Influence of water stress on leaf death among rice lines: comparison between glasshouse and field

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Summary. The ability of different rice lines to maintain green leaves under water stress was examined at two different growth stages in the field and in the glasshouse. Lines behaved differently for leaf death under stress between the field and the glasshouse experiments, and also between young seedling and later stages of growth. In the glasshouse, lines which used water slowly tended to maintain more green leaf area, but this was not always the case in the field. Whilst high leaf death was generally associated with low leaf water potential, there was some genotypic variation in this association.

Introduction

Rice grown in rainfed fields may be subjected to water stress at any time during the growth season. The ability to maintain green leaf area throughout water stress enables the plant to recover quickly when stress is relieved. It is a common practice amongst breeders to screen rice seedlings for their ability to maintain green leaves during water stress in the field (3). The objectives of these studies were to investigate (i) whether genotypic differences in the ability to maintain green leaves during drought is the same at different growth stages, (ii) whether screening in the glasshouse and the field give similar results, and (iii) factors that may contribute to genotypic differences in the rate of leaf death during water deficit.

Materials and methods

Two glasshouse experiments (Glasshouse I and 2) and one field experiment were conducted. In the Glasshouse I and Field experiment, 22 lines were selected on the basis of their diverse origin, whereas in Glasshouse 2 a subset of 12 lines was used.

Glasshouse I

The 22 lines were grown in pots with four replications. Two stress periods were, early stress commenced 38 days after sowing (DAS - 12 days duration), and late stress commenced 64 DAS (3 days duration). The following measurements were made: (i) Drought score (DS), a measure of leaf death, was recorded at the end of each stress period using a scale of 0-9; 0... no leaf death, 5 ... 50% of all leaves fully dried, 9 ... all plants apparently dead (2), (ii) Leaf rolling score (LRS) was recorded at the end of each stress period using a scale of 1-5; I ... no rolling, 5 ... leaves fully rolled (5), (iii) Leaf water potential (LWP) was determined using a pressure chamber in the early afternoon of day 5 in the late stress, (iv) Leaf area (LA) was determined by measuring the length and width of each leaf one day before imposing early stress, (v) Plant water use (WU) was determined by weighing pots at the beginning and the end of each stress period.

Glasshouse 2

Twelve lines were grown at four plant densities, I, 2, 4 and 6 plants per pot. There were four replications. The stress period commenced 30 DAS, and measurements were made over a period of 25 days for I and 2 plants per pot and for 20 days for 4 and 6 plants per pot. Characters measured in Glasshouse I were also measured in a similar manner in this experiment, except that LWP was determined prior to dawn.

Field

This experiment was conducted at Redland Bay, 45 km south-east of Brisbane. There were three replications. Early stress was imposed 28 DAS and continued for 27 days. Stress was imposed using a rainout shelter which covered the experimental area when rain fell. After the plants had recovered fully from the stress, which was achieved using frequent irrigation for a week, they were allowed to grow under rainfed conditions, and late stress developed around 90 DAS. During the early stress period DS, LRS and LWP were determined as for Glasshouse 2. Light interception was measured by using a I m long quantum line sensor on day 6 of stress. Water use was determined by measuring soil water content at the beginning and the end of the stress period. Stomatal conductance was determined near noon on days 4 and 10 of stress. Osmotic potential of young leaves was determined by taking leaf samples at predawn just before the commencement of the stress period and on days 16 and 29 of stress. Osmotic adjustment was calculated as the difference in osmotic potential corrected for relative water content. In the late stress, only DS was determined.

Results

Glasshouse I

Stress developed rapidly, particularly in the late stress and mean DS of 5.1 and 5.3 were obtained by 12 and 7 days after the stress was imposed in early and late stress periods. respectively (Table I). On both occasions there was significant genotypic variation in DS. While some lines such as Leb Mue Nahng III. RDI9 and RDI had high DS and others such as Ceysvoni had low DS in both stress periods, there was no significant correlation (r = 0.41) in DS between the two periods. In both stress periods DS was significantly correlated with LRS (r = 0.65* and r = 0.79* late and early stress, respectively). In early stress DS was also significantly correlated with leaf area (r = 0.49*) and water use (r = 0.51*), indicating that lines which had high leaf area tended to use water faster, and stress developed more rapidly with a resultant high DS. On the other hand there was no significant correlation between DS and water use (r = 0.20) in late stress when the plants were larger and water stress developed rapidly for all genotypes. Drought score was however significantly correlated with LWP (r = -0.59*). lines with more negative LWP having greater leaf death in the late stress.

Glasshouse 2

Development of water stress symptoms was generally slower in this experiment than in Glasshouse I. As plant number per pot increased, water was used at a greater rate and plants exhibited more rapid leaf death. For example mean DS across different lines varied from 6.0 to 0.2 at 15 days after stress among different plant densities. For each genotype DS on day 15 of stress increased approximately linearly with the increase in leaf area. However there was large genotypic variation in DS for a given leaf area. Despite having similar leaf areas at the beginning of the stress period, Lemont, Myliang 23, and Moroberekan differed greatly in their DS (2.0, 4.5 and 8.0 respectively - all 6 plants per pot) (see Table I). During the stress period DS increased and LWP decreased with time for all lines. For the 6 plants/pot treatment. in which LWP was measured twice when stress was severe, the correlation coefficient between DS and LWP for all lines combined was -0.89. Thus lines with large DS tended to have lower LWP (e.g. Rikuto Norin 12, Hatamegumi), and those with small DS had high LWP (e.g. Lemont, IRGA 409). Exceptions were DPI 99295 which had a high DS (7.0) despite a high LWP and BK88 BR6 which had a small DS (3.3) despite a low LWP.

Field

In this experiment DS of 1-3 were recorded by day 8, but increases thereafter to day 27 were rather slow (DS ranged from 2.3 to 6.7 at day 27). This slow increase in DS was associated with slow decrease in LWP. The DS observed at day 27 was generally smaller than those recorded in the glasshouse experiments (Table 1). While Rikuto Norin 12 had consistently high DS and Ceysvoni, Lemont and Myliang 23 consistently low DS in all experiments. there was no significant correlation between DS obtained in the field and in the glasshouse. Similarly the correlation coefficient between DS in early stress and late stress in the field was low (r = 0.33). The poor correlation was caused by rather high DS in late stress period for five lines which also flowered rather late. Genotypic differences in DS in early stress were associated with differences in LRS, but not with stomata! conductance, water use or light interception. Similar to Glasshouse 2, DS was generally associated with LWP. and BK88 BR6 had a small DS (2.7) despite a low LWP. DPI99295, Rikuto Norin 12 and IRGA 409 had higher DS than expected from the values of LWP. A multiple regression of DS with LWP and osmotic adjustment showed that osmotic adjustment had a significant effect in reducing DS.

Discussion

As leaf death and hence DS are water-stress induced characters, lines which were severely stressed had high DS. In the glasshouse experiments, lines with high leaf area or treatments with a larger number of plants per pot exhibited higher DS. When rooting volume is confined by pot size. rapid water extraction would induce rapid development of water stress and hence high DS. Thus in the glasshouse an avoidance mechanism to reduce water use, such as a small leaf area, would contribute to a low DS.

In the field study, however. DS was not associated with either plant size, as measured by light interception, or water use. These results suggest that avoidance mechanisms identified in the glasshouse study may not always contribute to a lower DS in the field when stress develops during seedling stages. Under upland conditions rice roots descend rapidly and water extraction takes place in the lower soil layers (I) which would have contributed to the slow development of water stress in the field. Lines with rapid water use did not always have increased leaf death, as more water was available at depth. In addition, the slow development of stress meant that osmotic adjustment was fully expressed, and lines with high osmotic adjustment were able to maintain more green leaves. However the situation appeared to be different at later stages when full ground cover was obtained and roots were fully developed. For these larger plants transpiration would have been high and available soil water would have been exhausted more quickly. These differences are likely to be contributed to the differential DS response of genotypes between field and glasshouse. and between early and late stress in the field. During the rainy season when field screening for drought resistance is not possible. the use of glasshouse has been suggested (4). However, these results indicate some of the difficulties in using DS obtained in the glasshouse to select for drought resistance under field conditions. Similarly DS obtained during the seedling stage does not appear to be a good indicator of leaf death in later stages.

Table I. Drought scores measured on five occasions in one field and two glasshouse experiments. Drought scores in Glasshouse 2 are from the 6 plants per pot treatment

Lines	Drought score					
	Origin	Glasshouse 1		Glasshouse 2	Field	
		Early Stress	Late Stress		Early Stress	Late Stress
Tsukuba-Hatamochi	Japan	6.3	6.3	7.5	2.7	1.7
Hatamegumi	Japan	6.3	1.0	7.5	5.3	2.3
Rikuto Norin 12	Japan	7.0	-	8.8	5.3	3.7
Todoroki-Wase	Japan	4.0	5.8	7.0	3.0	1.3
Myliang 23	Korea	1.8	3.8	4.5	3.0	1.3
Bluebelle	USA	4.5	4.8	-	3.7	2.3
Lemont	USA	4.0	4.0	2.0	2.7	1.7
Ceysvoni	Surinam	1.5	2.3	-	3.0	1.0
IR19746-28-22	Philippines	5.5	-	-	3.7	3.7
CPIC 8	Cuba	-	8.3	-	4.3	3.3
IRGA 409	Brazil	5.5	6.0	3.8	5.0	4.0
Labelle	USA	1.0	4.3	-	4.3	3.0
BK88 BR6	Thailand	7.3	4.3	3.3	2.7	4.3
Leb Mue Nahng 111	Thailand	7.0	8.3	-	3.3	3.7
Moroberekan	Senegal	5.0	3.0	8.0	2.3	3.7
63-83	Africa	4.3	3.0	-	3.3	3.7
Khao Dawk Mali 105	Thailand	5.3	7.0	-	3.0	4.3
RD19	Thailand	7.3	7.3	-	3.0	4.3
RD1	Thailand	9.0	9.0	7.3	2.3	1.3
RD9	Thailand	3.5	7.0	-	3.3	3.3
DPI 99295	Australia	2.8	7.0	7.0	6.7	4.0
DPI 99332	Australia	0.8	4.5	-	4.0	3.7
DPI 99440	Australia	4.8	4.5	5.5	4.0	3.3
Mean		5.1	5.3	6.0	3.7	3.0
l.s.d. ($P = 0.05$)		4.0	2.8	2.8	1.9	0.4

Both field and glasshouse studies indicated that, in general, genotypic variation in DS is related to variation in LWP. Thus, avoidance mechanisms to maintain high LWP would be useful for slow development of leaf death. The lines, Ceysvoni, Lemont and Myliang 23 consistently had high LWP and low DS and it would be useful to study them further in order to investigate why they arc able to maintain high LWP. However, there were also some genotypic differences in the response of DS to LWP which may mean that some lines can tolerate internal water deficit better than others. For example, BK88 BR6 was identified to possess such a character and it also had the highest osmotic adjustment in the field experiment. The use of any of these lines in a breeding programme may enhance drought resistance in rice.

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