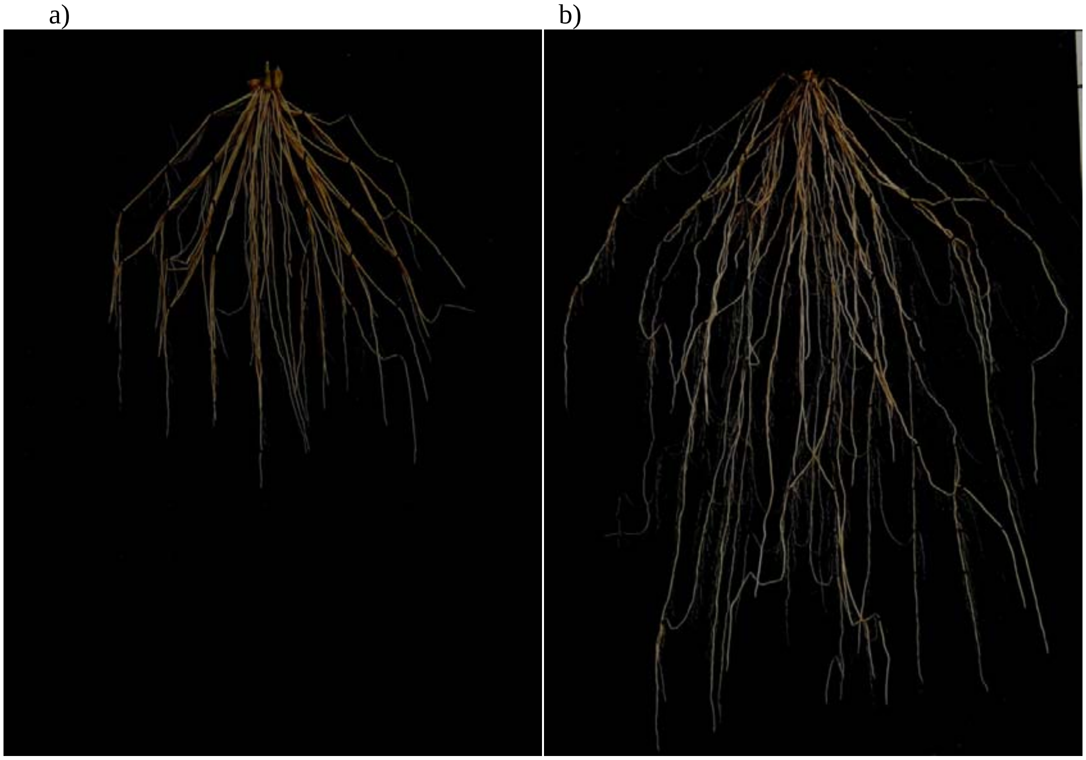
The depth of the roots from the crowns to the tips of the root produced under the aerobic (42 cm) treatment were significantly longer than that under the flooded (23 cm) treatment and the horizontal distribution (rooting width at 9cm depth) was 18% wider for the aerobic compared to the flooded (22.5 vs 19.1 cm) treatment (Plate 1). In general, the rooting depth of a variety is deepest when it is grown under aerobic conditions and the shallowest under submerged conditions (Yoshida and Hasegawa 1982) .Under flooded (anaerobic) conditions, rice tends to develop shallow root systems with enhanced aerenchyma which provides less resistance for internal atmospheric O_2 diffusion to the root tips (Suralta and Yamauchi 2008; Colmer 2003).

Table 1. The effect of a) aerobic or flooded water supply and b) genotypic differences (and their means and least significant differences (LSD)) for above ground dry matter (AGDM, g/plant); root dry matter (RDM, g/plant); total dry matter (TDM, g/plant) and various root measurements determined from WinRhizo including: root length (cm/plant); average root diameter (mm); number of forks per plant; root length density (cm/m^3); projected root area (cm^2); root volume (cm^3); root surface area (cm^2); number of root tips; root depth from crown (cm); root width at 9 cm depth from soil surface (cm); and the specific root length (cm/ g), for three rice genotypes grown in root chambers.

	a) water supply				b) genotypic differences			
Trait	Aerobic	Flooded	Mean	LSD	Lemont	PSBRc9	Tachiminori	LSD
AGDM (g/plant)	3.3	3.19	3.25	ns	2.92	3.85	2.97	0.733
RDM (g/plant)	0.961	1.109	1.035	ns	0.889	1.329	0.888	0.395
TDM (g/plant)	4.26	4.3	4.28	ns	3.81	5.18	3.86	1.055
Root length (cm/plant)	830	398	614**	141.5	586	716	541	ns
Root diameter (mm)	0.542	0.589	0.57	ns	0.529	0.604	0.563	ns
Number of forks per plant	2149	900	1525**	724.5	1083	2193	1298	887.3
Root length density (cm/m^3)	0.141	0.063	0.098**	0.022	0.093	0.114	0.086	ns
Projected area (cm^2)	43.1	23.9	33.5**	7.47	29.3	41.5	29.7	9.15
Root volume (cm^3)	1.88	1.16	1.52**	0.501	1.26	1.98	1.33	0.614
Surface area (cm^2)	135.3	75.1	105.2**	23.47	92.1	130.4	93.2	28.74
Number of root tips per plant	2589	613	1601**	616.4	1644	1757	1403	ns
Root depth from crown (cm)	42.43	23.57	33**	1.997	31.93	38.46	28.61	2.446
Root width at 9 cm depth (cm)	22.52	19.14	20.83*	2.541	20.36	23.25	18.89	3.112
Specific root length (cm/ g)	929	456	692**	194.8	734	665	678	ns

Plate 1: Root morphology of Lemont grown under a) flooded and b) around field capacity aerobic conditions

a) b)



Genotype response

Genotype differences in above-ground dry matter and root dry matter were significant with PSBRc-9 producing the highest above-ground dry matter and root dry matter (3.85 g/plant and 1.33 g/plant) compared to Lemont and Tachiminori (respectively 2.92-2.97g AGDM/plant and 0.888-0.889g RDM/plant; Table 1b). Genotype differences in root length density were not significant although PSBRc-9 (0.114 cm/cm^3) tended to produce greater root length density compared to Lemont (0.09 cm/cm^3) and Tachiminori (0.08 cm/cm^3). However, roots produced by PSBRc-9 (130 cm^2) had significantly greater surface area compared to Lemont (92 cm^2) and Tachiminori (93 cm^2). The rooting depth (38.5 cm) and width (23.3 cm) for PSBRc-9 was also 20-35 % and 14 -23% greater than that produced by Lemont and Tachiminori.

Conclusion

When water conditions in the aerobic system were maintained around field capacity there was no difference in above or below ground biomass production between rice growing under aerobic or flooded conditions. Furthermore, total root length and surface area was respectively 139 and 80 % greater under aerobic conditions with specific root length doubled. Genotypic differences existed with PSBRc-9 producing significantly greater above ground plant and root dry weights than Lemont and Tachiminori which behaved similarly. While total root length was not significantly different among genotypes, the branching, surface area and rooting depth from the crown were all significantly greater in PSBRc-9 than Lemont and Tachiminori. Provided adapted genetic material is utilised there appears to be no reduction in above ground growth under aerobic conditions. The reduction in water supply is possibly offset by the greater potential exploitation of the soil volume due to greater root development under aerobic conditions with high levels of water supply.

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