Crop Breeding and Applied Biotechnology 5:183-190, 2005
Brazilian Society of Plant Breeding. Printed in Brazil

Repeatability estimates of genetic, phenotypic and environmental correlations in oats with and without fungicide application

Giovani Benin[1], Irineu Hartwig[1*], Fernando Irajá Félix de Carvalho[1], Antônio Costa de Oliveira[1], Eduardo Alano Vieira[1], Ivandro Bertan[1], José Antônio da Silva[1], Igor Pires Valério[1] and Guilherme Ribeiro[1]

Received 19 January 2005

Accepted 5 June 2005

ABSTRACT - *Estimates of associations among traits are not very precise when based on annual data since the year factor influence the phenotype strongly. Therefore, objective of this work was to estimate the repeatability coefficients and number of years needed for an accurate prediction of genetic, phenotypic and environmental correlations among six important traits in oat with and without fungicide application (treatments). Nine oat cultivars were evaluated for four years (2000, 2001, 2002, and 2003) with and without fungicide, in a random block design with three replications. In the absence of fungicide, two years of trial evaluation were enough to provide reliable phenotypic and genetic correlation estimates; the same was not true for the experiments with fungicide application where at least seven (phenotypic) and 21 (genetic) years were required. In both treatments the environmental correlation estimates were little predictable.*

Key words: *Avena sativa* L., G x E interaction, predictability, selection criteria, indirect selection.

INTRODUCTION

One of the basic goals of oat (*Avena sativa* L.) breeding programs is to obtain higher yielding genotypes. When the objective is the selection of genotypes with a strong performance for all selection targets, correlation estimates can be a more reliable support to obtain the desired genotypes.

There are several examples in current literature for the potential use of correlation in hexaploid oat (*Avena sativa* L.) breeding (Sampson 1971, Chandhanamutta and Frey 1973, Chapko and Brinkman 1991, Benin et al. 2003a, b). The use of this estimate in a really effective manner in oat breeding is however restricted by the presence of significant interactions between genotypes x locals and genotypes x years, influencing the expression of phenotype and, therefore, the magnitude and direction of correlations (Falconer and Mackay 1997, Benin et al. 2003a).

Besides the difference in environments (locals and years), the disease leaf rust (*Puccinia coronata* f. sp. *avenae*) strongly influences the performance of oat genotypes. It occurs on almost all cultivation sites, but at a more severe level under conditions of high humidity (Harder and Haber 1992). Losses of over 50% have been observed in some regions of southern Brazil (Martinelli et al. 1994), especially in unfavorable environments (Benin et al. 2003a), increasing the magnitude of genotype x environment interactions. The difficulties of breeding for

[1]Centro de Genômica e Fitomelhoramento, Faculdade de Agronomia “Eliseu Maciel” (FAEM), Universidade Federal de Pelotas (UFPel), C. P. 354, 96.010-900, Pelotas, RS, Brasil. [*]E-mail: iriwig@ufpel.tche.br

resistance to this disease are mainly due to the extreme variability presented by the pathogens, with a mutation rate estimated at one mutant per 2000 produced spores (Zimmer et al. 1963) and also to the environmental conditions that aggravate the disease severity.

It is therefore evident that correlation estimates obtained in only one or few years are little reliable and may lead to wrong selecting strategies. It is essential to estimate how many years the genotypes must be evaluated to obtain a higher precision measure of the genetic associations between traits. In this sense, the use of the repeatability coefficient of agronomical traits and correlations represent an effective tool to overcome this drawback, providing more reliable information on the genetic control of important agronomical traits.

The concept of repeatability can be expressed as the correlation between measures of a given trait in an individual repeated in time or space. This coefficient expresses the proportion of total variation that is explained by variations in function of the genotype and those attributable to the environment. The repeatability ranges from 0 to 1, where r = 1 is the maximum value in which the trait is expressed with high stability. High values of this coefficient indicate that it is possible to predict the real value of a genotype with a small number of measures, which points to small gains in accuracy with an increase in the number of measures (Kempthorne 1973, Falconer and Mackay 1997).

Objectives of this study were: i) to estimate the coefficients of repeatability and number of years needed for an accurate prediction of the real value for the traits: days from emergence to flowering, days from flowering to maturation, plant stature, grain yield, hectoliter weight and weight of 1000 grains in experiments with and without fungicide application, ii) to estimate the repeatability of genetic, phenotypic and environmental correlations and the number of years needed for an accurate prediction of the real value of these estimates, with or without fungicide treatments.

MATERIAL AND METHODS

The experimental data were obtained in experiments from the Brazilian oat cultivar recommendation assays (EBCRA) conducted in 2000, 2001, 2002 and 2003 on the experimental area of the Centro de Genômica e Fitomelhoramento, Centro Agropecuário da Palma, Capão do Leão country, in the state of Rio Grande do Sul, Brasil, lat 31º 52' 00'' S, long 52º 21' 24'' W and alt 13.24 m asl. All trials were installed in randomized complete block designs with six replications (three with and three without fungicide application). Each plot was composed of 5 m long rows with 0.20 m spacing between rows at a density of 70 viable seeds sown per linear meter. The useful plot comprised three internal rows (3 m^2). Depending on the year, Tebuconazole fungicide was applied once or twice at a dose of 0.75 L ha^{-1} of the commercial product. Fertilizer was applied every year according to the soil analysis and weeding realized manually.

The measured variables were: grain yield in kg ha^{-1} (GY), weight of 1000 grains in g (WTG), hectoliter weight in kg hL^{-1} (HW), plant height in cm (PH), days from flowering to maturation (DFM) and days from emergence to flowering (DEF). A joint analysis of variance was performed considering the genotype and year effects as fixed and random, respectively. Two independent analyses were performed: one for the experiments with fungicide and another for the experiment without fungicide. The means of the traits evaluated in the four years were compared using the least significant distance (LSD) at 5% error probability. Through the expected mean square (Falconer and Mackay 1997), the genetic, phenotypic and environmental correlations were estimated, based on the four years of evaluation of experiments with and without fungicide treatment, using software Genes (Cruz 2001). Later, an analysis of variance was performed separately for each year and the correlations between the six evaluated traits estimated, in the conditions with and without fungicide treatment, using the procedure described above.

The repeatability coefficient (r) estimates of the evaluated agronomical traits and the genetic, phenotypic and environmental correlation estimates were obtained by the principal component analysis, based on the correlation matrix (Abeywardena 1972). This method was chosen because it is the most indicated when the genotypes present a cyclic behavior for the measured traits (high genotype x environment interaction). Once the repeatability was estimated (r), the number of years required to predict the real value of individuals (n_0) with the desired value of the genotypic determination coefficient (R^2) was obtained by the expression: $n_0 = R^2 (1-r)/(1-R^2) r$, with genotypic determination values (R^2) of 0.80, 0.85, 0.90, 0.95, and 0.99. The determination coefficient (R^2), which represents an confirmation of the real value prediction for the selected individuals based on (n) years, was obtained by the expression: $R^2 = nr/1+r (n-1)$. These estimates were obtained with software Genes (Cruz 2001).

RESULTS AND DISCUSSION

The mean square values, resulting from the analysis of variance of treatments with and without fungicide application are shown in Table 1. It is possible to observe significant differences for the cultivar, year and interaction cultivar x year sources of variation, for all the evaluated traits, except for the traits GY and WTG. The significant differences for the cultivar effect in most traits of both experiments evidences the occurrence of genetic differences among the cultivars. Besides, the significance of the year and interaction cultivar by year for all evaluated traits in both treatments evidences differences between years and genotypes regarding their responses to variations in years. This fact expresses the need for an evaluation of the repeatability of the genetic, phenotypic and environmental correlation estimates, under the conditions where the experiments were performed. Significance for the year effect for trait GY has also been reported, even higher magnitude compared to the local effect.

The absence of significant differences among genotypes for the traits GY and WTG with fungicide application and presence of significant differences without fungicide for the same traits (Table 1) appears to be an indication that the studied genotypes have similar grain yield and average grain weight potential but distinct levels of crown rust resistance. Since the traits GY and WTG are notably influenced by the presence of crown rust (Doehlert et al 2001), i.e., when no fungicide was applied, only the most resistant genotypes (URS 20 and URS 21) expressed this condition and did not present a considerable reduction in GY and HW compared to the treatment with fungicide (Table 2); cultivar URS 20 presented the highest WTG. However, with fungicide application, the evaluated cultivars did not differ for traits GY, HW and WTG, with exception of cultivar UFRGS 15, which performed worse for HW (Table 2). The higher resistance level of cultivars URS 20 and URS 21 to oat crown rust as a function of the small reduction in GY and WTG when no fungicide is applied had already been reported (Benin et al. 2003a, Lorencetti et al. 2004). Table 1 further shows that the variation coefficients ranged from 1.94 to 23.28%, providing accuracy to the estimates obtained in these experiments. However, the higher magnitude of variation coefficients in the treatment without fungicide on points to the reinforced need for controlling the experimental procedures (increased plot size and number of replications), aiming at more reliable results.

The repeatability coefficient estimates for the traits GY and WTG (Table 3), despite somewhat superior in the treatment without fungicide were generally low. This demonstrated the difficulties breeders face when identifying the best genotype values, which begin with

Table 1. Summary of univariated analysis of variance for the traits days from emergence to flowering (DEF), days from flowering to maturation (DFM), plant stature (PS), grain yield (GY), hectoliter weight (HW) and weight of a thousand grains (WTG), in four years of experiments with nine oat cultivars, in the conditions with and without fungicide

Sources of variation	df	Mean Square					
		DEF	DFM	PS	GY	HW	WTG
		days	days	cm	kg ha^{-1}	kg hL^{-1}	g
		without fungicide					
Cultivars	8	390.94*	268.20*	1398.53*	2791145.79*	296.04*	98.53*
Years	3	6056.46*	1296.06*	4672.23*	14391845.07*	391.91*	1063.22*
Cultivars x year	24	24.40*	34.01*	122.11*	766223.68*	78.64*	41.11*
Error	64	4.92	9.41	17.91	118714.59	4.78	11.65
Mean		91.74	37.64	105.24	1479.62	34.83	24.31
CV (%)		2.41	8.14	4.02	23.28	6.28	14.04
		with fungicide					
Cultivars	8	205.14*	181.96*	599.86*	302595.37	57.08*	45.77
Years	3	5370.04*	2750.06*	1522.23*	21318838.39*	489.74*	884.37*
Cultivars x year	24	65.99*	38.04*	106.33*	362294.59*	26.48*	54.80*
Error	64	3.16	6.01	26.10	192130.01	6.01	18.60
Mean		91.37	40.87	110.65	2732.29	45.12	32.33
CV (%)		1.94	5.99	4.61	16.04	5.43	13.33

* Significative at 5% error probability by the *F* test

Table 2. Comparison of means through the least significant distance (LSD) of traits days from emergence to flowering (DEF), days from flowering to maturation (DFM), plant stature (PS), grain yield (GY), hectoliter weight (HW) and weight of a thousand grains (WTG), in four years of experiments with nine oat cultivars, in the conditions with and without fungicide

Cultivar	Trait					
	DEF days	DFM days	PS cm	GY kg ha^{-1}	HW kg hL^{-1}	WTG g
			without fungicide			
UPF 15	95	36	108	1296	34	24
UPF 16	90	37	96 I	1278	30 I	22
UPF 18	97 S*	36	122 S	1600	37	26
UFRGS 14	94	35	103	1343	31	28
UFRGS 15	100 S	29 I	86 I	771 I	28 I	21
UFRGS 17	93	38	112	1168	34	23
UFRGS 19	83 I	44 S	98	1395	35	21
URS 20	89	41	111	2156 S	43 S	30 S
URS 21	84 I	44 S	112	2310 S	41 S	25
Mean	91	37	105	1479	34	24
Amplitude+	17	15	36	1539	15	9
LSD	3.6	5.0	6.9	562	3.5	5.5
			with fungicide			
UPF 15	92	39	111	2553	44	32
UPF 16	92	41	108	2753	43	29
UPF 18	98 S	35 I	125 S	2528	45	34
UFRGS 14	92	40	107	2892	44	36
UFRGS 15	95 S	38	99 I	2735	41 I	34
UFRGS 17	92	40	114	3043	47	31
UFRGS 19	85 I	47 S	107	2687	49	31
URS 20	91	42	110	2673	47	33
URS 21	85	46 S	116	2727	46	31
Mean	91	40	110	2732	45	32
Amplitude[z]	13	12	26	515	7	7
LSD	2	4	8	715	4	7

*Means followed by S and I in the columns, are superior or inferior, respectively, to the mean of the character at 5% error probability

[z]Difference between the highest and the lowest character mean

the analysis of a phenotype, considering few years of evaluation, i.e., indicating irregularity in the replication of the trait between one evaluation and another. A possible cause for the low repeatability estimates obtained can be the large differences between the environmental conditions, regarding the presence of significant differences for year and genotype x year interaction (Table 1). In the treatment with fungicide application, 30 to 45 years of evaluation would be required to obtain a determination coefficient of 0.85 for the traits GY and WTG, respectively. Although the repeatability of these traits was superior in the treatment without fungicide application, the same were not high, requiring six (GY) to nine (WTG) years to obtain a determination coefficient of 0.85.

The higher repeatability coefficients of the traits GY and WTG observed in the treatment without fungicide application in relation to the treatment with fungicide application can be based on different levels of resistance to oat crown rust of the studied cultivars, since the disease affects these traits considerably (Doehlert et al. 2001). Since the genotypes have different levels of resistance to leaf rust, it would therefore be expected that this resistance were expressed every year, i.e., the most resistant genotypes would tend to be more productive and have a higher WTG throughout the years when compared to the susceptible ones, when no fungicide is applied. This makes the ranking order stable over the years and the repeatability coefficients therefore tend to be higher in the absence of fungicide application. On other hand, the genotypes are not able to express their resistance genes in the treatment with fungicide application. Once the evaluated genotypes present similar potentials for GY and WTG but evidence a significant genotype x year interaction for such traits (Table 1), these variations tend to be maximized, leading to a profound change in the ranking order of the genotypes for these traits and reducing the repeatability coefficient estimates. Besides, fungicide application enables the genotype to express all its genetic potential, so the differences of year (good and bad year) are more easily detected. However, we underline that this scenario would be different in the case of studying contrasting genotypes for the traits GY and WTG, which would result in a superior repeatability coefficient, since the differences among genotypes would be constant throughout the years, causing smaller changes in the ranking order.

The repeatability coefficient estimates of the traits DEF, DFM, PS, and HW in both treatments (with and without fungicide) ranged from 0.55 to 0.83 evidencing average regularity in the replication. At least four years of experiments were necessary to obtain a determination coefficient of 0.85 for these traits, with exception of trait HW, which needed five years. These results, together with the presence of significant years and cultivars x years interaction (Table 1), support the hypothesis that many years are necessary for a precise estimate of studied cultivar performance for the phenotyped traits.

Repeatability represents the maximum value heritability can achieve (Falconer and Mackay 1997). The difference between repeatability and heritability is mainly caused by the fact that the phenotypic variance used to estimate the repeatability is not only of genetic origin, once the permanent environmental component of variance among individuals remains associated with it. Thus, the repeatability is closer to the heritability when the estimated variances are purely genetic. Likewise, the repeatability values obtained in the present study for the traits DEF, DFM and PS agree with the heritability values observed for these traits in oat (Mittelmann et al. 2001).

In the treatment without fungicide application, the repeatability estimates and the determination coefficient of phenotypic (0.80 and 0.94) and genetic (0.80 and 0.94) correlation were high, showing accuracy of the obtained estimates and higher regularity of these estimates for the studied cultivars (Table 4). Besides, they indicate that the expression of the evaluated traits possess a good genetic control and that the environmental variance was relatively low, compared with the variance among genotypes. These results indicate that a few years of evaluation are sufficient to obtain a reliable estimate of phenotypic and genetic correlations for the studied cultivars. Only two years of experimental procedures were therefore necessary to obtain a determination coefficient of 0.85 for both the genetic and phenotypic correlation, providing a more reliable support for large genetic gains through indirect selection, i.e., associated traits.

In the treatment with fungicide application, the repeatability and determination coefficient of the phenotypic (0.45 and 0.77) and genetic (0.20 and 0.52)

Table 3. Repeatability (R) and determination (R^2) coefficient, and the number of necessary measures for obtaining different R^2, using the principal component methods based on the correlation matrix, for the traits days from emergence to flowering (DEF), days from flowering to maturation (DFM), plant stature (PS), grain yield (GY), hectoliter weight (HW) and weight of a thousand grains (WTG), in four years of experiments with nine oat cultivars, in the conditions with (F) and without fungicide (WF)

Trait		r	R^2	Years to obtain an R^2 of:				
				0.80	**0.85**	**0.90**	**0.95**	**0.99**
DEF	WF	0.83	0.95	1	1	2	4	21
	F	0.72	0.91	2	2	3	7	38
DFM	WF	0.67	0.89	2	3	4	9	49
	F	0.74	0.92	1	2	3	7	36
PS	WF	0.73	0.92	1	2	3	7	36
	F	0.58	0.85	3	4	7	14	72
GY	WF	0.47	0.78	5	6	10	22	113
	F	0.16	0.43	21	30	47	99	519
HW	WF	0.55	0.83	3	5	7	15	80
	F	0.59	0.85	3	4	6	13	70
WTG	WF	0.40	0.73	6	9	14	29	150
	F	0.11	0.33	32	45	72	152	792

correlations, respectively, were considerably inferior to the same estimates obtained in the absence of fungicide application (Table 4). These results of medium to low magnitude evidence the need of evaluating the cultivars for many years to obtain reliable estimates, i.e., to obtain a determination coefficient of 0.85, at least 7- 21 years of experimental procedures are required to establish reliable estimates of phenotypic and genetic correlation for the studied cultivars, respectively.

From the six evaluated phenotypic traits, four (DEF, PS, GY, and WTG) presented lower repeatability and determination coefficients in the treatment with fungicide application, compared to the treatment without fungicide application. This is probably the cause for lower values of repeatability and determination coefficients observed for the genetic and phenotypic correlation in experiments with fungicide application for the studied cultivars. As mentioned similarly for the traits GY and WTG, these differences in values in both treatments are due to a higher predictability of performance of resistant genotypes to crown rust in experiments without fungicide application, i.e., the same phenotypic trait expression in the treatment with fungicide application within each year, together with the presence of interaction cultivars x years, which enables the maximization of performance differences of traits in the different years.

The repeatability and the determination coefficient of the environment correlation evidenced considerable differences between the distinct conditions of experimental procedures. The estimates were higher with fungicide (0.30 and 0.63) compared to the experiments without fungicide application (0.15 and 0.40), respectively (Table 4), indicating a smaller predictability in the latter treatment for the studied cultivars. However, although the repeatability coefficients of the environmental correlations were higher in the treatment with fungicide application, they were extremely low and would require 13 years to reach a determination coefficient of 0.85; to obtain an equivalent value for the determination coefficient in the absence of fungicide, 34 years of evaluation would be needed (Table 4).

There were differences in magnitude and direction of genetic, phenotypic and environmental correlations in the treatments with and without fungicide application (Table 5). The estimates of genetic (0.95) and phenotypic correlations between HW x GY in the environments without fungicide application can help in the selection of higher yielding genotypes through the trait hectoliter weight. The same is not true in the experiments with fungicide application, where the genetic (0.18) and phenotypic (0.14) correlation were not significant since the environmental conditions did not favor grain filling. Similar results were observed by Benin et al. 2003a. In the experiments without fungicide application, GY was also genetically (0.83) and phenotypically (0.74) correlated with DFM, indicating that a longer period of grain filling tends to result in higher grain yields in the studied cultivars. Besides, the genetic and phenotypic correlation between DFM x HW were positive and significant in both treatments (Table 5) supporting the hypothesis that a better filling is obtained by an increase in the number of days from flowering to maturation for the studied cultivars. However, the significance of genetic (-0.67) and phenotypic (-0.63) correlations between HW x DEF in the experiments with fungicide application evidenced a reduction in HW with

Table 4. Repeatability (R) and determination (R^2) coefficient, and the number of necessary measures for obtaining different R^2, using the principal component methods based on the correlation matrix, for the phenotypic, genetic and environmental correlation estimates in four years of experiments, with nine oat cultivars, in the conditions with (F) and without fungicide (WF) application

			Years to obtain an R^2 of:				
Condition	r	R^2	Phenotypic correlation				
			0.80	0.85	0.90	0.95	0.99
WF	0.80	0.94	1	2	3	5	25
F	0.45	0.77	5	7	11	23	121
Condition	r	R^2	Genetic correlation				
			0.80	0.85	0.90	0.95	0.99
WF	0.80	0.94	1	2	3	5	23
F	0.20	0.52	15	21	33	71	372
Condition	r	R^2	Environmental correlation				
			0.80	0.85	0.90	0.95	0.99
WF	0.15	0.40	24	34	54	115	602
F	0.30	0.63	9	13	21	44	231

Table 5. Genetic (r_G), phenotypic (r_P) and environmental (r_E) correlation estimates between the traits days from emergence to flowering (DEF), days from flowering to maturation (DFM), plant stature (PS), grain yield (GY), hectoliter weight (HW) and weight of a thousand grains (WTG), in four years of experiments with nine oat cultivars, in the conditions with and without fungicide

Traits	With fungicide			Without fungicide		
	r_G	r_P	r_E	r_G	r_P	r_E
DEF[1] x DFM	-0.98*	-0.97*	-0.46^{ns}	-0.95*	-0.92*	-0.37^{ns}
DEF x PS	0.13	0.12	-0.06^{ns}	-0.04^{ns}	-0.06^{ns}	-0.09^{ns}
DEF x GY	-0.22	-0.14	-0.09^{ns}	-0.69*	-0.61^{ns}	-0.01^{ns}
DEF x HW	-0.67*	-0.63*	-0.00^{ns}	-0.57^{ns}	-0.49^{ns}	0.05^{ns}
DEF x WTG	0.54	0.41	-0.02^{ns}	-0.01^{ns}	-0.05^{ns}	-0.06^{ns}
PS x DFM	-0.19	-0.19	-0.03^{ns}	0.43^{ns}	0.40^{ns}	-0.00^{ns}
GY x DFM	0.30	0.18	0.01^{ns}	0.83*	0.74*	-0.11^{ns}
HW x DFM	0.69	0.65*	0.12^{ns}	0.78*	0.70*	-0.04^{ns}
WTG x DFM	-0.57	-0.43	-0.00^{ns}	0.21^{ns}	0.23^{ns}	-0.04^{ns}
GY x PS	-0.34	-0.26	-0.36^{ns}	0.65*	0.60^{ns}	0.03^{ns}
HW x PS	0.25	0.23	0.02^{ns}	0.80*	0.70*	-0.11^{ns}
WTG x PS	-0.11	-0.06	0.17^{ns}	0.83*	0.64*	0.14^{ns}
HW x GY	0.18	0.14	0.13^{ns}	0.95*	0.90*	0.17^{ns}
WTG x GY	-0.24	-0.02	0.18^{ns}	0.77*	0.65*	0.02^{ns}
WTG x HW	-0.21	-0.10	0.24^{ns}	0.60^{ns}	0.61^{ns}	0.04^{ns}

* significative at 5% error probability by the *t* test, at n-2 degree freedom (0.632)

an increase in number of days from emergence to flowering for the studied cultivars. Thus, oat breeders will probably have difficulties in developing genotypes that combine short cycle and grain filling potential. However, in order to achieve these objectives, it is suggested that they must prioritize the development of genotypes that present a smaller number of days from the emergence of plantlets to flowering and a higher number of days from flowering to maturation, in order to reduce the cycle and to guarantee a longer grain filling period. The genetic (-0.24) and phenotypic (-0.02) correlations between WTG x GY in experiments with fungicide application do not support the indirect selection of higher yielding genotypes through WTG, in agreement with (Benin et al. 2003a). However, in the absence of fungicide application, the WTG was genetically (0.77) and phenotypically (0.65) correlated with GY. This result had been expected as a function of the disease effect of reduced seed weight which promoted differences between resistant and susceptible cultivars which did not become apparent when the disease was being controlled. Without fungicide, the most resistant genotypes presented highest seed weight and grain yield, once more in agreement with the results obtained by (Benin et al. 2003a). The high and negative correlations between DEF x DFM, in both conditions of conduction of experiments, were already expected.

CONCLUSIONS

The effects of environmental variation among crop years and fungicide application strongly influence the expression of important agronomical traits in oat and, consequently, the estimates of repeatability and correlation between traits in the studied genetic constitutions. In experiments without fungicide application, one or two trial years of evaluation are sufficient to establish highly reliable phenotypic and genetic correlations, as opposed to experiments with fungicide application, where a higher number of years is required.

Estimativas da repetibilidade da correlação genética, fenotípica e de ambiente em aveia com e sem a aplicação de fungicida

RESUMO - *O fator ano exerce grande influência na expressão do fenótipo, tornando as estimativas de correlação não muito precisas, quando baseadas apenas em um ano de avaliação. Desta forma, este trabalho foi desenvolvido com o objetivo de estimar os coeficientes de repetibilidade e o número de anos necessários para uma predição acurada da correlação genética, fenotípica e de ambiente entre seis caracteres de importância agronômica em aveia (*Avena sativa *L.), em presença e ausência de fungicida. Durante quatro anos (2000, 2001, 2002 e 2003), nove cultivares de aveia foram avaliadas em presença e ausência de fungicida, em blocos completos casualizados com três repetições. Na ausência de aplicação de fungicida, dois anos de experimentos foram suficientes para a obtenção de alta confiabilidade das estimativas de correlação fenotípica e genética, ao contrário de experimentos com a aplicação de fungicida, onde no mínimo sete (fenotípica) e 21 (genética) anos foram necessários. Em ambas as condições experimentais, a correlação de ambiente apresentou baixa previsibilidade.*

Palavras-chave: *Avena sativa* L., interação G x E , predição, critério de seleção, seleção indireta.

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