Traits of importance for aerobic rice

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Abstract
Irrigation water is limited and costly and for the Australian Rice Industry based in the Riverina, this has become a major limitation to production. Aerobic production (well-watered, non-flooded) has been proposed to improve water productivity. However, historically in Australia, varieties have been developed for continuously flooded growing conditions and as such the appropriateness of the germplasm to aerobic adaptation needs to be explored. Deeper rooting is one trait that is believed to be associated with improved aerobic performance by ensuring plants are less susceptible to fluctuations in water availability in the top 20 cm of the soil profile. Two field experiments evaluating 20 genotypes were conducted to examine genetic variation and relationships between root traits and grain yield. Two methods for root trait observations were conducted. A basket method was utilised for 15 genotypes in one experiment, while soil cores at maturity were collected from all plots in both experiments. Highly significant ($p<0.01$) genetic variation existed for grain yield and root traits in both experiments and the expression of traits were consistent between experiments (r_g = >0.90). Grain yield had a highly significant genetic correlation (r_g= 0.56**) with the percentage of roots below 20 cm at maturity which demonstrated the advantage of a deeper root system in aerobic conditions. Several lines, most notably Australian variety Sherpa, demonstrated high yields in aerobic conditions but only moderate expression of deep roots. These results suggest the incorporation of deep rooting characteristics into high yield potential backgrounds (e.g. Sherpa) has the potential to close the yield gap between aerobic and traditional flooded production.

Key Words
Aerobic rice, yield, deep roots, root angle.

Introduction
Water availability is the largest constraint to the Australian Rice Industry based in the Riverina, and there is an ever increasing need to improve water productivity to stay commercially competitive. Aerobic rice (non-flooded, well-irrigated) has been proposed to improve water productivity and with the appropriate development of adapted genotypes and management practices, the yield may approach that of flooded production methods (Kato 2009). A perceived limitation of commercial varieties in Australia, and globally, to aerobic production conditions are their shallow root systems with as much as 80% of the roots occurring in the top 20 cm of the soil. Thus, current varieties are particularly susceptible to fluctuations in water availability in the surface soil. Research on the relationship between rooting traits and grain yield has been extensively examined under severe water stress but has been limited to just a few genotypes in the comparatively higher moisture conditions under aerobic conditions. In this paper we examined the genetic variation and relationships among roots traits and grain yield in 20 diverse genotypes relevant to the Australian breeding program in two irrigated aerobic experiments.

Methods
Two experiments were conducted side by side at the University of Queensland, Gatton, Australia in 2017/18. Each consisted of the same 20 genotypes with one experiment being irrigated with 24mm thrice weekly (Control; Monday, Wednesday and Friday), and the other 24mm twice weekly (intermittent water stress (IWS); Monday and Friday; Table 1). Both experiments were arranged in a randomized complete block design with 3 and 4 replications for the control and IWS, respectively. The plots were sown with single row hand planter (Earthway 1001-B) on the 29 November 2017 and consisted of 6 rows at a spacing of 0.2m and were 2m in length.

To examine root traits at heading, the basket method described by Kato (2006) was used for 15 genotypes in the control experiment only. A 2mm mesh basket (diameter 13cm, height 6cm) was filled with soil and buried within a plot and planted with three seeds, which were later thinned to one.

Cultural Details

Prior to the experiments, an oat cover crop was grown and incorporated into the soil 2 months prior to sowing. A basal fertilizer application of 600 kg/ha of Nitrophoska® (12%N, 5.2%P, 14.1%K, Incitec Pivot) occurred before the last cultivation. Additional applications of Urea at the rate 80kg/ha were applied at 33 and 60 days after sowing (DAS). The experiments were treated with pre and post-emergent herbicide to ensure weed control.

Measurements and Analysis

The ECH$_2$O EC-5 (Decagon Devices) with a SMM1 Soil Moisture Meter (ICT International) were used to quantify volumetric water content at 10 and 20cm in the IWS experiment. The date on which 50% of a plot had reached heading was recorded. At heading, the baskets were extracted and the soil surrounding the basket was carefully washed. The number of roots that penetrated the basket were counted, and were classed as shallow if root penetration between 0-50° and 140-180° angle, and deep if between 50-140°. The deep root ratio was calculated as the ratio of the number of root classed as deep to shallow. At maturity, 0.8m^2 quadrat cut was taken to estimate grain yield, samples were dried at 35°C before being threshed and weighed.

After all plots were harvested, a 1m soil core (50mm diameter) was extracted from each plot and divided into 0.1m increments. Each 0.1m core was broken in half and the number of roots exposed on each broken surface was determined to estimate roots/cm^2 (core-break counts, CBC). CBCs have previously been demonstrated to be directly proportional to root length densities but its relationship is dependent on soil type (Drew and Saker 1980). The percentage of roots below 20 cm was calculated as the sum of CBCs below 20cm to the total sum of CBCs.

A multiplicative mixed linear model was implemented in AsReml-R (V4.3, VSNi) in the R environment (V3.4.4; R Core Team, https://www.R-project.org/) for the analysis. The best spatial model was fitted for each trait within experiments where genotype was treated as a random effect (Gilmour 1997). Best linear unbiased predictors (BLUPs) were obtained from the model, and generalised heritability was estimated from its variance parameters. Genetic correlations between traits within each experiment were estimated using the variance parameters from separate bivariate models; unless stated otherwise correlations refer to genetic correlations.

Results and Discussion

Grain Yield

No significant difference in grain yield occurred between the control and the intermittent water stress treatment with a mean yield of 5.27 and 5.61 t/ha, respectively (Table 1). This was largely due to 260 mm of rainfall occurring during the reproductive period. Grain yield had high heritability in both the control (0.91) and IWS (0.80). Strong congruency in genotypic performance across both experiments was observed with a genetic correlation of 0.99. Averaged across experiments, Yunlu 52, Sherpa, Lemont, VA37 and IRAT109 (7.0-8.1 t/ha) achieved the highest predicted yield, while KKN9-229 (2.7 t/ha) and Lijiangheigu (3.3 t/ha) the lowest.

Root Traits

The penetrated root number (RN) and deep root ratio (DRR) at heading using the basket method was highly repeatable for the 15 genotypes with a heritability of 0.91 and 0.94, respectively. The two traits had a strong correlation to each other (r_g=0.85**), and days to heading (r_g= 0.67*-0.68*). IRAT109, Reiziq, Yunlu29 and Apo, (DRR 0.47-0.57, RN 43-52 /plant) had the largest deep root ratio and were amongst the highest predicted values for total root number penetrating the basket, while Takanari, UPLRi7, and M205 (DRR 0.23-0.24, RN 10-17 /plant,) were amongst the lowest. There were several genotypes showing some inconsistency in the correlation between the two traits with Sherpa (RN 40 /plant, DRR 0.35) demonstrating a relatively high root number but moderate deep root ratio, while RL11 (RN 16 /plant, DRR 0.43) showed a high deep root ratio but low root number.

IWS had a 14% reduction in the percentage of roots below 20 cm in comparison to the control (42%). Similar to grain yield, there was strong congruency between the two experiments (r_g= 0.99**) in the percentage of roots below 20 cm. Lemont, 2171, RT37A and IRAT109 (47-51%), had the greatest percentage of roots below 20 cm, while Lijiangheigu, Takanari, RL11 and M205 (28-33%) had the lowest predicted values. Australian variety Sherpa had a moderate proportion of roots below 20cm at 39%. A significant genetic correlation existed between the percentage of roots below 20cm, with deep root ratio (r_g=0.58*) and penetrated root number (r_g=0.47*) via the basket method at heading.

Table 1: BLUPs for deep root ratio (DRR) and penetrated root number (RN, /plant) using the basket method for 15 genotypes in the irrigated control, and predicted mean grain yield (GY, t/ha) and percentage of roots below 20cm (DR%, %) for 20 genotypes averaged across control and intermittent water stress (IWS) experiments.

		Heading		Maturity	
Genotype	Origin	DRR	RN	GY	DR%
Apo	Philippines	0.47	51	4.37	37
Doongara	Australia	0.25	29	6.01	38
IR64	Philippines	0.27	21	5.08	33
IRAT109	Côte d'Ivoire	0.57	52	6.97	47
KKN 9-229	Australia	0.31	14	2.68	42
Lemont	USA	0.40	48	7.78	51
Lijiangheigu	China	0.30	11	3.28	28
M205	USA	0.24	10	6.33	33
Reiziq	Australia	0.52	47	5.65	37
RL11	Australia	0.43	16	4.61	31
Sherpa	Australia	0.35	40	7.87	37
Tachiminori	Japan	0.28	24	5.93	39
Takanari	Japan	0.23	17	4.58	31
UPLRi7	Philippines	0.24	17	4.63	40
Yunlu29	China	0.51	43	3.61	34
2171	Australia	-	-	6.12	48
RT37A	Australia	-	-	5.13	48
YRL39	Australia	-	-	5.17	39
VA37	Australia	-	-	7.75	39
Yunlu52	China	-	-	8.13	40
Mean	Control	0.36	29	5.27	42
	IWS	-	-	5.61	36
H^2	Control	0.94	0.91	0.91	0.69
	IWS	-	-	0.80	0.32
5% LSD		0.15	17	1.86	14

Relationship between Maturity Root Traits and Grain Yield

The percentage of roots below 20cm had a highly significant association with yield averaged across experiments (r_g=0.56**; Figure 1b). These findings suggest that deeper rooting is advantageous in maintaining higher grain yield in aerobic conditions. The deep rooting genotypes are likely able to achieve higher yield as genotypes are able to access water at depth reducing the effect of fluctuations in water availability particularly in the top 10 cm of soil (Figure 1a). The fraction of plant available water (FPAW) fell below 0.7, 1 or 2 days after irrigation in the top 10cm, while it remained above 0.7 at 20 cm. Plant growth starts to decrease when the FPAW falls below a threshold of 0.7 in rice (Lilley & Fukai 1994).

There were exceptions such as Sherpa and VA37 which had the highest predicted grain yield in both experiments but only moderate percentage of roots below 20cm. The grain yield of Sherpa and VA37 could potentially be increased further with the introgression of deep rooting traits. While soil coring is potentially possible for screening root traits, it is relatively labour intensive, the development of more efficient screening methods would be advantageous. The genetic correlations with root traits at heading suggest the percentage of roots below 20cm could be increased by both increasing root number per plant and the deep root ratio/ root angle with IRAT109 considered the most appropriate donor for these two traits.

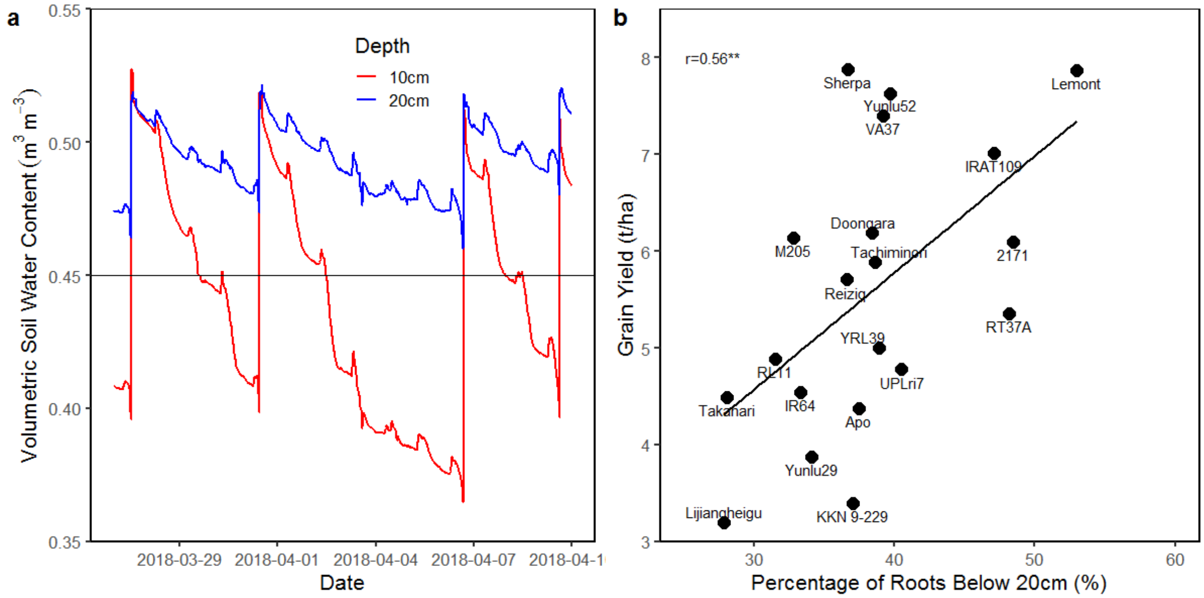

Figure 1: The (a) fluctuations in volumetric water content at 10 and 20cm depths over a 15 day period in the IWS experiment with the horizontal line (0.45 m^3 m^{-3}) equivalent to 0.70 FPAW, and (b) the mean genetic relationship between the percentage of roots below 20cm and grain yield (t/ha) averaged across control and intermittent water stress aerobic experiments.

Conclusion

There was a distinct advantage in having a deep root system in a genotypes ability to achieve high yield in two aerobic experiments conducted at Gatton, Queensland. A deeper root system allowed greater access to available water, and these genotypes were less likely affected by fluctuations in water availability in the top 20cm of soil. Yunlu52, IRAT109, Lemont, Sherpa, and VA37 were amongst the highest yielding genotypes in both experiments. Sherpa and VA37 only had moderate expression of deep roots, but relatively high RN, whereas the likes of IRAT109 and Lemont had highest proportion of roots below 20cm. The results herein suggest that the indirect selection for a larger percentage of roots below 20cm could be achieved by simultaneously selecting for a higher deep root ratio and root number. There appears to be opportunity to improve the yield under aerobic conditions if donor genotypes with deep rooting can be combined with high yield potential genotypes.

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References

Drew MC and Saker LR (1980). Assessment of a rapid method, using soil cores, for estimating the amount and distribution of crop roots in the field. Plant and Soil 55**,** 297-305.

Gilmour AR, Cullis BR and Verbyla AP (1997). Accounting for natural and extraneous variation in the analysis of field experiments. Journal of Agricultural, Biological & Environmental Statistics 2**,** 269-293.

Kato Y, Abe J, Kamoshita A and Yamagishi J (2006). Genotypic variation in root growth angle in rice (*Oryza sativa* L.) and its association with deep root development in upland fields with different water regimes. Plant and Soil 287**,** 117-129.

Kato Y, Okami M and Katsura K (2009). Yield potential and water use efficiency of aerobic rice (*Oryza sativa* L.) in Japan. Field Crops Research 113**,** 328-334.

Lilley J and Fukai S (1994). Effect of timing and severity of water deficit on four diverse rice cultivars II. Physiological responses to soil water deficit. Field Crops Research 37**,** 215-223.