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EFFICIENCY OF SIMULTANEOUS SELECTION OF LOWLAND RICE (*Oryza sativa* L.) WITH AND WITHOUT CONTROLLED IRRIGATION*

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ABSTRACT

Main effect and genotype x environment interaction components of variance, the expected gains for indirect and direct selection, correlation between environments, intraclass correlation, and the concordance coefficient for yield were estimated to adjust the breeding program of irrigated and rainfed lowland rice conducted by EMBRAPA/CNPAF, and to evaluate the possibility of selecting lines from one system adapted to both growing systems.

The genetic gains (assuming a selection intensity of 40%) in rainfed lowland lines, with selection and response in irrigated environment ($G_{SLV2/2}$ = 6.80% and 8.00%) were superior to the genetic gains in irrigated lines, with selection and response in rainfed lowland environment ($G_{SLI1/1}$ = 5.37% and 6.90%) for the crosses CICA 8/Metica 1 and 17388//7153/5738, respectively.

The superiority of the genetic gains in rainfed lowland lines, the high values of the correlations between environment and the concordance coefficients suggest that it is viable to develop a program of irrigated rice breeding with initial selections (until F_5) being made in the rainfed lowland environment and evaluations and final selection in both environments.

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INTRODUCTION

Information about the magnitude of genotype x environment interactions permit the breeder to choose broadly adapted genotypes or genotypes adapted to specific environments. The selection of genotypes specifically adapted to special environments requires separate breedind programs in each subregion, with consequent increased manpower, genetic, and financial costs.

On the other hand, as pointed out by Allard and Bradshaw (1964), the stability with which the breeder is usually concerned does not imply a general phenotype constancy in variable environments. Stability means that phenotypic traits of economic importance such as yield and quality will remain stable. Thus, a low genotype x environment interaction for these traits is of interest to the breeder as long as the economic return is high and stable regardless of year or location, somehow compensating for transient environmental fluctuations.

In Brazil, rice is grown under four major types of conditions: 1) lowland rice with controlled irrigation (irrigated rice), 2) lowland rice without controlled irrigation (rainfed lowland rice), 3) upland rice, and 4) unfavored upland rice.

Although irrigated and rainfed lowland rice cultures present distinct peculiarities, they share some characteristics, most important among them the almost total lack of hidric stress. This has contributed to the fact that lines selected in one of these systems behave satisfactorily in the other. Genetic breeding programs are based on separate selection and testing of promising lines under both culture conditions from segregant generations to final competition trials from which the new cultivars arise.

In view of the above considerations, a way of reducing operational costs would be preliminary selection in only one culture system of genotypes adapted both to irrigated and rainfed lowland culture conditions. Thus, the objectives of the present study were: a) to test by simultaneous response to selection the possibility of selecting lines adapted to both culture systems, and b) to obtain technical information that might permit a restructuring of the genetic breeding programs involving irrigated and rainfed lowland rice conducted by "Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)/Centro Nacional de Pesquisa de Arroz e Feijão (CNPAF)".

MATERIAL AND METHODS

The trials were conducted in two environments represented by irrigated and rainfed lowland rice culture systems in the 1988/89 season.

The lines tested in the trial were F_6 generations from the triple cross 17388//7153/5738 and from the single cross CICA 8/Metica 1. The triple cross was obtained at "Centro Internacional de Agricultura Tropical - CIAT" (International Center of Tropical Agriculture), and the single cross at CNPAF. The lines were obtained from the same F_2 populations independently grown in each culture system according to the methodology proposed by Rangel *et al.* (1984, 1987) and Ferreira *et al.* (1988). Each trial consisted of 40 lines taken at random from the rainfed lowland environment and of 39 lines from the irrigated environment by crossing, plus two checks (CICA 8 and Metica 1). Each trial was conducted in both environments.

The experimental design consisted of four 9 x 9 triple lattices. Each plot (3.6 m^2 total area) consisted of three 4.0 m rows spaced 0.30 m apart. Because of the relative homogeneity of the experimental material in terms of plant cycle and height, two rows of the CICA 8 cultivar were used as borders around each replication. Thus, the useful area of the plot for data collection was represented by the full plot.

Data for grain yield per cross were analyzed individual and joint analysis of variance by the method of Cochran and Cox (1980), considering line effects to be random and environmental effects to be fixed. The various components of variance, the $\hat{b}$ variation index, and the coefficient of genetic variation were estimated from these analyses.

The expected gains by selection, reported as kg/3.6 m^2 (G_S) and percent of the mean (G_S%), for each cross were estimated using the formulas proposed by Vencovsky (1987), simulating 40% selection intensity.

Intraclass correlations (i.e. the correlation between treatment means within a trial) and correlation between environments per cross were obtained for irrigated rice and rainfed lowland rice lines using the formulas proposed by Steel and Torrie (1980).

The concordance coefficient was determined as suggested by Hamblin and Zimmermann (1986). The lines were classified by grain yield in each environment. The best 40% rainfed lowland rice lines were then selected in the rainfed lowland environment and the frequency of these lines among those occupying the first positions in the irrigated environment was determined, with the result expressed as a percentage. The same procedure was adopted for the irrigated rice lines selected in the irrigated environment.

RESULTS AND DISCUSSION

For the CICA 8/Metica 1 cross, the range of grain yield (kg/3.6 m^2) variation among rainfed lowland lines in the rainfed lowland and irrigated environments was 1.83 to 3.31 (mean, 2.60) and 2.22 to 3.50 (mean, 2.90), respectively, whereas for the irrigated rice lines, grain yield ranged from 1.99 to 3.36 (mean, 2.59) in the rainfed lowland environment, and from 2.50 to 3.49 (mean, 2.88) in the irrigated environment. For the 17388//7153/5738 cross, the grain yield of rainfed lowland lines ranged from 1.83 to 2.95 (mean, 2.44) and from 1.76 to 2.81 (mean, 2.37) in the rainfed lowland and irrigated environments, respectively, and the grain yield of irrigated rice lines ranged from 1.78 to

3.00 (mean, 2.26) and from 1.71 to 2.77 (mean, 2.27) in the two environments, respectively. These data indicate the productive potential of some progenies and the possibility of successful selection.

Table I shows that there was a highly significant difference between irrigated and rainfed lowland rice lines in the two crosses and in the two environments. These results confirm the considerable variation existing between the lines used.

Table I - Individual analyses of variance of grain yield performed on adjusted treatment means obtained in the trials conducted in rainfed lowland (RL) and irrigated (I) environment for the two crosses.

Source of variation	d.f.	Mean square				E (MS)
		CICA 8/Metica 1		1738//7153/5738		
		RL	I	RL	I	
Treatments	80	0.0701**	0.0551**	0.0710**	0.0783**	$\sigma^2 + \sigma_L^2$
Lowland lines (RL)	39	0.0882**	0.0702**	0.0544**	0.0730**	$\sigma^2 + \sigma_{RL}^2$
Irrigated lines (IL)	38	0.0554**	0.0422**	0.0604**	0.0781**	$\sigma^2 + \sigma_{IL}^2$
Checks	1	0.0619*	0.0154ns	0.1139*	0.0101ns	
Groups	2	0.0004ns	0.0255ns	0.5754**	0.2216**	
Effective mean error	272	0.0148	0.0148	0.0176	0.0176	σ^2
CVe (%)		7.44	7.84	10.42	9.10	

E (MS), Expected mean squares calculated with the adjusted means of three replications.

** and *, Significant at the 1% and 5% level, respectively, by the F test.

ns, Not significant.

Because of the homogeneity of the effective errors, we opted for the use of an effective mean error per cross in the analyses of variance. This permits a more consistent comparison of the various components of variance of the same cross, since they are estimated with the same error.

Highly significant interactions ($P < 0.01$) between environment and irrigated and rainfed lowland rice lines were obtained for both crosses (Table II), indicating that the lines behaved differently in the two environments.

Table II - Joint analyses of variance of grain yield performed on adjusted treatment means obtained in two environments for the crosses CICA 8/Metica 1 and 17388//7153/5738.

Source of variation	d.f.	CICA 8/Metica 1	17388/7153/5738	E (MS)
		MS	MS	
Replications/Environments	4	-	-	-
Environments (E)	1	0.0401	0.0984	-
Treatments (T)	80	0.0940^{**}	0.0997^{**}	$\sigma^2 + 2\sigma^2_T$
Lowland lines (RL)	39	0.1270^{**}	0.0960^{**}	$\sigma^2 + 2\sigma^2_{RL}$
Irrigated lines (IL)	38	0.0648^{**}	0.1077^{**}	$\sigma^2 + 2\sigma^2_{LI}$
Checks	1	0.0694^{*}	0.0959^{*}	-
Groups (G)	2	0.0171^{ns}	0.0217^{ns}	-
T x E	80	0.0314^{**}	0.0347^{**}	$\sigma + 2\sigma^2_{TE}$
RL x E	39	0.0314^{**}	0.0314^{**}	$\sigma^2 + 2\sigma^2_{RLE}$
IL x E	38	0.0328^{**}	0.0308^{**}	$\sigma^2 + 2\sigma^2_{ILE}$
Check x E	1	0.0078^{ns}	0.0281^{ns}	-
Between G x E	2	0.0154^{ns}	0.1754^{**}	-
Effective mean error	272	0.0148	0.0176	σ^2
CVe (%)		7.69	9.78	

E (MS), Expected mean squares calculated with the adjusted means of three replications.

** and *, Significant at the 1% and 5% level, respectively, by the F test.

ns, Not significant.

For the CICA 8/Metica 1 cross, the genetic variances for the rainfed lowland and irrigated rice lines in the rainfed lowland environment were greater than the respective variances in the irrigated environment. The opposite occurred for the 17388//7153/5738 cross (Table III).

Except for the irrigated rice line in the irrigated environment, with a coefficient of genetic variation of 5.75%, the remaining coefficients of genetic variation (CVg%) were higher than 7.00% for both crosses (Table III). The CVg% estimates obtained by others for rice lines ranged from 7.19% to 16.80% (Sen *et al.*, 1969; Goud *et al.*, 1969; Mishra *et al.*, 1973; Das and Borthakur, 1974). In maize, several investigators consider CVg% values higher than 7.00% to indicate the genetic potential of a population (Lima *et al.*, 1974; Santos, 1977; Santos and Naspolini Filho, 1986; Bigoto, 1988).

Table III - Estimates of genetic variances, line x environment interactions, effective errors and coefficients of genetic variation, and variation indices per cross for grain yield (kg/3.6 m^2) for the rainfed lowland (RL) and irrigated (I) environments, separately and jointly.

Estimates[a]	CICA 8/Metica 1			17388//7153/5738		
	Rainfed Lowland	Irrigated	Joint	Rainfed Lowland	Irrigated	Joint
$\hat{\sigma}^2_{RL}$	734 ± 195	554 ± 156	561 ±140	368 ± 122	554 ± 162	392 ± 106
$\hat{\sigma}^2_{IL}$	406 ± 125	274 ± 96	250 ± 70	428 ± 136	605 ± 175	450 ± 120
$\hat{\sigma}^2_{RLE}$	-	-	83 ± 35	-	-	69 ± 35
$\hat{\sigma}^2_{ILE}$	-	-	90 ± 37	-	-	66 ± 35
$\hat{\sigma}$	148	148	148	176	176	176
$\hat{CV}_{gRL\%}$	10.42	8.12	8.61	7.86	9.93	8.25
$\hat{b}_{RL}$	1.28	1.12	1.12	0.83	1.02	0.86
$\hat{CV}_{gIL\%}$	7.78	5.75	5.79	9.15	10.83	9.39
$\hat{b}_{IL}$	0.96	0.78	0.75	0.90	1.07	0.92

[a] Estimates of variance multiplied by 10^4.

$\hat{\sigma}^2_{RL}$ and $\hat{\sigma}^2_{IL}$ = genetic variances of the rainfed lowland and irrigated lines, respectively.

$\hat{\sigma}^2_{RLE}$ and $\hat{\sigma}^2_{ILE}$ = genetic variance of the rainfed lowland line x environment and irrigated line x environment interactions, respectively.

$\hat{\sigma}^2$ = variance of the effective error.

$\hat{CV}_{gRL\%}$ = coefficient of genetic variation for the rainfed lowland line.

$\hat{CV}_{gIL\%}$ = coefficient of genetic variation for the irrigated line.

$\hat{b}_{RL}$ and $\hat{b}_{IL}$ = variation index for the rainfed lowland and irrigated lines, respectively.

The variation index $\hat{b}$ proposed by Vencovsky (1987) quantified the proportion of genetic variability in relation to environmental variability. Since the effect of the means is removed, it is possible to compare variability in populations tested in different environments. Analysis of the variation index $\hat{b}$ obtained in the present study shows that, in general, the rainfed lowland lines presented $\hat{b}$ values higher than 1.0 in both environments, demonstrating the presence of sufficient genetic variability to favor selection (Table III). The ideal selection environment would be one in which the genotypes express the highest level of genetic variabil'ty, thus permitting the identification of superior individuals.

The variances of line x environment interactions, although highly significant were of low magnitude when compared with the genetic variances of the irrigated and rainfed lowland rice lines of the two crosses (Table III).

According to Comstock and Moll (1963), the breeder's aim in a breeding program should be to obtain varieties that will behave well over a broad range of environments, or cultivars highly adapted to special types of environments. The first alternative is recommended when genotype x environment interaction is small, whereas the second is recommended when genotype x environment interaction is of large magnitude. Furthermore, according to Perkins and Jinks (1971), and Hill (1975), evidence has been accumulated which shows that the magnitude of genotype x environment interaction is subjected to genetic control. Thus, on the basis of the small magnitude of the line x environment interactions obtained here and of the fact that this parameter is under genetic control, a rice breeding program aiming at the simultaneous selection of varieties having a high potential for yield and adapted to irrigated and rainfed lowland conditions would be perfectly feasible.

The gains expected by selection (Table IV) show that the genetic gains in rainfed lowland lines of the CICA 8/Metica 1 cross were generally superior to the genetic gains in irrigated lines. The opposite occurred for the lines of the 17388//7153/5738 cross.

Table IV - Expected gains, origin of the lines, final evaluation and selection and response to selection for the irrigated and rainfed lowland rice lines obtained from the crosses CICA 8/Metica 1 and 17388//7153/5738.

Cross	Origin	Final evaluation and selection	Response	Expected gains	
				$kg/3.6\ m^2$	% of the mean
CICA 8/Metica 1	RL	RL	RL	0.2247	8.64
	RL	RL	I	0.1463	5.63
	RL	I	I	0.1973	6.80
	RL	M	M	0.1944	7.07
	I	I	I	0.1234	4.28
	I	I	RL	0.0720	2.50
	I	RL	RL	0.1392	5.37
	I	M	M	0.1312	4.81
17388//7153/5738	RL	RL	RL	0.1353	5.54
	RL	RL	I	0.1187	4.86
	RL	I	I	0.1897	8.00
	RL	M	M	0.1552	6.47
	I	I	I	0.1937	8.53
	I	I	RL	0.1229	5.41
	I	RL	RL	0.1559	6.90
	I	M	M	0.1671	7.36

RL, Rainfed lowland environment; I, irrigated environment; M, mean for the two environments.

The genetic gains in the rainfed lowland lines with selection and response in the irrigated environment ($G_{SRL2/2}$ = 0.1973 and 0.1897 kg/3.6 m^2) were superior to the genetic gains in irrigated lines with selection and response in the rainfed lowland environment ($G_{SIL1/1}$ = 0.1392 and 0.1559 kg/3.6 m^2) for the crosses CICA 8/Metica 1 and 17388//7153/5738, respectively (Table IV). This superiority of the rainfed lowland lines may be due to the fixation of favorable alleles during the initial selection in the rainfed lowland growing system, which were fully expressed in the two environments. This was clearly demonstrated by the variation indices b in the rainfed lowland lines, which were usually higher than 1.0 (Table III).

The estimated genetic gains indicate that one of the alternatives for a breeding program of irrigated rice would be to make the initial selections (until F_5) in the rainfed lowland environment, and evaluations and final selection separately in each environment. This program may increase the probability of obtaining highly productive lines adapted to both rainfed lowland and irrigated environments, with the additional advantage of reduced costs and manpower. Several investigators have suggested similar schemes for several crops such as barley (Rasmusson and Glass, 1967), wheat (Boyd *et al.*, 1976), and beans (Francis *et al.*, 1978a,b).

Analysis of correlation estimates between environments (Table V) shows that, except for the correlation for the irrigated rice lines of the CICA 8/Metica 1 cross which was 0.33, all others were higher than 0.50, confirming the estimated genetic gains.

Table V - Estimates of intraclass correlations and correlations between environments, and concordance coefficients for grain yield data (kg/3.6 m^2) for the rainfed lowland rice lines (r_{RLRL}, r_{RL1RL2} and CC_{RL}) and irrigated lines (r_{ILIL}, r_{IL1IL2} and CC_{IL}) by cross.

	CICA 8/Metica 1			17388//7153/5738		
	Rainfed lowland	Irrigated	Rainfed lowland and irrigated	Rainfed lowland	Irrigated	Rainfed lowland and irrigated
r_{RLRL}	0.83**	0.79*	-	0.68**	0.76**	-
r_{ILIL}	0.73**	0.65*	-	0.71**	0.77**	-
r_{RL1RL2}			0.61**			0.51**
r_{IL1IL2}			0.33*			0.56**
CC_{RL} (%)			62.5			50.0
CC_{IL} (%)			62.5			56.2

**, * Significant at the 1% and 5% level of probability, respectively, by the *t* test.

When the intraclass correlations are compared with the correlations between environments for the rainfed lowland lines of the two crosses in the two environments (Table V), a consistency is observed among these parameters, supporting the argument that the rainfed lowland environment could be used for the initial selections within a program of irrigated rice breeding.

For the cross CICA 8/Metica 1, the concordance coefficient was 62.5% for the irrigated and rainfed lowland rice lines (Table V). This means that 10 of the 16 lines selected from 40 (40% selection intensity) in one environment are also included among the 16 best lines in the other environment.

The concordance coefficients were also high for the cross 17388//7153/5738, corresponding to 50% for the rainfed lowland and irrigated lines (Table V).

The concordance coefficient of the worst 40% of the irrigated and rainfed lowland lines for the two crosses was 56.2%, i.e., 9 of the 16 lines selected out of 40 in one environment were repeated in the other environment.

According to Fehr (1987), genotype x environment interaction may be caused by the fluctuation of genotype classification within, but not between, groups. This interaction does not justify setting up independent breeding programs for each environment, at least during the initial phases.

The concordance coefficients of the best and worst 40% of the irrigated and rainfed lowland rice lines support the hypothesis that fluctuation in genotype classification occurred within the groups. Thus, an irrigate rice breeding program with initial selections made in only one environment may be perfectly viable.

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RESUMO

Estimaram-se os componentes da variância dos efeitos principais e das interações genótipos x ambientes, os progressos esperados por seleção direta e indireta, as correlações intraclasses e entre ambientes e, o coeficiente de concordância para a produção entre as linhagens selecionadas em dois ambientes. Visou-se dar alguns subsídios que possibilitem ajudar no redirecionamento dos programas de melhoramento genético de arroz irrigado e de várzea úmida conduzidos pela EMBRAPA/CNPAF, e avaliar a possibilidade de selecionar linhagens num dos sistemas que sejam adaptadas aos dois sistemas de cultivo.

Os ganhos genéticos (assumindo-se uma intensidade de seleção de 40%) nas linhagens de várzea, com seleção e resposta no ambiente irrigado ($G_{SLV2/2}$ = 6,80% e 8,00%) foram superiores aos ganhos genéticos nas linhagens de irrigado, com seleção e resposta no ambiente várzea úmida ($G_{SLI1/1}$ = 5,37% e 6,90%), para os cruzamentos CICA8/Metica 1 e 17388//7153/5738, respectivamente.

A superioridade dos ganhos genéticos nas linhagens de várzea, juntamente com os altos valores para as correlações entre ambientes e coeficientes de concordância, indicam ser perfeitamente viável o desenvolvimento de um programa de melhoramento genético de arroz irrigado, com as seleções iniciais (até F_5) somente em várzea úmida, e as avaliações e seleções finais nos dois sistemas de cultivo, independentemente.

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