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Determination of genetic variability for physiological traits related to drought tolerance in African rice (*Oryza glaberrima*)

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Relative water content, water potential and transpiration of Africa rice (*Oryza glaberrima*) were investigated in a controlled condition under phytotron. Two *Oryza sativa* cultivars, IR55423-01 (a drought tolerant genotype) and IR64 (drought sensitive genotype) and 8 *O. glaberrima* accessions were grown under droughted and watered conditions. The fraction of transpirable soil water (FTSW) was used as an indicator of water availability. Transpiration was determined by changes in daily pot weights and the ratio of transpiration of droughted to watered plants expressed as normalized transpiration ratio (NTR). The FTSW was greater in *O. glaberrima* accessions CG14, RAM118 and RAM 152 than all the *O. sativa* checks; suggesting that they might have the capacity to close their stomata earlier in response to drought stress, in other to keep transpiration rate similar to the rate of uptake of soil water resulting in maintenance of the water balance of the plant. RAM 3 had the greatest dehydration tolerance and some accessions such as RAM 134, RAM152 and RAM163 had lower dehydration tolerance than RAM 3, CG 14 and IR55423-01' but survived longer suggesting that other avoidance mechanisms such as leaf movement and reduction of leaf area complemented these traits and enhanced their survival. In general, it is necessary to keep FTSW above 0.53, in order to keep transpiration and plant water status high in preventing reduction in dry matter production which will lead to higher yields.

Key words: Drought tolerance, *O. glaberrima*, *O. sativa*, fraction of transpirable soil water (FTSW), dehydration tolerance.

INTRODUCTION

Among the abiotic stresses, drought is the major stress affecting rice productivity under rainfed and upland ecosystems. It causes severe damage at different stages of rice growth, resulting in considerable yield loss (Mackill et al., 1996). Drought causes reductions of leaf area, dry matter production, decline in plant water status and transpiration. The reduction of leaf area is a drought avoidance mechanism, aimed at reducing plant water use rate and hence conserves water during periods of drought (Jones, 1992). Furthermore, water deficits cause

reduction of stomatal conductance (Jones, 1992), and this leads to reduced carbon assimilation and consequently low biomass production (Delfine et al., 2001; Medrano et al., 2002). Water deficits also influence dry matter partitioning in plants (Jones, 1992). Studies have shown that more dry matter is partitioned to the root as compared to the shoot in plants facing drought (Arora and Mohan, 2001; Wilson, 1988).

The variables that regulate water balance of plant follows the approach of Sinclair and Ludlow (1986) (Figure 1). Stage I exists when water is freely available from the soil, and both stomatal conductance and water vapor loss are maximal. The rate of water loss from the plants is therefore determined by environmental

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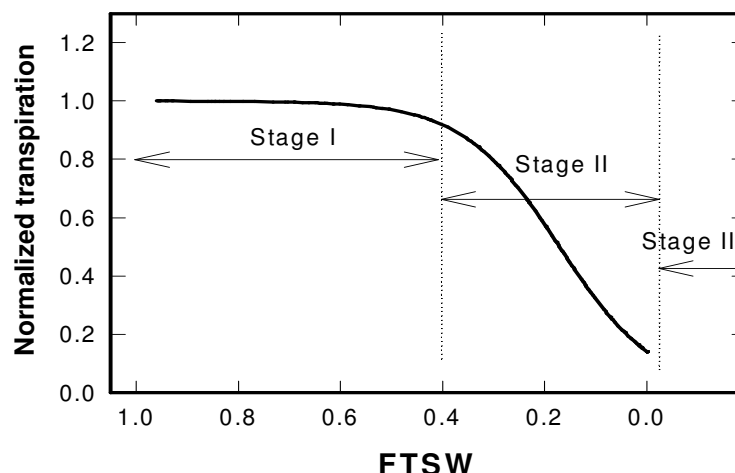
Figure 1. Relative transpiration rate calculated as a function of fraction of transpirable soil water (FTSW).

conditions around the shoot. Stage II begins when the rate of water uptake from the soil cannot match the potential transpiration rate. The reduction in the rate of soil water supply is believed to be the results of declining soil hydraulic conductivity, as the volumetric water content decreases. These lead to a decline in stomatal conductance in order to keep transpiration rate similar to the rate of uptake of soil water resulting in maintenance of the water balance of the plant. The transition from stage I to II occurred when 80% of the extractable soil water had been lost. Stage III begins when the ability of the stomata to compensate for declining rate of uptake from the soil has been exhausted, and stomatal conductance is at a minimum. Maintenance of plant water balance during stage III depends on epidermal conductance being sufficiently small, that the low rate of uptake of soil water can replenish the water loss. The plant dies when the plant water balance declines to the critical plant water status.

Plants respond to declining water potential through several mechanisms such as accumulation of solutes within cells that is osmotic adjustment (Jones, 1992; Ludlow and Muchow, 1990; Angadi and Entz, 2002; Flower et al., 1990) and reduced or closing of the stomata (Morgan, 1992; McCree and Richardson, 1987; Wright et al., 1997). For many crops, transpiration declines only after a third of the extractable soil water in the root zone has been left (Sadras and Milroy, 1996), but instances of crops showing a decline in transpiration at higher levels of extractable soil water have been reported (Henson et al., 1989a; Ameglio et al., 2000). This decline precedes changes in the water status of the plant, and is hence attributed to a non-hydraulic root signal produced by roots growing in a drying soil (Davies et al., 2002b; Chaves et al., 2002). Increase in transpiration efficiency under drought has been reported in various crops (Jones, 1992) which is attributed to the

fact that, partial stomatal closure under increasing water deficits leads to more decline in transpiration, as compared to dry matter production (Nguyen et al., 1997; Nobel, 1999).

There is a need to develop rice varieties that use water efficiently and are tolerant to drought during different stages of crop growth period. Only a limited genetic variability exists in indica rice for drought tolerance; however, *Oryza glaberrima*, the African rice although low yielding is tolerant to abiotic stresses including drought tolerance (Jones et al., 1997). Only limited information are available concerning the adaptive responses of *O. glaberrima* to drought. The objective of this study therefore, was to evaluate the adaptive responses of selected *O. glaberrima* genotypes to drought, in terms of relative water content, water potential, and transpiration. The study aimed at establishing the relationships describing the effects of drought on relative water content, water potential and transpiration under controlled conditions in a phytotron. In addition, we aim to determine genetic variability in different accessions of *O. glaberrima* for different drought related traits. The findings would lead to the identification of genetic donors for drought tolerance.

MATERIALS AND METHODS

Plant material used

In this experiment, physiological response involving leaf water potential (LWP), leaf relative water content (RWC) and total biomass of eight *O. glaberrima* accessions and two *Oryza sativa* cultivars for drought stress at vegetative (dry down) stage was compared under phytotron conditions at the International Rice Research Institute (IRRI) during 2007. Screening was carried out under controlled conditions (29/21°C and 75% relative humidity). The test materials comprised of RAM 3, RAM118, RAM121, RAM131, RAM134, RAM152, RAM163, CG14 and IR64 (drought

susceptible check) and IR55423-01 (drought tolerant check). The 8 *O. glaberrima* accessions were obtained from Mali in West Africa and referred to in this study as rice from Mali (RAM). The RAMs were found to be drought tolerant under field conditions in Mali (Cisse, Personal communication). The 8 genotypes had all characteristics of *O. glaberrima*; short ligule, lack of secondary branches and had black hull and seed pericarp.

The setup was based on a replicated dry-down design using potted plants in a phytotron, with gravimetric monitoring of soil moisture and plant transpiration, to compute FTSW (Fraction of Transpirable Soil Water: FTSW=AWS/TTSW, with AWS, available soil water content and TTSW, total transpirable soil water content). Stressed plants were re-watered after a severe stress level was attained. A set of 100 pots (10 genotypes) representing 10 plants per entry was used. Each pot was filled with 10 kg of soil mix (2:1:1 upland soil, sand and coconut coir dust), fertilized and then irrigated to saturation. About 5 seeds were transplanted per pot and thinned to 3 plants per pot at the 1st tiller stage. Entries were grown in a randomized complete block design (RCBD) with 5 replications.

Treatments

Two water treatments were used, droughted and watered. The treatments began at 21 days after sowing, just before onset of flowering. At the beginning of the treatments, soil moisture in all pots was raised to 100% water holding capacity (WHC). Droughted pots thereafter, received no more water, while watered pots were watered daily to maintain the soil moisture at 100% WHC.

Measurements on water relations

Of the 3 plants per pot, plant 1 was sampled 24 days after transplanting (beginning of water treatments) to determine the initial biomass accumulation. Plant 2 was sampled at the end of the progressive soil drying during vegetative stage dry-down (when transpiration in droughted plants was below 10% of that in watered plants) to determine again the biomass accumulation (25 days after the initial stress application). Lastly, plant 3 was rewatered at the end of the dry down and harvested at maturity to record data on agronomic traits.

Data recording

Data were recorded on the following traits; (1) daily during dry-down on soil water status, (2) fraction of transpirable soil water (FTSW) and (3) transpiration. At the end of the dry down experiments, data were recorded on plant water status such as leaf relative water content (RWC), leaf osmotic potential (OP) and leaf water potential (LWP). Total biomass was determined at the beginning of the drought stress. One plant from each pot was uprooted and the soil washed to remove the roots. Then all the plant parts (leaves, stem, and roots) were separately oven dried at 70°C for 3 days. Total plant biomass was determined by recording dry weight of plant parts. Before oven drying the samples, whole plant leaf area was determined with a leaf area meter. Biomass and leaf area were once again recorded for plants of all the genotypes at the end of the experiment (90 DAS).

Determination of water status

Data on leaf relative water content (RWC), leaf osmotic potential (OP), leaf water potential (LWP) were measured every alternate day at midday. The first measurement was taken in a well watered plant in the morning (predawn) after the last irrigation and the last measurement taken when the plant was wilted (that is when the rolling of the youngest leaves is complete and the oldest leaves are also completely desiccated. Wilting range 55 to 65% depending on the cultivar.

Measurements of RWC, OP and LWP

The midsection of the same 2nd youngest fully expanded leaf blade was measured.

Leaf relative water content (RWC): Leaf samples (5 to 10 cm of the leaves) were taken 4 to 6 times (replication) from each genotype/stress treatment and placed in a pre-weighed airtight vial which is slightly longer than the samples, with it basal part to the bottom. The vial is immediately placed in a cooler (10 to 15°C) and weighed to obtain weight of leaf samples (W), nano-pure water was then added to each vial and samples were left to hydrate for 24 h in the refrigerator. After 24 h, samples were taken out of water, dried and immediately weighed to obtain fully turgid weight (TW). The samples were then oven dried at 80°C for 72 h and weighed (after cooling in a dessicator) to determine the dry weight (DW). Readings were recorded. Leaf relative water content (RWC) was calculated as:

RWC (%) = [(W-DW)∕(TW-DW)] x 100

Where W= sample of fresh weight, TW= sample of turgid weight, DW= sample of dry weight.

The RWC of drought plants was divided by that of control plants to give RWC ratio, which was then expressed as a function of FTSW.

Leaf water potential (LWP): Leaf water potential was measured using a pressure chamber, midsection of the same 2nd youngest fully expanded leaf blade was used. A leaf (or a stem) was cut off a plant with an assumption that, the sap was sucked back into the xylem, since it is under tension. That tension is broadly equal to LWP. The detached leaf is sealed in a steel chamber with only the cut end (petiole) protruding out. Pressure was applied to the chamber (from a compressed nitrogen cylinder) until a sap meniscus appears at the xylem surface, the pressure reading was recorded as the xylem (leaf water) potential.

Analysis of the soil water status

Fraction of transpirable soil water (FTSW) was used as an indicator of water availability. Transpiration was determined by changes in daily pot weights and ratio of transpiration of droughted to watered plants expressed as normalized transpiration ratio (NTR). Available soil water was expressed as the FTSW for each pot in the droughted plants. FTSW at day i for each pot was calculated as:

$$\text{FTSW} = \frac{\text{Pot weight at day I - Final pot weight}}{\text{Initial pot weight - Final pot weight}}$$

where initial pot weight refers to weight of pot at 100% water holding capacity, while final pot weight, refers to weight of the pot when transpiration of stressed plants was less than 10% of that of the watered plants.

Transpiration

Transpiration was determined by daily pot weight measurements. In

Table 1. Amount of soil water extracted by *O. sativa* and *O. glaberrima* cultivars under well watered (control) and the drought stress conditions (Total Transpirable Soil Water, TTSW).

	TTSW (mass of water in kg) mean ± S.E	
Genotype	Drought stress	No drought stress*
O. glaberrima		
CG 14	4.16±0.01[ab]	4.14±0.00[b]
RAM 3	4.13±0.01[de]	4.13±0.00[b]
RAM 118	4.16±0.00[abc]	4.15±0.00[ab]
RAM 121	4.13±0.01[cde]	4.14±0.00[b]
RAM 131	4.13±0.01[bcde]	4.15±0.00[ab]
RAM 134	4.14±0.00[bcde]	4.14±0.00[b]
RAM 152	4.19±0.01[a]	4.19±0.01[a]
RAM 163	4.15±0.00[bcd]	4.15±0.00[ab]
O. sativa		
IR64(susceptible check)	4.13±0.006[cde]	4.14±0.002[b]
IR55423-01 (tolerant check)	4.12±0.010[e]	4.12±0.007[b]
Trial mean	4.15	4.15

* = well watered plants, means with the same letter are not significantly different (P<0.05).

this case, the difference in weights between two consecutive days was considered as water lost through transpiration. Transpiration data were analyzed using the double normalization procedure outlined by Ray and Sinclair (1997).

$$\text{Transpiration ratio (TR)} = \frac{\text{Transpiration of droughted plants}}{\text{Average transpiration of watered plants}}$$

A second normalization was done so that TR rate of each plant was centered on a value of 1.0 when soil water content in each pot was high (FTSW = 0.50). First, a mean TR was calculated for each pot for the period when soil moisture was high, and then daily TR for each pot was divided by this mean TR, to give a daily normalized transpiration ratio (NTR). Transpiration efficiency (TE) was determined as the slope of the linear function between dry matter produced (DM) and cumulative transpiration (CT).

Total transpirable soil water (TTSW)

This was computed as the difference between initial pot weight and its weight on the day when RT reached 0. l., RT = 0.1 being defined as the end-point of transpirable soil water. RT of less than 0.1 indicated that stomatal conductance had decreased approximately one order of magnitude below that of well watered plants. Also, definition of the end-point of transpirable water at RT = 0.1 proved convenient because, after this date, substantial differences existed in the time species survived, yet only small amounts of water were still being lost. Consequently, by definition, the amount of transpirable soil water represents the amount of soil water consumed in stages I and II. In contrast to previous definitions of extractable soil water (Ritchie, 1973; Meyer and Green, 1981), the end of stage II occurred when FTSW = 0.

Statistical analysis

Analysis of variance (ANOVA) was conducted using the General

Linear Model (GLM) procedure of SAS program version 9.1 (SAS Institute, 1999) with type III which is generally used for data with missing values. Frequency distribution of all the drought related traits studied were performed using univariate procedure of SAS system and normal distribution was evaluated by using the current version of Shapiro-Wilk test. Simple statistics of each trait was computed using phenotypic means to determine possible relationship among the traits.

RESULTS

Transpiration rate and soil water supply (stages I and II)

In this study, fraction of transpirable soil water (FTSW) was used as an indicator of water availability. Transpiration was determined by changes in daily pot weights and the ratio of transpiration of drought stress to non-stressed plants expressed as normalized transpiration ratio (NTR).

Total transpirable soil water (TTSW)

Significant differences were observed among *O. glaberrima* accessions and between *O. sativa* lines in the total amount of transpirable soil water (TTSW) (Table 1). *O. glaberrima* showed high degree of variation for amount of soil water extracted, ranging from 4.13-4.19 kg. IR55423-01, the tolerant check, had the lowest (4.12 kg) and *O. glaberrima* accession RM152 (4.19 kg) had the highest TTSW in both drought stress as well as in well watered treatments. Two *O. glaberrima* accessions, CG14 and RAM 118 were similar with RAM 152 which

Table 2. Mean FTSW values at which stomatal closure begins to occur at vegetative stage.

Genotype	NTR		FTSW	
	Range	Mean ± S.E	Range	Mean ± S.E[1]
O. glaberrima				
CG 14	1.92-2.25	2.09±0.08 [a]	0.42-0.47	0.44 ±0.01[a]
RAM 3	2.60-3.02	2.81±0.11 [ab]	0.32-0.36	0.34 ±0.01[ns]
RAM 118	1.78-2.03	1.91±0.06 [ab]	0.47-0.52	0.49 ±0.01[ab]
RAM 121	2.33-2.72	2.53±0.10 [b]	0.35-0.39	0.37 ±0.01[a]
RAM 131	2.42-2.77	2.59±0.09 [ns]	0.35-0.39	0.37 ±0.01[a]
RAM 134	2.52-2.90	2.71±0.10 [a]	0.33-0.36	0.35 ±0.01[ns]
RAM 152	1.69-2.01	1.85±0.08 [ab]	0.47-0.53	0.50 ±0.02[ab]
RAM 163	1.66-1.89	1.78±0.06 [ab]	0.50-0.55	0.53 ±0.01[ab]
O. sativa				
IR64 (susceptible check)	2.03-2.65	2.34±0.16	0.32-0.38	0.35 ±0.02[b]
IR55423-01 (tolerant check)	1.81-2.13	1.97±0.80 [a]	0.43-0.48	0.45 ±0.02[a]
Trial mean		2.26		

a = significant between *O. glaberrima* and IR64, b = significant between *O. glaberrima* and IR55423-01 and ns= not significant ($P < 0.05$).

had the highest TTSW.

Based on mean values for TTSW, 3 *O. glaberrima* accessions, CG14, RAM 118 and RAM152 had significantly higher TTSW than the susceptible check IR64, while 4 accessions, namely CG14, RAM118, RAM152 and RAM 163 had relatively higher TTSW than the tolerant check IR55423-01. However, all cultivars tested lost about 4 kg of transpirable water during the drought conditions.

Normalized transpiration ratio (NTR) and fractions of transpirable soil water (FTSW)

O. glaberrima showed a high degree of variation for NTR, ranging from 1.66 (RAM 163) to 3.02 (RAM3) (Table 2). With the exception of RAM 131, significant differences were observed among *O. glaberrima* accessions and both *O. sativa* lines tested. RAM 121 and 134 had significantly higher NTR than the tolerant check IR55423-01. Fractions of transpirable soil water (FTSW) value at which the stomata begin to close for each of the *O. glaberrima* accessions were compared with IR64 and IR55423-01 varieties (Table 2).Based on the data. IR64 was found be very late in closing its stomata where as IR55423-01 had a high FTSW. *O. glaberrima* showed high degree of variation for FTSW ranging from 0.34-0.53. *O. glaberrima* accessions, RAM 118, RAM 152 and RAM 163 had higher values than the drought tolerant variety IR55423-01 (FTSW 0.45). With the exception of two *O. glaberrima* lines (RAM 3 and RAM 134); all the *O. glaberrima* lines had relatively high FTSW values as compared to IR 64 (FSTW 0.35).

Due to differences in plant size and micro environmental variation both within and between experiments, many of the genotypes had RT values that were well below or well above 1.0. To reduce this variation, data were normalized by dividing the individual RT values by the mean of all RT values for all entries obtained when FTSW was greater than 0.5. Thus when soil was still moist (FTSW > 0.5), normalized values of RT were assumed to be one.

Water relations

### *Dehydration tolerance (stage III)*

There were no significant interactions or cultivar effects for the water relations of the test entries, hence only water treatment effects were considered. There were marked differences among the cultivars in dehydration tolerance (Table 3). Three *O. glaberrima* accessions, RAM 134, RAM152 and RAM163 and the sensitive check IR64, died at highest water potentials but relatively at intermediate relative water contents. On the other hand, RAM 3 had the highest dehydration tolerance, dying at the lowest water potential and lowest relative water content.

O. glaberrima lines such as CG14, RAM 131 and *O. sativa* tolerant check, IR55423-01 died at much higher relative water content than its leaf water potential would suggest based on the relationship between these two parameters among the other cultivars. The RWC of stressed plants was divided by that of controlled to give RWC ratio, which was then expressed as a function of FTSW. The FTSW thresholds at which this ratio changed from unity could not be determined precisely by the experiment due to few and unevenly distributed data points. In general however, the relationship showed that

Table 3. Dehydration tolerance of O. *sativa* and O. *glaberrima* under well watered (control) and drought stress conditions.

Genotypes	Leaf water potential Bars)		Relative water content (%)	
	Drought stress	No drought stress*	Drought stress	No drought stress*
O. glaberrima				
CG 14	-34.6±1.0[abc]	-2.48±0.16[ab]	61.48± 099[a]	88.40±0.49[a]
RAM 3	-36.04±1.45[a]	-3.44±0.14[ab]	44.64± 4.33[b]	86.76±0.03[a]
RAM 118	-32.44±0.31[abc]	-2.32±0.22[b]	62.25±1.24[a]	86.22±0.20[ab]
RAM 121	-33.08±0.52[abc]	-2.54±0.15[ab]	54.12±1.34[a]	87.53±0.21[a]
RAM 131	-35.4±1.25[ab]	-3.5±0.16[a]	59.81±0.46[a]	87.83±0.31[a]
RAM 134	-28.68±0.88[bcd]	-3.06±0.02[ab]	62.12±1.20[a]	86.47±0.12[ab]
RAM 152	-25.44±1.90[d]	-3.4±0.13[ab]	59.13±0.25[a]	84.34±0.80[b]
RAM 163	-27.92±1.12[cd]	-3.12±0.04[ab]	61.98±1.15[a]	86.88±0.01[a]
O. sativa				
IR64 susceptible check)	-28.72±0.86[bcd]	--3.06±0.02[ab]	59.093±0.24[a]	86.418±0.14[ab]
IR55423-01 (tolerant check)	-32.16±0.22[abcd]	-3.08±0.03[ab]	58.805±0.15[a]	87.686±0.26[a]
Trial mean	-31.45	-3	58.343	86.854

* Well watered, means with the same letter are not significantly different ($P < 0.05$).
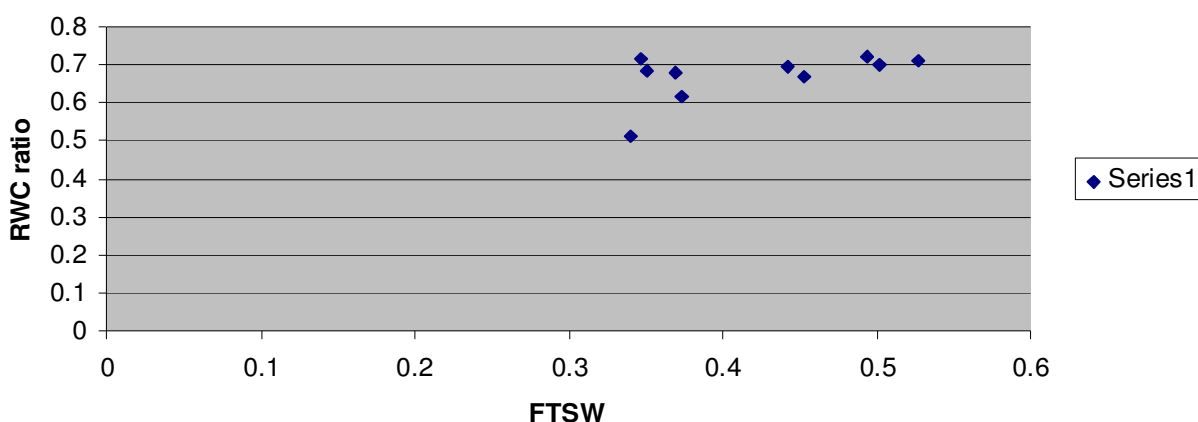
Figure 2. Scatter diagrams of the ratio of RWC of drought to watered plants as functions of FTSW for rice cultivars.

RWC ratio changed as FTSW fell below 0.4 (Figure 2).

DISCUSSION

Rate and soil water supply (Stages I and II)

Transpiration among the fast growing *O. glaberrima* accessions began to decline at fraction of transpirable soil water (FTSW) thresholds higher (ranging from 0.34 to 0.53) than the commonly reported range of 0.3 to 0.4 (Sadras and Milroy, 1996). The decline in transpiration among the fast growing accessions at relatively high FTSW thresholds seems to suggest the presence of non-hydraulic root signals, regulating the plant's response to drought. The effect of root signals in causing an early decline in transpiration and stomata conductance during soil drying has been reported in rice (Nguyen et al., 1997)

and many crops such as sugarcane (Nable et al., 1999), tomato (Holbrook et al., 2002), sunflower (Cellier et al., 1998), wheat (Nan et al., 2002) and lupins (Rodrigues et al., 1995). The observed results where transpiration began to decline at higher FTSW could be explained in two ways.

Firstly, water extraction in a given soil layer depends on root length density as well as soil extraction efficiency (Moreshet et al., 1996; Penning de Vries et al., 1989). Although root growth was not determined in this study, it is possible that the *O. glaberrima* accessions such as CG14, RAM 118 and RAM152 might have higher root length density or had higher soil water extraction efficiency; as some *O. glaberrima* accessions have been documented to have high root biomass accumulation and thin roots with better soil penetration ability, to help it compete effectively for soil nutrients and water (WARDA, 1996).

Secondly, the differences in soil water extraction could be explained by canopy characteristics of the accessions used, as some *O. glaberrima* have been shown to possess early plant vigor and high specific leaf area leading to high canopy growth for a given amount of assimilates (Dingkuhn et al., 1999; Adeyemi and Vodouhe, 1996). Higher sensitivity of transpiration in *O. glaberrima* to drought as compared to IR64 might be related to leaf area development. Dingkuhn et al. (1999) showed that, faster leaf area development in *O. glaberrima* cultivars compared to *O. sativa* cultivars led to a higher rate of soil drying, causing it to reach the endpoint between 4 to 6 days earlier than IR64. Yeo et al. (1999) observed that *O. glaberrima* cultivars ranked highest in sensitivity to transpiration when they compared nine rice species for dry matter production and other growth parameters under drought. Similarly, Angadi and Entz (2002) attributed low water extraction by a dwarf cultivar of sunflower, as compared to a standard height cultivar to its lower leaf area. Salih et al. (1999) also found that the sorghum cultivar with the higher leaf area also had higher transpiration rates.

Transpiration

The similarity of NRT and FTSW among *O. glaberrima* and *O. sativa* cultivars does not mean that they do not react differently to water deficits in both stages I and II. The rate at which leaf water potential falls, and the value it reaches, differs markedly among all the tested, suggesting that in the event of terminal drought which starts in early vegetative stage of plant growth, transpiration starts to decline once about 50% of the available soil water has been used up. Moreover, these FTSW thresholds for transpiration were similar to those reported for many crops including rice; where the author suggested that relative transpiration is equal to unity (1), whenever FTSW fall to 0.2 (Ritchie, 1973). There is a general agreement in the literature that, evapotranspiration in many crops reduces only when two thirds of the extractable soil water in the root zone has been used (Turner, 2000; Sadras and Milroy, 1996).

Decline in transpiration seem to have preceded decline in the plant water relations in this study; suggesting the presence of non-hydraulic root signals in regulating transpiration. The amount of transpirable soil water was greater in *O. glaberrima* accessions CG14, RAM118 and RAM 152 than in irrigated and upland rice cultivars. This suggests that *O. glaberrima* accessions, CG14, RAM 118 and RAM 152 might have the capacity to close their stomata earlier, in response to drought stress than the tolerant check in other to keep transpiration rate similar to the rate of uptake of soil water resulting in maintenance of the water balance of the plant. Thresholds for *O. glaberrima* accessions were similar to the tolerant check; IR55423-01 (FTSW 0.45) which might suggest that both cultivars start to closes their stomatas at the same period.

Water relations

Measures of relative water content (RWC) and water potential (WP) are indices of plant water status, which are useful in monitoring the development of stress in plants growing under drought conditions. In this study, the RWC and WP all remained relatively unchanged until FTSW range of 0.34 to 0.53**.** Below this soil moisture level, RWC declined rapidly to 86 to 88% of that in watered treatment; while WP declined two to three folds. This pattern of change in plant water status with declining soil moisture has been reported in many other crops (Qian and Fry, 1997; Gesch et al., 1992; Henson et al., 1989a; Erickson et al., 1991; Jensen et al., 1989; Machado and Paulsen, 2001). Similarly, it has been reported that water potential of well-watered plants can decline with ontogeny due to increasing demand for water as the leaf area increases (Allen et al., 1998; Flower et al., 1990).

In this study both WP and RWC in the watered plants were maintained in the range that well-watered plants are expected to maintain (Sinclair and Ludlow, 1986). Thus, the possibility that water deficits developed in watered plants to levels that could substantially reduce the magnitude of OA in this study was minimal. *O. glaberrima* (RAM 3) had the greatest dehydration tolerance; it survived longest in stage III due to high dehydration tolerance. Some of the *O. glaberrima* accessions, RAM 134, RAM152 and RAM163 had lower dehydration tolerance than RAM 3, CG 14 and IR55423-01 (drought tolerant check), but survived longer, suggesting that other avoidance mechanisms such as leaf movement and reduction of leaf area complemented these traits and enhanced their survival.

Conclusion

Based on the results, it is necessary to keep the fraction of transpirable soil water (FTSW) above 0.53 for *O. glaberrima* cultivars and 0.30 for IR64, in order to keep transpiration and plant water status high and thereby, preventing reduction in dry matter production which will lead to higher yields. The 3 *O. glaberrima* accessions, CG14, RAM 118 and RAM 152 which were identified to possess some desirable traits, such as dehydration tolerance and transpiration, in order to conserve water could be a potential source of donors to develop drought tolerant genotypes. The experiment shows that, genetic variability for physiological traits such as leaf water potential and relative water content exist in *O. glaberrima* accessions which can be utilized in crosses to improve the tolerant levels of most *O. sativa* varieties in future breeding work.

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