

Genotype x environment interaction and indirect selection of rice in irrigated and nonirrigated flood plain areas*

Plínio César Soares¹, Carlos Siqueyuki Sedyama², Cosme Damião Cruz³ and José Carlos Silva³

ABSTRACT

Two rice (*Oryza sativa* L.) cross progenies were raised independently from the F₂ to the F₄ generation in both irrigated and nonirrigated wet flood plain areas (wetlands). In the F₄ generation, lines from each cross and each environment were selected and in the F₆ generation they were tested for yield in both environments for two successive years (1988/89 and 1989/90). Each trial included 15 or 16 lines from each cross and each environment and two check varieties (Inca and MG 1) evaluated in an 8 x 8 triple lattice design. The objectives of this study were to determine the importance of genotype x environment interaction and the possibility of performing indirect selection in just one environment to obtain a cultivar suited to both environments. The data suggests: 1) irrigation gives a more uniform environment and favors the selection of higher yielding rice cultivars, because it allows greater expression of genetic potential and provokes greater genetic variance for yield; 2) the absence of genotype x environmental interactions permits the cultivation of the same cultivar in both irrigated and nonirrigated flood plain areas; and 3) in breeding programs of rice for flood plain areas, it is possible to continue the segregating populations in the irrigated system up to the F₄ generation, select the superior cultivars, and make the final evaluations of these cultivars in both environments.

INTRODUCTION

Genetic x environment interactions are of fundamental importance to the plant breeder for the development of new cultivars, when cultivars are compared across a series of environments, their relative classification may be altered, making it difficult to evaluate the relative superiority of cultivars (Eberhart and Russell, 1966). To minimize the genetic x environment interaction and enhance the predictability of the behavior of a given genotype, it is necessary to identify the more stable ones. However, stable

genotypes, adapted to a wide range of environments, are usually difficult to obtain.

Rice cultivars grown in basin irrigated or in nonirrigated wet flood plain areas have their own peculiarities, but they also have some converging characteristics, such as the lack of hydric stress. It seems that cultivars selected in a given system may have satisfactory performance in the other system and vice-versa. The traditional rice breeding programs in Minas Gerais and other states, where irrigated and wetland rice culture systems are used, evaluate and select lines in each cropping system from the early segregating generations up to the final evaluation trials (Soares, 1993).

One of the main objectives of the present study is to propose an alternative method to reduce operational costs of wetland rice breeding programs:

* Part of a thesis presented by P.C.S. to the Universidade Federal de Viçosa (UFV), in partial fulfillment of the requirements for the Doctoral degree. Send correspondence to C.S.S.

¹ EPAMIG-Viçosa, Caixa Postal 216, 36571-000 Viçosa, MG, Brasil.

² Departamento de Fitotecnia, UFV, 36571-000 Viçosa, MG, Brasil.

³ Departamento de Biologia Geral, UFV, 36571-000 Viçosa, MG, Brasil.

genotypes are selected for both environments but the selection is made in just one environment. In this scheme, the final trials are not altered, i.e., they are conducted in both environments. Another objective is to analyze the genetic x environment interaction for lines selected in irrigated and nonirrigated wet flood plain areas.

MATERIAL AND METHODS

Evaluation trials were conducted during the 1988/89 and 1989/91 growing seasons in basin irrigated and nonirrigated flood plain areas. The trials included 15 or 16 F₆ lines from two rice crosses, 16497//Cica 4/Camponi and 6850/17631//Cica 7, from the International Center for Tropical Agriculture - CIAT.

Segregating F₂ populations of each cross were advanced in each cropping system (environment) by the National Rice and Bean Research Center (CNPAP/EMBRAPA), following the methodology recommended by Rangel (1984) and Ferreira *et al.* (1988). The populations were advanced to the F₄ generation, when the best lines were selected and advanced to the F₆ generation. Each trial included two check cultivars (Inca and MG 1) and 15 or 16 best F₆ lines from each cross and each environment. The trials were conducted in both environments for two successive years in an 8 x 8 triple lattice design. Each plot had four 5 m rows spaced 0.30 m. The two lateral rows and the 0.5 m of each row extremity were considered borders.

The analysis of variance of grain yield was performed according to Cochran and Cox (1980), considering treatment effects as random and cropping system effects as fixed. Initially, the analysis of variance was performed for each environment and then the data from the two environments in each year were analyzed across environments. From these analyses, the variance components, the coefficient of genetic variation (CV_g), the genetic variation index (b), and the heritabilities (h²) were estimated, following Vencovsky (1987). The estimates of expected genetic gains by direct and indirect selection, expressed in g/2.4 m² (G) and in percentage of the mean (G%), were obtained for each cross for the growing season of 1988/89, according to Falconer (1964) and Vencovsky (1987). A 40% selection intensity was adopted.

RESULTS AND DISCUSSION

The coefficient of variation of the experiments ranged from 11.6 to 15.2%. Considering the average

variation by the criterion established by Gomes (1987), the precision of the trials was good and acceptable.

In both crosses and both growing years the grain yield in the irrigated environment was always superior to that of the nonirrigated environment, for lines selected in wet plain or under irrigation. Based on the overall average of the lines in each environment, the yield potentials of the lines were similar in both crosses. The average yield ranged from 4916 to 5442 kg/ha, in 1988/89, and from 4117 to 5229 kg/ha, in 1989/90. These yields may be considered as good for both environments.

In the first growing season, the genetic variances in the two environments were significant for rice lines of the cross 6850//17631/Cica 7 selected in irrigated and nonirrigated systems. For the cross 16497//Cica 4/Camponi, however, the genetic variance was significant only for the lines selected under irrigation in both environments. The results demonstrate that there is variability among the lines, mainly among the genotypes selected under irrigation, suggesting that it is possible to select superior lines from these crosses.

In the second growing season, different results were observed. In the cross 16497//Cica 4/Camponi, only the mean square for irrigated lines grown in an irrigated environment was significant ($P \leq 0.05$). For the remaining environments, the F tests were not significant. For the cross 6850/17631//Cica 7, the situation was reversed: significant variation was detected only among wetland lines grown in the wet flood plain environment.

No significant interactions were detected among lines and environments for both crosses and for both growing seasons. These results suggest that lines selected in wet plain, or under irrigation, had similar behavior in both environments. For the breeder seeking superior lines selected in one environment that would perform well in another environment, the nonsignificant interactions would enhance selection. Rangel (1990), in a similar study conducted in Goiânia-GO, arrived at different results. Rangel (1990) reported a significant genotype x environment interaction ($P < 0.01$) among lines from both crosses. Lines selected under irrigation had a different response when tested in the nonirrigated system.

The estimates of genetic variances were generally larger for lines initially selected in the irrigated environment, allowing larger genetic gains from selection. The coefficients of genetic variation (CV_g%) were used to estimate the relative genetic variability among lines for the grain yield in g/2.4 m² (Tables I, II). These estimates express the amount of genetic

variability among lines, in relation to their respective population means. The CVg% values were generally larger for lines initially selected in the irrigated environment than for lines initially selected in the wetland. In the average of the irrigated and nonirrigated environments, the CVg% values ranged from 0.9 to 7.1 for wetland lines, while it ranged from 6.1 to 12.4 for irrigated lines. These estimates of CVg% were similar to those reported in rice (Goud *et al.*, 1969; Mishra *et al.*, 1973; Rangel, 1990). Research conducted in Brazil with maize (*Zea mays* L.) reported CVg% values greater than 7% (Santos and Napolini Filho, 1986; Bigoto, 1988).

Vencovsky (1987) established a genetic variation index (b) which quantifies the proportion of the genetic variability in relation to the environmental variability. The b values obtained for all crosses, cropping systems, and growing seasons, suggested that the irrigated lines were superior to nonirrigated lines, mainly for the cross 6850//17631/Cica 7 evaluated

in 1988/89 (Tables I, II). The b values for the irrigated lines were 1.00 for wet plain and 0.99 for the irrigated system, compared to 0.64 and 0.53 for the lines selected for wet plains, in the respective environments. In the second growing season, the b value estimates were lower than the ones of the first growing season, ranging from 0.20 to 0.72. These results indicate the occurrence of larger genetic variability among lines selected under irrigation, which favors the selection within this group of lines. These results are in accordance to those obtained by Soares (1987), who concluded that high productivity environments are more appropriate to select superior genotypes. High productivity environments permit greater discrimination among lines because of greater genetic variability among these lines.

The genetic gains for irrigated rice lines (Table III), selected and evaluated in the wetland ($G_{I:W/W} = 10.5$ and 10.6%), were superior to the genetic gains of the wetland lines selected and evaluated in the irrigated

Table I - Estimates of genetic parameters for grain yield ($g/2.4 m^2$) of the irrigated and wetland lines, per cross and per environment and across two environments (1988/89).

Estimates	16497//Cica 4/Camponi			6850//17631/Cica 7		
	Wetland	Irrigated	Combined	Wetland	Irrigated	Combined
σ_{WL}^2	613.9	-1056.8	115.1	9863.2	7514.7	7915.6
σ_{IL}^2	19768.5	7421.6	15844.9	21839.9	26674.4	23451.6
σ_{WLE}^2	-	-	-336.6	-	-	773.5
σ_{ILE}^2	-	-	-2249.9	-	-	805.5
σ_e^2	22804.0	26559.2	24681.6	22804.0	26559.2	24681.6
CV _{gWL} (%)	2.2	-	0.9	8.1	6.7	7.1
\hat{b}_{gWL}	0.17	-	0.12	0.64	0.53	0.96
CV _{gIL} (%)	11.6	6.4	12.3	12.8	12.4	12.4
\hat{b}_{gIL}	0.91	0.51	1.67	1.00	0.99	1.68
\hat{h}_C^2 (%)	58.2	46.4	-	68.4	65.3	-
\hat{h}_{WL}^2 (%)	7.5	-	-	56.5	45.9	-
\hat{h}_{IL}^2 (%)	72.2	45.6	-	74.2	75.1	-

σ_{WL}^2 and σ_{IL}^2 - genetic variance of the wetland and irrigated lines, respectively.

σ_{WLE}^2 and σ_{ILE}^2 - genetic variance of the interaction of wetland lines x environment and of irrigated lines x environment, respectively.

σ_e^2 - variance of effective error.

CV_{gWL} (%) - coefficient of genetic variation for wetland lines.

CV_{gIL} (%) - coefficient of genetic variation for irrigated lines.

\hat{b}_{gWL} and \hat{b}_{gIL} - index of genetic variation for wetland and irrigated lines, respectively.

\hat{h}_C^2 , \hat{h}_{WL}^2 and \hat{h}_{IL}^2 - heritability for cross, for wetland and irrigated lines within cross, respectively.

environment ($G_{W:I/I} = -0.9$ and 3.8%) in the cross 16497//Cica 4/Camponi and 6850//17631/Cica 7, respectively. In the average of the two crosses, the direct genetic gain in the irrigated environment ($G_{I:I/I} = 7.5\%$) was superior to the indirect genetic gain of the wetland lines selected in the wetland and evaluated in the irrigated environment ($G_{W:W/I} = 2.4\%$), while the direct genetic gain in the wetland environment ($G_{W:W/W} = 3.3\%$) was inferior to the indirect genetic gain of the irrigated lines selected in the irrigated environment and evaluated in the wetland ($G_{I:I/W} = 10.4\%$).

Plant breeders can orient selection programs to obtain cultivars that are adapted to a wide range of environments or to obtain cultivars adapted to a specific environment. Small and statistically nonsignificant genotype x environmental interactions favor the first situation, while significant interactions favor the second alternative. Considering the nonsignificant lines

x environment interactions and the estimates of the genetic gains for the grain production by direct and indirect selection, it seems effective selection of a highly productive cultivar can be achieved in just one environment, adapted to both the basin irrigated and the wet plain environments.

It can be inferred that the irrigated cropping system, compared with the wet plain cropping system, allows for a more uniform environment and favors the selection of more productive rice genotypes. Because of greater variability among lines at greater grain production levels, greater selection gains would be expected. In breeding programs designed to develop new rice cultivars for wet flood plains areas, it seems viable to carry the segregant populations up to the F₃ or F₄ generation, select the progenies in the irrigated cropping system, and then perform the final evaluation trials in both irrigated and nonirrigated wet flood plain areas.

Table II - Estimates of genetic parameters of the grain yield ($g/2.4 m^2$) of the irrigated and wetland lines, per cross and per environment, and across two environments (1989/90).

Estimates	16497//Cica 4/Camponi			6850//17631/Cica 7		
	Wetland	Irrigated	Combined	Wetland	Irrigated	Combined
σ_{WL}^2	1166.1	2759.7	775.8	7283.4	3531.7	5222.2
σ_{IL}^2	5855.0	7307.8	7091.0	5835.0	827.3	4410.8
σ_{WLE}^2	-	-	1187.1	-	-	185.1
σ_{ILE}^2	-	-	-509.6	-	-	1079.7
σ_e^2	22539.2	20618.4	21578.8	22539.2	20618.3	21578.8
$CV_{gWL} (\%)$	3.6	4.3	2.6	8.4	4.8	6.4
\hat{b}_{gWL}	0.24	0.28	0.35	0.72	0.41	0.87
$CV_{gIL} (\%)$	7.3	6.6	7.2	7.9	2.4	6.1
\hat{b}_{gIL}	0.48	0.43	0.98	0.68	0.20	0.84
$\hat{h}_C^2 (\%)$	42.3	48.2	-	47.3	24.0	-
$\hat{h}_{WL}^2 (\%)$	13.4	28.6	-	49.2	33.9	-
$\hat{h}_{IL}^2 (\%)$	43.8	51.5	-	43.7	10.7	-

σ_{WL}^2 and σ_{IL}^2 - genetic variance of the wetland and irrigated lines, respectively.

σ_{WLE}^2 and σ_{ILE}^2 - genetic variance of the interaction of wetland lines x environment and of irrigated lines x environment, respectively.

σ_e^2 - variance of effective error.

$CV_{gWL} (\%)$ - coefficient of genetic variation for wetland lines.

$CV_{gIL} (\%)$ - coefficient of genetic variation for irrigated lines.

\hat{b}_{gWL} and \hat{b}_{gIL} - index of genetic variation for wetland and irrigated lines, respectively.

\hat{h}_C^2 , \hat{h}_{WL}^2 and \hat{h}_{IL}^2 - heritability for cross, for wetland and irrigated lines within cross, respectively.

Table III - Expected genetic gains in g/2.4 m² and in percentage of the average, origin of the lines, place of final evaluation and selection, and place of response to the selection for the wetland and irrigated lines obtained from the crosses 16497//Cica 4/Camponi and 6850//17631/Cica 7.

Cross	Origin of the line	Place of final evaluation and selection	Place of response to selection	Expected gains	
				g/2.4 m ² (G)	Percent of the average (G%)
16497//Cica 4/Camponi	W	W	W	6.8	0.6
	W	W	I	5.0	0.4
	W	I	I	-10.5	-0.9
	W	Average	Average	1.8	0.2
	I	I	I	61.1	4.5
	I	I	W	148.9	11.0
	I	W	W	127.8	10.5
	I	Average	Average	123.1	9.6
6850//17631/Cica 7	W	W	W	74.6	6.1
	W	W	I	54.0	4.4
	W	I	I	48.7	3.8
	W	Average	Average	66.5	5.3
	I	I	I	138.2	10.5
	I	I	W	117.2	9.9
	I	W	W	123.2	10.6
	I	Average	Average	142.1	11.5

W - Wetland environment. I - Irrigated environment.

RESUMO

Linhagens F₆ de dois cruzamentos de arroz foram avançadas independentemente desde F₂, e foram selecionadas na geração F₄, no sistema de cultivo irrigado por inundação ou em várzea úmida. Em 1988/89 e 1989/90, essas linhagens foram avaliadas em ensaios comparativos de rendimento, nos dois ambientes. Cada ensaio foi constituído de 15 ou 16 linhagens de arroz de cada cruzamento e cada tipo de ambiente, e de duas testemunhas (Inca e MG 1). Estudou-se a interação genótipo x ambiente e avaliou-se, por meio da resposta indireta à seleção, a possibilidade de efetuar, em apenas um dos ambientes, a seleção preliminar de genótipos de arroz promissores para ambos os sistemas de cultivo. Concluiu-se que: 1) o sistema de cultivo irrigado, em relação ao de várzea úmida, possibilita ambiente mais uniforme, por permitir maior expressão do potencial genético para produção de grãos e proporcionar maior manifestação da variância genética desse caráter; 2) a ausência de interação genótipo x ambiente permite a utilização das mesmas linhagens nas várzeas irrigadas e nas várzeas úmidas sem irrigação; e 3) em programas de melhoramento genético de arroz de várzea, é possível conduzir as populações segregantes até F₄ e selecionar as progênies no sistema de cultivo irrigado e, subsequentemente, proceder à avaliação final das linhagens, tanto no ambiente irrigado, quanto em várzea úmida sem irrigação.

REFERENCES

- Bigoto, C.A.** (1988). Estudo da população ESALO-PB 1 de milho (*Zea mays* L.) em cinco ciclos de seleção recorrente. Master's Thesis, Escola Superior de Agricultura "Luiz de Queiroz", USP, Piracicaba, SP.
- Cochran, W.G.** and **Cox, G.M.** (1980). *Diseños Experimentales*. Editorial Trillas, México, pp. 661.
- Eberhart, S.A.** and **Russell, W.A.** (1966). Stability parameters for comparing varieties. *Crop Sci.* 6: 36-40.
- Falconer, D.S.** (1964). *Introduction to Quantitative Genetics*. The Ronald Press, New York, pp. 365.
- Ferreira, R.P., Cutrin, V.A.** and **Rangel, P.H.N.** (1988). *Programa de melhoramento de arroz irrigado no CNPAF*. In: Reunião da Cultura de Arroz Irrigado, 17, Pelotas. *Anais... Pelotas: EMBRAPA/CPATB*, pp. 3-9.
- Gomes, F.P.** (1987). *Curso de Estatística Experimental*. Nobel, São Paulo, pp. 465.
- Goud, J.V., Nayar, K.M.D.** and **Rao, M.G.** (1969). Recent trends in rice breeding in Mysore State, III. Adaptation and genotypic and phenotypic variability in three environments. *Plant Breed.* 62: 129-137.
- Mishra, K.N., Nanda, J.S.** and **Chaudhary, R.C.** (1973). Correlation, path-coefficient and selection indices in dwarf rice. *Indian J. Agric. Sci.* 43: 306-311.

- Rangel, P.H.N.** (1984). Melhoramento do arroz para condições de várzeas úmidas. In: EMBRAPA/CNPAP. *Melhoramento Genético do Arroz*. Goiânia, pp. 89-112.
- Rangel, P.H.N.** (1990). Eficiência da seleção simultânea de arroz (*Oryza sativa* L.) em várzea, com e sem irrigação controlada. Doctoral Thesis, Escola Superior de Agricultura "Luiz de Queiroz", USP, Piracicaba, SP.
- Santos, M.S.** and **Naspolini Filho, V.** (1986). Estimativas de parâmetros genéticos em três ciclos de seleção entre e dentro de famílias de meios-irmãos no milho (*Zea mays* L.) dentado composto Nordeste. *Rev. Brasil. Genet.* 9: 307-319.
- Soares, P.C.** (1987). Correlações, coeficientes de trilha e resposta indireta à seleção em genótipos de arroz (*Oryza sativa* L.) cultivados sob irrigação por inundação contínua e em várzea úmida. Master's Thesis, Universidade Federal de Viçosa, Viçosa, MG.
- Soares, P.C.** (1993). Interação genótipo x ambiente e resposta indireta à seleção de linhagens de arroz (*Oryza sativa* L.) cultivadas sob irrigação por inundação contínua e em várzea úmida. Doctoral Thesis, Universidade Federal de Viçosa, Viçosa, MG.
- Vencovsky, R.** (1987). Herança quantitativa. In: *Melhoramento e Produção do Milho* (Paterniani, R. and Veigas, G.P., eds.). Fundação Cargill, Campinas, pp. 135-214.

(Received December 21, 1994)