Journal of the Arkansas Academy of Science

Volume 44 Article 25

1990

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SCREENING RICE (*ORYZA SATIVA* L.) GENOTYPES FOR DROUGHT TOLERANCE UNDER FIELD CONDITIONS

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ABSTRACT

We evaluated the root pulling resistance (RPR) technique developed at the International Rice Research Institute (IRRI) for transplanted rice (*Oryza sativa* L.) to determine its applicability for assessing the drought tolerance of direct seeded rice. Experiments were conducted in 1988 and 1989 at the University of Arkansas at Pine Bluff Agricultural Research Farm. Fifty genotypes from four countries were grown with and without irrigation. The genotypes identified as drought tolerant germplasm by the RPR method in both years were significantly correlated. In both 1988 and 1989, RPR was directly related to maximum root length, root number, and root dry weight. Root dry weight (RWT) had the highest correlation with RPR in both 1988 ($r = 0.82^{**}$) and 1989 ($r = 0.46^{**}$). Cultivars with the greatest root lengths and root dry weights had the highest root pulling resistances.

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food for the majority of the world. Rice consumption in the U.S.A. increased from 2.5 million tons in 1980 to 3.6 million tons in 1989. The U.S. rice crop is flood irrigated and supplies about 19% of the world rice trade (USDA, 1989).

Arkansas is the leading rice producing state in the U.S. with about 42% of the total production in 1989 (Arkansas Agricultural Statistics Service, 1990). All Arkansas rice is grown under irrigated conditions. Approximately 70 to 90 ha-cm of irrigation water is required for rice during the growing season (Arkansas Cooperative Extension Service, 1982). Underground water levels are dropping in some irrigated regions, and salinity, alkalinity, sodicity, and Zn-deficiency are likely to occur in some areas, posing a threat to crop production (Gilmour, 1989). Two actions to help alleviate the problem are to reduce the use of irrigation water by developing rice germplasm with increased water-use efficiency and to make better use of surface (runoff) water. Arkansas rice growing areas receive about 50 to 60 cm of rainfall during the growing season (April through October). A drought tolerant cultivar or one with increased water-use efficiency would reduce the need for water.

Rice is grown under a wide range of conditions throughout the world. A broad spectrum of cultivars and land races with varying degrees of adaptation to water stress are present within currently available rice germplasm. Drought tolerance in rice can minimize the high irrigation requirements and contribute to water use efficiency. Rice plants avoid water stress, to a great extent, by developing more extensive and deeper root systems, which can be measured by root pulling resistance (RPR).

Research at the International Rice Research Institute (IRRI) demonstrated that a highly developed root system was the most important mechanism needed to maintain an adequate flow of water to the canopy during extended dry periods (Steponkus *et al.*, 1980). Greater root depth and density of rice plants resulted in more available water and nutrients during periods of drought, and these plants maintain a more uniform transpiration rate (O'Toole, 1982).

The amount of vertical force required to uproot a rice plant is known as root pulling resistance (RPR) (O'Toole and Soemartono,1981). RPR is positively correlated with root length density (RLD) which is the development of a root system in the deeper soil profile (Ekanayake *et al.*, 1986). The RPR technique was used at IRRI to screen rice genotypes under transplanted conditions. Data are not available on this technique for direct seeded rice. Experiments were conducted in 1988 and 1989 to evaluate RPR and its applicability as a screening tool to evaluate rice germplasm for drought tolerance under dry seeded conditions.

MATERIALS AND METHODS

Experiments were conducted in 1988 and 1989 at the University of Arkansas at Pine Bluff Agricultural Experiment Station. Fifty genotypes that originated in 4 countries (Pakistan, Philippines, India, and U.S.A.) were grown on Calloway silt loam soil with two water treatments described below. Three seeds per hill were seeded in 2 rows of 10 hills each. Hills were spaced 40 cm apart so that, when a plant was pulled for RPR measurement, the next plant remains undisturbed. The tests were seeded June 3 in 1988 and June 1 in 1989. Between 5 and 7 days after emergence the seedlings were thinned to 1 plant per hill. Experiments were conducted in a randomized complete block (RCB) design with a split-plot arrangement. In each of 4 blocks (replications), genotypes as subplots were randomized within an irrigation treatment as a mainplot. Rice was flooded 2 weeks after emergence. Between 5 and 10 cm of water was maintained in the irrigated plots throughout the season while rainwater was immediately drained from the non-irrigated plots. The tests received 33 and 53 cm of rainfall in 1988 and 1989, respectively. Normal rainfall for this period is about 49 cm (Arkansas Agricultural Statistics Service, 1989).

Nitrogen (Urea) was applied in 3 splits; the first was a preflood application of 56 Kg N/ha, and that application was followed by 29 Kg N/ha at 30 days and another 29 Kg N/ha at 45 days after seeding in 1988. The third split of N was not applied in 1989.

Data were collected on maximum root length (RL), total root number (RN), root dry weight (RWT), and RPR measurements. Data on shoot components consisted of plant height (PHT), days to 50% heading (DH), and grain yield and were measured in 1989 only.

The RPR measurements were taken only from the irrigated plots at 30 and 35 days after emergence in 1988 and 1989, respectively. RPR and pulled root components were measured as described by O'Toole and Soemartono (1981) and Ekanayake *et al.* (1986). The rice plant was held at the base (ground level) by a clamp attached to a spring balance and was pulled vertically. The force required to uproot the plant was measured by a spring loaded scale and recorded in kilograms. The RPR technique was not designed for screening rice germplasm under dry conditions. However, attempts were made to pull under dry condition, but the stems of the rice plant broke before being uprooted when pulled from the non-irrigated plots, and RPR measurements were not possible.

Analyses of variance for all data and correlations among different traits were performed using SAS (SAS User's Guide: Statistics, 1982 edition. SAS Institute Inc., Cary, NC). Drought tolerant genotypes were identified as those with the higher RPR values.

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RESULTS AND DISCUSSION

The genotypes in this study varied widely in PHT, DH, and potential yield (PY). Grain yield on a single plant basis and other above ground plant parameters were measured in the 1989 experiment. The ranges of PHT, DH, and PY under irrigated conditions were 66-177 cm, 73-117 days, and 41-597 g/5 plants, respectively. On an average, PHT was decreased by 17 cm and DH was delayed by 6 days due to non-irrigated conditions. There were significant genotype-by-irrigation interactions for PHT and DH. Grain yield under non-irrigated conditions was 34% less than under irrigated conditions. RPR was not correlated with PHT, DH, or PY. The grain yields of late maturing genotypes were adversely affected by reduced panicle exsertion and reduced spikelet fertility due to low temperature ($< 15\,^{\circ}C$) in late September. Many of the tall genotypes lodged at flowering. For some genotypes, lodging was less under non-irrigated conditions than under irrigated conditions.

The RPR data were consistent across genotypes in both years. There was a significant correlation ($r = 0.32$, $P > 0.05$) between 1988 and 1989 RPR values. Four plants per entry per replication were sampled for RPR in 1988 as compared to only 2 plants being sampled per entry per replication in 1989. The coefficient of variation (C.V.%) for RPR means was 5.2% in 1988 as compared to 12.7% in 1989. The larger C.V. probably was due to the smaller sample size used in 1989. These data demonstrated that a sample size of 4 plants per replication is sufficient for RPR measurements.

Price *et al.* (1989) showed that RPR was correlated with RL, RN, and RWT in 1988. In the 1989 experiment, the correlations were significant only for RL and RWT, and the magnitudes of correlation coefficient were smaller than in 1988 (Table 1). In general, the correlations were greater for RL and RWT than RN. These data indicated that RL and RWT were the most reliable attributes of deep root system and were reflected in RPR. O'Toole and Soemartone (1981) found RL and RWT to be significantly correlated with RPR, whereas Ekanayake *et al.* (1986) found RL to be nonsignificant and RWT to be highly significant. Data from our tests in 1988 and 1989 show that RWT coupled with RL can be used as an indirect indicator of RPR and consequently root-related drought tolerance.

Table 1. Correlation coefficients (r) of root pulling resistance (RPR) with maximum root length (RL), total root number (RN), and root dry weight (RWT), in 1988 and 1989 experiments.

Experiment		r		
		RL	RN	RWT
1988	RPR	0.69**	0.61**	0.82**
1989	RPR	0.33*	0.11	0.46**

*, ** Significant at 0.05 and 0.01 probability levels, respectively. N=50.

RPR has been found to be correlated with visual drought scores based on leaf rolling, leaf desiccation, and dry matter production at the vegetative stage (Puckridge and O'Toole, 1980; O'Toole and Soemartono, 1981; Ekanayake *et al.*, 1985). In this study, visual rating on leaf rolling and leaf desiccation revealed significant difference among genotypes. However, the relationship between RPR and leaf rolling or between RPR and leaf desiccation was not established. The varying degrees of moisture of the field and differential sensitivity of the genotypes in leaf rolling to water stress, irrespective of RPR values, were probably the reasons for lack of this relationship. Moreover, due to frequent rainfall, the stress was not severe enough to manifest the advantage of high RPR in reducing leaf desiccation.

Puckridge and O'Toole (1980) observed that the higher drought tolerance in the high RPR cultivars was due to increased water extraction from the soil profile. RWT is a function of RL, RN, root branching (RB), and root thickness (RTH). RPR was correlated with both RL and RWT but the greatest correlation was between RPR and RWT in both years (Table 1). Furthermore, genotypes with the highest RWT and RPR performed better under drought stress. The RPR and RWT data for six germplasm accessions and three U.S. rice cultivars are presented in Table 2. These data demonstrated that in geneal, germplasm with a high RPR was accompanied by a high RWT in both 1988 and 1989. The Pakistan accessions 'Munji Sufaid Pak 23B' and 'Dhan Sufaid Pak 299' maintained their high RPR and corresponding RWT in both experiments. Other Pakistan accessions 'Coarse Pak 76 S', 'EB Pak 204', and 'Hansraj Pak 13' had intermediate RPR and RWT. The U.S. cultivars 'Newbonnet', 'Mars', and 'Nortai', as a group, had the lowest RPR and RWT values in both years, but in 1989 the RWT values for these U.S. cultivars were not significantly lower thanthose for some of the Pakistan cultivars.

Table 2. Mean comparison among nine rice genotypes for root pulling resistance (RPR) and root dry weight (RWT) in 1988 and 1989 experiments.

Genotype	Country of Origin	1988 RPR (Kg)	1988 RWT (g)	1989 RPR (Kg)	1989 RWT (g)
Munji Sufaid Pak 23B	Pakistan	22.3 a*	2.16 a	16.0 ab	0.57 a
Dhan Sufaid Pak 299	Pakistan	22.2 ab	2.09 b	15.8 ab	0.79 a
Basmati Nahan Pak 381	Pakistan	21.7 b	1.11 e	22.0 a	0.65 a
Coarse Pak 76S	Pakistan	21.6 b	2.11 b	13.2 bc	0.47 bc
EB Pak 204	Pakistan	18.5 c	1.53 c	13.7 bc	0.42 bc
Hansraj Pak 13	Pakistan	15.9 d	1.30 d	13.6 bc	0.52 b
Newbonnet	U.S.A.	14.0 e	0.74 f	10.5 e	0.27 c
Mars	U.S.A.	9.9 f	0.51 h	11.0 de	0.27 c
Nortai	U.S.A.	9.3 f	0.56 g	12.0 cd	0.42 bc
C.V.%		5.2	4.3	12.7	36.2

* Means within columns with the same letters are not significantly different at the 0.05 probability level.

These data suggest that RWT is a direct indicator of RPR. Furthermore, the RPR method as a tool for screening rice germplasm for drought tolerance was shown to have potential in direct seeded rice culture. The development of root systems in terms of RL and RWT was reflected in RPR.

This technique was developed at IRRI to measure root pulling resistance in lowland transplanted culture. The advantage of this technique is that the drought tolerance of rice can be measured without subjecting the rice plant to drought conditions. The RPR technique of screening rice germplasm for root-related drought tolerance is useful in direct seeded U.S. rice culture.

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