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CORRELATION AND PATH ANALYSIS OF DROUGHT TOLERANCE TRAITS ON GRAIN YIELD IN RICE GERMPLASM ACCESSIONS

Mohankumar M. V.[1], Sheshshayee M. S.[1], Rajanna M. P.[2] and Udayakumar M.[1]
[1]Department of Crop Physiology, University of Agricultural Sciences, GKVK, Bangalore, India
[2]Department of Genetics and Plant Breeding, University of Agricultural Sciences, VC Farm, Mandya, India
E-Mail: mohancrphy@gmail.com

ABSTRACT

Rice is an extensively consumed cereal crop, which serves as a major source of carbohydrate in human diet. Rice cultivation requires more than 50% of the total irrigation water used for agriculture. Therefore saving irrigation water without much compromising with grain yield in rice cultivation is an important global agenda. In the present study the relevance of several drought tolerance traits in improving grain yield of rice under aerobic condition is studied. Analysis of variance indicated significant genetic variability among all plant traits. Grain yield was significantly correlated with root volume, root weight, total biomass total leaf area and Δ^{13}C. Path analysis indicated that root traits like root length and root weight positive direct effect on grain yield. Above ground traits like SLA, TDM, and TLA had direct positive direct effects on grain yield. The direct effect of Δ^{13}C on grain yield was negligible. Root length had highest positive indirect effect on grain yield via root volume. These results indicated that root play a pivotal role in improving grain yield. Yield displayed highest H^2_{BS}, where as Δ^{13}C displayed moderate heritability among the rice germplasm accessions.

Keywords: rice, grain yield, drought tolerance, WUE, root traits, carbon isotope discrimination.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the predominant food crops of the world, a grain of life for more than 70 per cent of the Asian population and the staple food crop for world's poorest and densely populated regions. Demographers indicate that by 2012 India's population will reach 1.2 billion, which accounts for about 18% of the world population and a concomitant production level of 3000 kg/ha from the present average productivity of 1930 kg is essential to feed the growing population. Rice is hydrophilic crop that is commonly grown under flooded condition; however, more than half of the world productivity comes from upland or rainfed conditions. Drought is a major abiotic stress affecting crop growth and yield stability. More than 80% of the Asian regions are drought prone and therefore development of rice cultivars suitable for semi-irrigated cultivation is indispensable. Breeding for drought tolerance is usually performed by selecting genotypes for high yield under water limited conditions (Arvind Kumar *et al*., 2008). This yield based selection has further lead to a narrow genetic variability for yield and component traits in recently developed cultivars (Araus *et al*., 2002). Therefore a trait based breeding approach has been proposed to improve rice yields under water limited conditions (Reynolds *et al*., 2010). More emphasis has been diverted in recent days to improve several physiological traits which confer drought tolerance without much compromising with yield reduction.

Plants are thought to have evolved numerous strategies for coping with limited water availability including changes in phenological, developmental and physiological traits (Passioura, 1996; Araus *et al*., 2002). Such traits which are evolved under water limited condition are adaptive traits and have only survival significance with little or no advantage for crop growth and productivity (Udayakumar and Prasad, 1994, Collins, *et al*., 2008). Any trait would have relevance only when it is associated with superior crop growth rates. From this context, water mining traits associated with roots and efficient use of water for biomass production (WUE) have great relevance.

Root occupies the pivotal position through its role in extracting water from deeper soil profiles. Deep rooted plants have also shown to be better productive under water limited conditions (Reynolds and Tuberosa, 2008). One of the major reasons for the slow progress in breeding for better root traits is the lack of proper phenotyping strategy and its amenability for phenotyping. Several strategies has been adopted by scientists for phenotyping root traits including, phenotyping in containers (Venuprasad *et al*., 2002), hydroponics (Martinez *et al*., 2004), Root imaging (Bouman *et al*., 2000; Zhang *et al*., 2005), mini-rhizotrons (Drouet *et al*., 2005) or mini-lysimeters (Udayakumar *et al*., 1998). However most of these techniques suffer from lack of precision and/or the inability to screen a large number of genotypes. In the present study a specially constructed 'root structures' were used to phenotype roots to overcome most of the disadvantages in other techniques. Apart from root, the other most important trait that has relevance in improving WUE under water limited conditions is WUE. According to the model proposed by Passioura (1977), Yield is a function of water use, water use efficiency and harvest index. Thus, effective use of the absorbed water is very important traits for enhancing biomass and yield (Yadav *et al*., 1997). Effective water use can be maximized by increasing intrinsic ability to fix more carbon per unit water transpired (water use efficiency). The main objective of the present investigation is to reveal the relationship between seed yield and drought tolerance traits and thereby to determine the selection criteria for increasing grain yield in rice under water limited conditions.

MATERIALS AND METHODS

Plant material

Field experiment was conducted using twenty eight advanced inbred lines of rice which were adapted to upland cultivation in 2008 growing season at the field facility, Department of Crop Physiology, University of Agricultural Sciences, Bangalore. These accessions were phenotyped for root traits and WUE under water limited conditions. Parallel, these selected lines were sown in aerobic condition in kharif, 2008 for recording yield and yield components.

Root phenotyping

Root phenotyping was done in a specially built root structures with a length and breadth of 60 × 4 feet and a height of five feet. The root structures were constructed with cement bricks to which soil consisting of mixture of red loamy soil and farm yard manure in 3:1 proportion (v/v) was filled. The soil was brought to field capacity and allowed to settle for 10 days. Seeds were directly sown on the root structures as per aerobic definition (Bouman *et al.*, 2002). A spacing of 25 × 25 cm was followed with one seedling per hill. The genotypes were replicated twice in a complete randomized complete block design (RCBD). Genotypes were irrigated once daily depending on the availability of moisture until the soil attained field capacity. All observations were taken from three plants from each replication. A sample of 3 leaves from one plant was taken and their area was determined by measuring the L X B of each leaf. The ratio of leaf area to the leaf dry weight was computed as Specific leaf Area. The remaining leaves of a plant were separately oven dried at 70°C for 72 h or to constant weight. Total leaf area (cm^2/plant) TLA) was recorded as the product of SLA and total leaf weight. Root structure was dismantled when the plants reached a stage of 50% flowering. High pressure of water was applied through PVC pipes to the soil to the dismantled root structure. The roots of each genotype were carefully harvested separately from the soil without damaging the roots. Harvested roots were dipped in a water and washed to remove the soil adhered to the roots. Several root associated parameters like root length (cm), root volume (ml, amount of water displaced by the fresh root in a 1000 ml measuring cylinder). The shoot, leaves and roots were separately transferred to the oven and dried at 70°C for 72 h or to constant weight and the dry weight was recorded.

Stable carbon isotope discrimination (CID) in leaf biomass

Stable carbon isotope ratio was measured with an Isotope Ratio Mass Spectrometer (IRMS; Delta plus, Thermo Fischer scientific, Bredmen, Germany) interfaced with an element analyzer (NA112, Carlo-Erba, Italy) with a continuous flow device (Conflo-III, Thermo Fischer scientific) installed in the Department of Crop Physiology, UAS, Bangalore. The dry leaf samples used for estimation of SLA were used for determination of carbon isotope ratios. Dried leaf samples were homogenized to a fine powder with a ball mill. Three replications from each genotype were used for $\delta^{13}C$ analysis. Carbon isotope discrimination ($\Delta^{13}C$) expressed in per mill (‰).

Statistical analysis

Analysis of variance (ANOVA) was carried out for each character, and subsequently ANOVA was used to determine whether there were any differences in the traits studied among rice accessions. Line means were separated by the use of protected critical differences (CD) at $P \leq 0.05$ using MSTAT-C software (Anonymous, 1998). Correlation and path analysis were performed using the software Statistical Package for Agricultural Research (SPAR 2.0).

RESULTS AND DISCUSSIONS

Analysis of variance indicated significant genetic variability in various above and below ground drought tolerance traits among rice germplasm accessions. Root traits such as root length, root volume and root biomass varied from a minimum of 36.5 cm, 14.17 cm^3 and 5.15 g $plant^{-1}$ to a maximum of 75.17 cm, 82.16 cm^3 and 17.07 g $plant^{-1}$, respectively. Significant genetic variability in some of these root traits have been demonstrated and implicated for improved drought tolerance in crop plants O'Toole and De Datta, 1986; Thangaraj *et al.*, 1990; Sharma *et al.*, 1994; Sinclair and Muchow, 2001). Kashiwagi *et al.*, 2006 demonstrated significant genetic variability in many root related traits in root hair density, hydraulic conductivity, root length density in chickpea. Above ground traits like Total Dry Matter (TDM), Specific Leaf Area (SLA) and Total Leaf Area (TLA) varied from minimum of 24.12 g $plant^{-1}$, 175.72 cm^2 and 1306 cm^2 to a maximum of 78.17 g $plant^{-1}$, 483.21 cm^2 and 5131 cm^2, respectively. $\Delta^{13}C$ in whole plant dry matter appears to be reliable indicator of plant WUE in pot grown sunflower and negative relationship was obtained between these two traits in structural carbon both in well watered and drought conditions (Johnson *et al.*, 1993). In the present study $\Delta^{13}C$ varied from 18.78 to 21.66, indicating the significant genetic diversity among rice accessions. Further total grain yield varied from 11.23 g $plant^{-1}$ to 38.26 g $plant^{-1}$ (Table-1). Several studies in wheat, as well as in other C3 species, genetic variability in $\Delta^{13}C$ is reflected in the variation in WUE at both the leaf and at the whole-plant level (Condon and Richards, 1993).

Table-1. Analysis of variance for drought tolerance traits.

Traits	Mean	Minimum	Maximum	SEm	CV	lsd $_{0.05}$
RL	50.39	36.50	75.17	3.32	9.33	13.02
RV	46.46	14.17	82.50	5.80	17.66	22.73
RW	11.15	5.15	17.07	1.04	13.24	4.09
TDM	42.08	24.12	78.18	4.12	13.84	16.14
SLA	251.10	175.72	483.21	20.15	11.35	78.96
TLA	2846.62	1306.39	5131.20	456.85	22.70	1790.31
$\Delta^{13}C$	20.20	18.78	21.66	0.47	3.32	1.86
Yield	23.07	11.23	38.26	1.92	11.80	7.54

RL = Root length (cm)
RV = Root volume (cm$^{3)}$
RW = Root weight (g plant^{-1})
TDM = Total dry biomass (g plant^{-1})
SLA = Specific Leaf area (cm^2)
TLA = Total Leaf area (cm^2)
$\Delta^{13}C$ = Carbon Isotope Discrimination (‰)
GY = Grain Yield (g plant^{-1})

CV = Coefficient of variation
SEm = Standard Error of Mean
lsd = Least square difference

Genotypic and phenotypic correlation coefficients for various drought tolerance traits are represented in Table-2. Root traits such as root volume and root dry biomass were positively and significantly correlated with grain yield. Leaf characters such as total leaf area (TLA) also correlated significantly with grain yield, However Specific leaf was not correlated with grain yield. WUE surrogate such as $\Delta^{13}C$ positively correlated with grain yield at 0.05%. Apart from grain yield a significant correlation was observed between $\Delta^{13}C$ and root volume, root biomass, TDM and TLA.

Table-2. Genotypic and phenotypic correlation coefficients for various drought tolerance traits.

		RL	RV	RW	TDM	SLA	LA	$\Delta^{13}C$	GY
RL	G	1	0.25	0.01	0.05	0.19	0.33*	-0.22	0.13
	P	1	0.23	-0.01	0.02	0.20	0.18	-0.17	0.10
RV	G		1	0.75**	0.88**	-0.21	0.75**	0.59**	0.48**
	P		1	0.67**	0.74**	-0.17	0.52**	0.40**	0.44*
RW	G			1	0.87**	-0.19	0.66**	0.90**	0.44*
	P			1	0.84**	-0.17	0.53**	0.56**	0.36*
TDM	G				1	-0.33*	0.67**	0.71**	0.48**
	P				1	-0.32*	0.62**	0.37*	0.38*
SLA	G					1	0.36*	-0.10	-0.12
	P					1	0.31*	-0.07	-0.07
TLA	G						1	0.58**	0.38*
	P						1	0.19	0.24
$\Delta^{13}C$	G							1	0.37*
	P							1	0.24
GY									1
									1

P = Phenotypic correlation coefficient
G = Genotypic correlation coefficient

* significant at 0.05
** significant at 0.01

To study the interrelationships between different drought tolerance traits, the direct and indirect effects of different characters were worked out using path analysis. Path coefficient analysis permits a thorough understanding of contribution of various characters by partitioning the correlation coefficient into components of direct and indirect effects. The direct and indirect effects of investigated characters on rice grain yield are presented in Table-3. The results showed that root traits like root length and root weight has a direct positive effect on grain yield.

These results indicate the importance of root in achieving higher crop yield under water limited conditions. Genotype or cultivars with deep root development will maintain higher leaf water potential under water limited conditions. If the genotype has high root restriction the genotype suffers from low leaf water potential status. This shows that a well developed root system will help the plant in maintaining high plant water status (Kato *et al*., 2007). Maintaining higher leaf water status under receding soil moisture conditions during grain filling is crucial for better grain yield. In areas where there is sufficient water availability, water extraction would exhaust the soil water resources resulting in the end season stress (Condon *et al*., 2002). The deeper root system would significantly increase the total biomass as well as yield. Jeena and Mani, (1990) studied root characters and grain yield on some upland rice varieties and indicated that high root length density and root weight, are important for selecting drought tolerant genotypes. Above ground traits like specific leaf area and total leaf area had a direct positive effect on grain yield. These results were in accordance to Rebetzke *et al*., 2004. They showed that rapid leaf area development (Specific leaf area) early in the season has potential to increase, water use efficiency and grain yield of winter cereals.

TDM had a positive direct effect on grain yield. These results were in accordance with Bidgoli *et al*., (2006). They demonstrated the direct effect of total biomass on seed yield in safflower. $\Delta^{13}C$ being the surrogate for whole plant level water use efficiency did not show any significant direct or indirect effect on grain yield for most of the traits. However an indirect positive effect was observed on grain yield via root weight and an indirect negative effect via total dry matter. Usually while selecting for high water use efficiency among conductance types would results in selection of low biomass types. The results of present study indicated the presence of both capacity and conductance types of accessions among the rice collections. Therefore care should be taken while selecting genotypes for higher WUE. Promising genotypes with high WUE coupled with moderately high total biomass should be identified for achieving higher crop yield. (Impa *et al*., 2005). The highest indirect effect on grain yield was noticed by root volume. Root length showed an indirect negative effect on grain yield via Root volume as well as TDM and a positive indirect effect via SLA. Root volume displayed an indirect positive effect via TLA. SLA displayed a negative indirect effect via root volume and TDM. Whereas a positive indirect effect was noticed for total TLA on grain yield via root volume and TDM indicating the importance of TLA and SLA in improving grain yield. These results were consistent with the findings of Tao *et al*., (2006).

Table-3. Direct and indirect effect of various traits on grain yield.

	Pathways of association	**Direct effect**	**Indirect effect**	**Residual effect**
1	**Root length**			
	a) Direct effect	0.2497		
	b) Indirect effect			
	Root volume		0.92	
	Root weight		-0.80	
	Total Dry Matter		0.05	
	Specific leaf area		0.56	
	Total leaf area		-0.76	
	$\Delta^{13}C$		0.04	
	c) Direct+ Indirect effect		0.25	0.69
2	**Root volume**			
	a) Direct effect	-0.0671		
	b) Indirect effect			
	Root volume		0.00	
	Root dry weight		0.40	
	Total Dry Matter		0.06	

	Specific Leaf Area		0.39	
	Total Leaf Area		-0.04	
	$\Delta^{13}C$		0.02	
	c) Direct+ Indirect effect		0.75	0.37
3	**Root weight**			
	a) Direct effect	0.4993		
	b) Indirect effect			
	Root length		0.01	
	Root volume		-0.03	
	Total Dry Matter		-0.01	
	Specific Leaf Area		-0.07	
	Total Leaf Area		0.47	
	$\Delta^{13}C$		0.00	
	c) Direct+ Indirect effect		0.87	0.25
4	**Total biomass**			
	a) Direct effect	0.2778		
	b) Indirect effect			
	Root length		-0.03	
	Root volume		-0.06	
	Root weight		-0.12	
	Specific Leaf Area		0.13	
	Total Leaf Area		0.03	
	$\Delta^{13}C$		0.00	
	c) Direct+ Indirect effect		-0.33	0.28
5	**Specific leaf area**			
	a) Direct effect	1.2595		
	b) Indirect effect			
	Root length		-0.03	
	Root volume		-0.36	
	Root weight		0.09	
	Total Dry Matter		-0.51	
	Total Leaf Area		-0.09	
	$\Delta^{13}C$		0.01	
	c) Direct+ Indirect effect		0.36	0.47
6	**Total leaf area**			
	a) Direct effect	0.2567		
	b) Indirect effect			
	Root length		-0.03	
	Root volume		0.25	
	Root weight		-0.14	
	Total Dry Matter		0.31	

	Specific leaf area		-0.06	
	Δ^{13}C		-0.01	
	c) Direct+ Indirect effect		0.58	0.31
7	**Δ^{13}C**			
	a) Direct effect	0.0295		
	b) Indirect effect			
	Root length		-0.04	
	Root volume		-0.02	
	Root weight		0.47	
	Total dry matter		-0.18	
	Specific leaf area		0.01	
	Total leaf area		0.10	
	c) Direct+ Indirect effect		0.37	0.31

Genetic parameters for characters considered are presented in the Table-4. It is observed that the magnitude of phenotypic variance was higher than the genotypic variance in most of the trait. These results indicate the influence of environment over the phenotypic expression. Similar results were observed by researchers.

Table 4. Genetic parameters for drought tolerance traits studied

	GCV	PCV	ECV	H_{BS}	GA
RL	18.60	20.80	9.33	79.90	34.24
RV	43.48	46.92	17.65	85.84	82.98
RW	32.08	34.70	13.24	85.45	61.08
TDM	29.58	32.66	13.84	82.04	55.20
SLA	22.03	24.78	11.35	79.04	40.35
TLA	30.61	38.11	22.70	64.53	50.65
Δ^{13}C	3.00	4.48	3.32	44.93	4.14
Yield	31.12	33.28	11.79	87.44	59.94

GCV: Genotypic coefficient of variation
PCV: Phenotypic coefficient of variation
ECV: Environment coefficient of variation
H_{BS}: Broad sense Heritability
GA: Genetic advance

Root volume displayed highest genetic advance of 82.98% with highest PCV and GCV of 43.48% and 46.91%. In an investigation consisting of 16 genotypes rice, carried out by Anasuya, (2003) the genetic parameters like genetic advance, GCV and PCV were assessed. Heritability serves as a good index for transmission of characters from one generation to next and it should be considered in terms of selection concept (Hanson 1959). Medium to high broad sense heritability (H^2_{BS}) was observed in different plant traits under study. High broad sense heritability was observed for most of the traits. Highest H^2_{BS} was noticed for grain yield per plant. Δ^{13}C displayed a medium heritability of 44.9%. Similar results were observed by several workers. Ray *et al.*, (1999) have demonstrated medium to high broad sense heritability among the physiological traits viz., WUE, Canopy temperature and yield in alfalfa cultivars grown in water stressed conditions in two cropping seasons. Heritability in WUE traits and Δ^{13}C was also reported in cowpea (Menendez and Hall, 1995). Greater magnitude of broad sense heritability coupled with higher genetic advance in root volume, root weight, grain yield, TDM and Δ^{13}C provided the evidence that these plant parameters were under the control of additive genetic effects. Results of high heritability and genetic advance of grain yield plant^{-1} are also in accordance with those reported by Li and Song (1991), Jha and Ghosh (1998) and Singha and Dash (2000). Hence Heritability provides better opportunities for selecting plant material regarding these traits.

CONCLUSIONS

Most of the above ground traits have been exploited for breeding drought tolerance. This has resulted in narrow variability in grain yield among recently developed cultivars especially under aerobic conditions in rice. In the present study it is clearly shown that below ground traits roots traits has a direct relevance in improving grain yield under aerobic condition. Based on the analysis several trait donor germplasm lines were selected for developing trait introgressed lines. Incorporation of these lines as trait donors in regular breeding would confer drought tolerance and improved grain yield of rice under aerobic condition.

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