Vol.4, No.12, 683-688 (2013)
http://dx.doi.org/10.4236/as.2013.412092

Agricultural Sciences

Decomposition of the interaction of common black bean group genotypes with the environment

Paula Pereira Torga[1*], Patrícia Guimarães Santos Melo[1], Helton Santos Pereira[2], Luis Cláudio de Faria[2], Maria José Del Peloso[2], Leonardo Cunha Melo[2]

[1]Universidade Federal de Goiás, Escola de Agronomia e Engenharia de Alimentos, Goiânia, Brazil;
[*]Corresponding Author: paulaptorga@yahoo.com.br, pgsantos@agro.ufg.br
[2]Embrapa Arroz e Feijão, Santo Antônio de Goiás, Brazil;
helton.pereira@.embrapa.br, luis.faria@embrapa.br, mariajose.peloso@cnpaf.embrapa.br, leonardo.melo@embrapa.br

Received 16 September 2013; revised 3 November 2013; accepted 7 December 2013

ABSTRACT

The purpose of this paper was to assess which environmental factor(s) (location, sowing season or years) in the common black bean genotypes interaction was more expressive and to verify the existence of genotypes with broad and/or specific adaptations to sowing season. Data of grain yield of thirteen genotypes were tested in twelve trials of value of cultivation and use during 2003 and 2004 in the south-central region of Brazil. Analyses of variance were performed with the decomposition of genotypes × environments interaction, which allowed a partial isolation of factors, and subsequently, eight trials were used which allowed a complete isolation of factors. The most important interactions were genotypes × years (R^2 = 2.5%) and genotypes × locations (R^2 = 1.9%), while genotypes × sowing seasons was the least important (R^2 = 1.4%). Thus, it is more important to evaluate the genotypes in different locations and years than at different seasons. Most genotypes showed wide adaptation, but some lines showed strong specific adaptation.

Keywords: *Phaseolus vulgaris*; Indication of Cultivars; Adaptability

1. INTRODUCTION

In Brazil, the common bean plant is grown during three seasons of the year and in almost all states. Thus, it is subject to different environmental conditions. Furthermore, it is used by different categories of farmers, from subsistence agriculture, with little or no use of technology, to modern farming, which uses high-tech production methods [1]. This significant environmental variation induces pronounced interactions with genotypes × environments (G×E), mainly regarding the grain yield characteristic. This fact has been confirmed by several studies conducted on the common bean plant in Brazil [1-6].

Paraná and Santa Catarina States respond for approximately 35% of the national common bean production, corresponding to 931,242 t in 2009, with an average yield of 1285 kg·ha^{-1} distributed over two sowing seasons—the rainy (50%) and drought (50%) seasons [7].

The diversity of environmental conditions in which the common bean is grown makes assessment test lines should be conducted in networks in various environments. This is done to get a good estimate of the genotypes × environments interaction (G×E), providing greater security in the indication. In the final phase of the improvement programs, bean lines are tested by year, sowing season, and location using repeated trials. The number of environments in which such trials are conducted must be a representative sample of the cultivation conditions for each region [1]. Because of this, in the evaluation phase of strains for the indication of new cultivars, the importance of this interaction is more evident and quite pronounced in culture conditions in common bean.

Common bean cultivar indications follow the standards of the Ministry of Agriculture/National Register of Cultivars (MAPA/RNC), which require cultivar indications by the state for each sowing season. Each state must conduct a minimum of three trials (three/year) over two years for each sowing season [8]. These standards make it very difficult to indicate new cultivars because of the high number of trials required for each state, which in total are at least six trials per sowing season. Thus, the indication of cultivars for all producing states is difficult and costly, and as a consequence, many states do not have new registered cultivars. However, these standards are being revised and possibly cultivars indication will be performed by region. An alternative to trying to reduce the number of trials to be conducted, for the indication of a new cultivars is verifying with environmental factors (locations, seasons or years). The interaction with genotypes is more expressive [2].

Some studies were conducted on the *carioca* common bean commercial type in the states of Minas Gerais [2], Goiás and Distrito Federal [9] and in Paraná and Santa Catarina [10]. In Minas Gerais and Goiás, the most significant interactions were genotypes × sowing season and genotypes × years, and in Paraná and Santa Catarina, genotypes × locations was the most significant. The difference in results highlights the importance of further studies because the genotypes, locations, years, and season during which the tests are conducted have a significant impact on the outcome and the breeder's decision-making process.

The purpose of this paper was to evaluate which environmental factor(s) (locations, sowing season, or years) the common black bean genotypes interaction was more expressive in the south-central region of Brazil and to verify the existence of genotypes with broad and/or specific adaptations to sowing seasons.

2. MATERIAL AND METHODS

Trials were conducted in south-central Brazilian region in states of Paraná and Santa Catarina in the municipalities of Abelardo Luz (26˚33'S, 52˚19'W, 760 m), Ponta Grossa (25˚05'S, 50˚09'W, 969 m), Prudentopólis (25˚12'S, 50˚58'W, 840 m) and Roncador (24˚36'S, 52˚16'W, 762 m) in the agricultural years of 2003 and 2004, in two sowing seasons (rain and drought). A total of 12 environments were selected, which corresponded to Abelardo Luz, Ponta Grossa and Roncador for two seasons in 2003, and Abelardo Luz, Ponta Grossa and Prudentópolis during two seasons in 2004. These trials were selected for the locations to be consistent over two sowing seasons in each year.

The experiments were conducted according to the requirements established for trials of value of cultivation and use of the common bean, according to Administrative Rule # 294, Ministry of Agriculture, Livestock, and Supply (MAPA), and used a delimitation of randomized blocks with three repetitions and plots of four 4 m rows. Yield data were obtained by disregarding the two sidelines. Each trial evaluated 13 genotypes from the black bean group (namely BRS Valente, FT Nobre, Diamante Negro, IPR Uirapuru, FT Soberano, TB 9409, TB 9713, CNFP 10138, CNFP 7966, CNFP 7972, CNFP 7994, CNFP 8000 and CNFP 9328).

The productivity data were subjected to individual analyses of variance, considering the treatment effects and localities as fixed factors. The analyses were conducted by using Genes software [11] and Sisvar [12]. Joint analyses were subsequently performed for each sowing season to obtain the genotype means for each season and for the two sowing seasons together. The purpose of this procedure was to decompose the genotypes x environments interaction in the genotypes × sowing season and genotypes × location/years. In the joint analyses, the treatment effects, locations, sowing seasons and years were designated as fixed entities. A compareson of means was performed using the Scott-Knott test at 10% probability.

To determine the contribution of each source of variation to the total variation, the determination coefficient (R^2) was estimated using the following expression: $R_i^2 = \frac{SQ_i}{SQ_t}$, in which SQ_i is the sum of squares of the variation source *i*, and SQ_t is the total square sum.

To verify the importance of this complex interaction, estimates of the complex interaction percentage were obtained by consulting Cruz and Castoldi [13], which was used to address all pairs of environmental facts for each region.

Data from the locations studied during the two sowing seasons and during the two years were used to isolate all of the environmental factors (location, sowing season, and year) and to separately evaluate the effect of each one to the interaction. To perform the analysis without confusing the different factors, the Abelardo Luz and Ponta Grossa locations were used in 2003 and 2004. Estimates of the R^2 for each variation source were obtained after the sum of squares decomposition.

To identify the genotypes with broad or specific adaptations to sowing seasons, these trials classified the genotypes for each season with and without factor confusion [14].

A Spearman correlation was estimated between the two sowing seasons, and it was based on the overall mean of the genotypes for each analysis period with and without confounding factors to confirm the importance of the complex interactions.

3. RESULTS AND DISCUSSION

For the individual analyses, the coefficients of variation (except the trials from Ponta Grossa during the 2003 drought) were below 20%, indicating good experimental accuracy (**Table 1**). The trial yield means ranged from 871 kg·ha^{-1} to 3958 kg·ha^{-1}, showing that the environmental conditions to which the genotypes were subjected were variable. Overall, the trials conducted during the rainy season had a higher yield average (2980 kg·ha^{-1}) than those conducted during the dry season (2237 kg·ha^{-1}) (**Table 1**). The measured productivity for both seasons

Table 1. Summary of analyses of variance for yield (kg·ha^{-1}) of twelve trials on black group common beans conducted in states of Paraná and Santa Catarina in 2003 and 2004.

Season[1]	Location	State	QM_G[2]	QM_E[3]	P[4]	Average[5]	CV[6]
Drought/2003	Abelardo Luz	SC	147,838	62,043	0.034	2191	11
	Ponta Grossa	PR	389,129	187,132	0.061	1949	22
	Roncador	PR	183,289	50,485	0.040	1383	16
Rain/2003	Abelardo Luz	SC	387,347	262,498	0.201	3916	13
	Ponta Grossa	PR	439,048	175,261	0.027	3569	12
	Roncador	PR	101,612	23,747	0.001	871	18
Drought/2004	Abelardo Luz	SC	115,335	106,091	0.414	2184	15
	Ponta Grossa	PR	511,985	83,494	0.000	3163	9
	Prudentópolis	PR	220,195	93,244	0.035	2554	12
Rain/2004	Abelardo Luz	SC	465,473	158,017	0.012	3958	10
	Ponta Grossa	PR	630,750	213,519	0.012	3320	14
	Prudentópolis	PR	470,860	40,774	0.000	2246	9

[1]Sowing season/year; [2]Average square of genotypes; [3]Average square of error; [4]Probability of non-existence for significant differences among genotypes; [5]Trial general average (kg·ha^{-1}); [6]Coefficient of variation (%).

was very similar, with only minor variations between years [7].

The joint analysis with the decomposition of the genotypes x environments interaction showed significant differences between genotypes (G), locations + years (L + Y) and sowing seasons (S), indicating the inconstancy of these sources of variation (**Table 2**). Significance was also observed for all interactions, indicating a differential response of genotypes for both sowing seasons and for the locations + years. Thus, the genotypes responded differently according to the sowing season and location + year planted. It is noteworthy that the interaction may be simple in nature, without causing change in the classifycation of genotypes in different environments, or complex, causing changes in classification [15]. Thus, if there is significant interaction and greater importance for the simple fraction, the genotype classification does not change significantly; thus, the indication may be generalized.

Of all of the interactions between genotypes and other factors, L + Y was the most important, with a coefficient of determination (R^2) equal to 3.7%, which is approximately five times higher than that of GxS (**Table 2**). It is noteworthy that, as the analysis has confounding factors, it is not possible to isolate the effects of locations and years to evaluate the importance of each for interaction. Even with this confusion, the locations and years were more important for the interaction than the sowing seasons, thus, it is more important to evaluate the genotypes in different locations and years than during different sowing seasons. The interaction L + Y x S showed the biggest R^2 (22.4%) (**Table 2**), showing that the sowing seasons are affected differently depending on the location and year.

The estimated Spearman coefficient for the productivity means of the genotypes between the two seasons was

Table 2. Summary of joint analysis of variance with a breakdown of the genotypes x environments interaction for the yield (kg·ha^{-1}) of twelve trials for black common beans as conducted in the states of Paraná and Santa Catarina.

Variation Source	DF	MQ	P	R^2 (%)
Genotypes (G)	12	592,574	0.000	1.4
Location + Year (L + Y)	5	47,951,561	0.000	47.3
Season (S)	1	64,545,161	0.000	12.7
G x L + Y	60	309,932	0.000	3.7
G x S	12	324,614	0.004	0.8
L + Y x S	5	22,691,813	0.000	22.4
G x L + Y x S	60	319,202	0.000	3.8
Residue	312	129,438	-	8.0
Total	467	-	-	-
Mean	2609	-	-	-
CV (%)	14	-	-	-

DF: Degrees of Freedom; MS: Mean square; R^2: Coefficient of determination.

0.03, emphasizing the classification change in genotypes and the predominance of the complex interaction fraction (**Table 3**). This finding indicates that even with the slightest sowing season interaction importance (**Table 2**), the cultivar indications cannot be based on only one of the seasons; thus, it is necessary to evaluate the genotypes from the two sowing seasons to make the correct indication.

One can observe the occurrence of genotypes with specific adaptation to the rainy season, IPR Uirapuru and BRS Valente, and with specific adaptation to drought, TB 9713. However, genotypes CNFP 8000 and CNFP 7994 presented broad adaptation (**Table 3**), showing that there are genotypes that can be recommended for the two sowing seasons without yield losses, which can be used to provide a widespread recommendation.

Pereira *et al.* [10] working with common bean genotypes in this same region, found values of significant correlations, between sowing seasons, for productivity and adaptability and stability, respectively, 0.69 and 0.76, indicating the predominance of simple fraction of the interaction. The contrast between the results of these studies indicate that the genotypes are of great importance in these evaluations, since the years for the assessment were the same in both works, with variation of only one site. The current study evaluated 13 black bean lines, and Pereira *et al*. [10] evaluated 16 lines of common bean. The results of these study indicate that different groups of genotypes have different sensitivities to variation between sowing seasons and emphasizes the importance of continuity in carrying in this type of study in breeding programs, testing the behavior of new strains with respect to G×E interaction.

The complex percentage was estimated among all pairs of evaluated environments (**Table 4**), and the results showed the predominance of the complex fraction. The average estimate of the complex percentage among pairs of environments for the same season was 85.1% (84.5% in rain and 85.7% in drought), which was equal to the average among pairs of environments for different seasons, which is 85.1% (**Table 4**). This result shows that the change among different sowing seasons has the same magnitude of variation within the same sowing season.

These trials were able to isolate the sowing season effect of the location and year effects in the decomposition of the genotypes × environments interaction. However, some factors were still confused, such as the location with the year. This confusion occurred because the set of locations was different from one year to another. To isolate the effect of all the factors, a joint analysis of eight environments common to both seasons and years was performed. Significant differences were observed for the sources of variation genotype, sowing seasons and years; for locations, there were no significant differences ($p \leq 0.05$) (**Table 5**).

The genotypes × years interaction (G×Y) and the

Table 3. Yield means ($kg \cdot ha^{-1}$) for sowing seasons rain fall, drought and overall for the 13 genotypes of black common bean, as evaluated by 12 trials (with confounding factors) and yield means ($kg \cdot ha^{-1}$) of the same genotypes evaluated in eight trials (without confounding factors) in south-central Brazil.

Trials with confounding factors						Trials without confounding factors					
Genotype	Overall	Rain	C	Drought	C	Genotype	Overall	Rain	C	Drought	C
CNFP 7994	2.887a	3.376a	1	2.397a	3	CNFP 8000	3.348a	4.053a	2	2.644a	2
CNFP 8000	2.845a	3.231a	2	2.458a	1	CNFP 7994	3.323a	4.139a	1	2.507b	3
IPR Uirapuru	2.660b	3.144a	3	2.176b	8	IPR Uirapuru	3.132b	3.880a	3	2.385c	6
CNFP 7966	2.649b	2.932b	7	2.366a	4	TB 9713	3.099b	3.462b	12	2.736a	1
FT Soberano	2.629b	2.930b	8	2.328a	5	CNFP 7966	3.092b	3.722b	5	2.463b	4
TB 9713	2.599b	2.779b	13	2.419a	2	CNFP 9328	3.045c	3.725b	4	2.365c	7
CNFP 9328	2.543b	2.933b	6	2.153b	10	CNFP 10138	2.989c	3.704b	6	2.273c	9
CNFP 10138	2.541b	2.906b	10	2.176b	9	FT Soberano	2.979c	3.509b	11	2.448b	5
CNFP 7972	2.537b	2.861b	11	2.213b	7	BRS Valente	2.948c	3.620b	8	2.276c	8
BRS Valente	2.531b	2.995b	4	2.068b	12	CNFP 7972	2.938c	3.653b	7	2.223c	11
Diamante Negro	2.521b	2.794b	12	2.248b	6	Diamante Negro	2.920c	3.583b	9	2.258c	10
TB 9409	2.515b	2.939b	5	2.090b	11	TB 9409	2.881c	3.551b	10	2.211c	12
FT Nobre	2.457b	2.919b	9	1.995b	13	FT Nobre	2.712c	3.379b	13	2.045c	13
Mean/Season	2.608	2980a	-	2.237b	-	Mean/Season	3.031	3.691a	-	2372b	-

[1]Means followed by the same letter do not differ according to the Scott-Knott test, $\alpha = 0,10$; [2]Genotype classification for each sowing season with respect to stability.

Table 4. Complex percentage estimates of genotypes x environments interactions among the trial pairs of black common beans conducted in the states of Paraná and Santa Catarina in 2003 and 2004.

Trials	2	3	4	5	6	7	8	9	10	11	12
1) Abelardo Luz - Rain/2003	75	93	75	80	100	100	100	98	96	86	95
2) Ponta Grossa - Rain/2003	-	100	83	88	56	100	68	100	81	69	75
3) Roncador - Rain/2003	-	-	92	65	95	37	78	48	95	90	100
4) Abelardo Luz - Drought/2003	-	-	-	73	94	74	93	90	100	77	100
5) Ponta Grossa - Drought/2003	-	-	-	-	76	98	100	100	72	82	98
6) Roncador - Drought/2003	-	-	-	-	-	79	49	92	92	67	88
7) Abelardo Luz - Rain/2004	-	-	-	-	-	-	97	86	84	86	100
8) Ponta Grossa - Rain/2004	-	-	-	-	-	-	-	87	40	90	96
9) Prudentópolis - Rain/2004	-	-	-	-	-	-	-	-	73	100	100
10) Abelardo Luz - Drought/2004	-	-	-	-	-	-	-	-	-	71	100
11) Ponta Grossa - Drought/2004	-	-	-	-	-	-	-	-	-	-	96
12) Prudentópolis - Drought/2004	-	-	-	-	-	-	-	-	-	-	-

Table 5. Summary of joint analysis with genotypes x environments interaction decomposition for the yield (kg·ha^{-1}) of eight black common bean trials, conducted in Ponta Grossa (PR) and Abelardo Luz (SC) in 2003 and 2004.

Fontes de Variação	DF	MS	P	R^2(%)
Genotypes (G)	12	721,873	0.000	3.4
Loctions (L)	1	298,037	0.177	0.1
Seasons (S)	1	135,686,849	0.000	54.0
Years (Y)	1	4.878.250	0.000	1.9
G x L	12	405,650	0.004	1.9
G x S	12	293,833	0.048	1.4
G x Y	12	524,224	0.000	2.5
L x S	1	14,456,190	0.000	5.8
L x Y	1	4,221,736	0.000	1.7
S x Y	1	9,758,724	0.000	3.9
G x L x S	12	427,602	0.003	2.0
G x L x Y	12	127,100	0.668	0.6
G x S x Y	12	299,667	0.043	1.4
L x S x Y	1	11,149,110	0.000	4.4
G x L x S x Y	12	286,955	0.055	1.4
Residue	208	162,354		13.4
Total	311	-	-	-
Mean			3.031	
CV (%)			13	

DF: Degrees of Freedom; MS: Mean square; R^2: Coefficient of determination.

genotypes × locations interaction (G×L) showed significant differences at 1% and the values of R^2 were 2.5% and 1.9%, respectively. The genotypes × sowing season interaction (G×S) was significant at 5% probability and showed a value of R^2 equal to 1.4%, confirming the minor importance of sowing season in the interaction with genotypes (**Table 5**). It is important to note that even with the high variation among the seasons (R^2 = 54%) and the high yield average during the rainy season (36% higher than the drought season), the interaction of this factor with the genotypes was small. This fact can also be explained by examining the average correlation values between genotypes, which were determined to be 0.23, 0.35 and 0.42 for the years, locations, and sowing seasons, respectively. The highest correlation value was obtained for the sowing season, indicating that the genotype classification change among the seasons was lower than it was among years and locations. These data further indicated that the best and worst genotypes remained constant between different seasons. However, the small variation between years changed the genotype classification; therefore, its correlation value was the lowest. Thus, of all the interactions between genotypes and other factors, G×Y contributed the most to the total variation (R^2 = 2.5%).

Results derived from data without confounding factors confirmed the previous analysis with confounding factors, which is more important for different years and locations than during different seasons. In all of the analyses performed, except for those from the dry season, genotypes CNFP 7994 and CNFP 8000 were ranked among the most productive and stable, which reinforces that the sowing seasons are the least important in the genotype x environment interaction (**Table 3**).

The results also confirm those obtained by Pereira *et al*. [10], in common bean, that the interaction G×S (1.5%) is less important than G×Y (3.0%) and G×L (5.0%). However, in this study the interplay caused change in the classification of genotypes, while the work of Pereira *et al*. [10] there was no change in the classification. These authors comment that in Paraná and Santa Catarina, less variation is expected in performance of genotypes between seasons because there are two sowing dates, both without irrigation and less climatic variation, quite similar when compared to other states where the variation between seasons is greater.

Ramalho *et al*. [2] evaluated *carioca* bean genotypes in the state of Minas Gerais during the drought and winter seasons, which have very different climatic conditions, and found greater significance for the G×S interaction. The authors concluded that it is more important to assess the genotypes during different seasons (1.91%) and years (1.92%) than at different locations (1.60%), indicating that Minas Gerais is a state with distinct sowing seasons, unlike what was observed in this study for Paraná and Santa Catarina.

Given the above, studying the decomposition of genotype environment interaction is very important because the results depend on the genotypes, the sowing seasons, locations, sites and years. Therefore, it is essential to monitor ongoing network evaluation genotypes to guide breeding programs.

4. CONCLUSIONS

1) In Brazil's south-central region, it is more important to evaluate black bean genotypes in different locations and years than in different sowing seasons.

2) Most genotypes are broadly adaptable, but some lines show strong specific adaptations to a certain sowing season.

3) The lines most suitable for recommendation are CNFP 8000 and CNFP 7994 because they have broader adaptation abilities when considering the two sowing seasons.

REFERENCES

[1] Melo, L.C., Melo, P.G.S., Faria, L.C., Diaz, J.L.C., Del Peloso, M.J., Rava, C.A. and Costa, J.G.C. (2007) Interaction with environment and stability of common bean genotypes in the South Centre Region of Brazil. *Pesquisa Agropecuária Brasileira*, **42**, 715-723. http://dx.doi.org/10.1590/S0100-204X2007000500015

[2] Ramalho, M.A.P., Abreu, A.F. and Santos, P.S.J. (1998) Interactions genotypes x sowing times, years and locations in the evaluation of bean cultivars in Regions South and Alto Paranaíba in Minas Gerais. *Ciência e Agrotecnologia*, **22**, 176-181.

[3] Oliveira, G.V., Carneiro, P.C.S., Carneiro, J.E. de S. and Cruz, C.D. (2006) Adaptability and stability of common bean in Minas Gerais State, Brazil. *Pesquisa Agropecuária Brasileira*, **41**, 257-265. http://dx.doi.org/10.1590/S0100-204X2006000200010

[4] Bertoldo, J.G., Coimbra, J.L.M., Nodari, R.O., Guidolin, A.F., Hemp, S., Barili, L.D., Vale, N.M. and Rozzeto, D.S. (2009) Stratification of the state of Santa Catarina in macro-environments for bean cultivation. *Crop Breeding and Applied Biotechnology*, **9**, 335-343.

[5] Pereira, H.S., Melo, L.C., Faria, L.C., Del Peloso, M.J., Costa, J.G.C., Rava, C.A. and Wendland, A. (2009) Adaptability and stability of common bean genotypes with carioca grain type for central Brazil. *Pesquisa e Agropecuária Brasileira*, **44**, 29-37. http://dx.doi.org/10.1590/S0100-204X2009000100005

[6] Gonçalves, J.G.R., Chiorato, A.F., Morais, L.K., Perina, E.F., Farias, F.L. and Carbonell, S.A.M. (2010) Study of the phenotypical stability of common bean plants with special grains. *Ciência e Agrotecnologia*, **34**, 922-931. http://dx.doi.org/10.1590/S1413-70542010000400018

[7] FEIJÃO (2011) conjuncture data on common bean (*Phaseolus vulgaris* L.) and caupi (*Vigna unguiculata* (L.) walp) production in Brasil: 1985 through 2011. http://www.cnpaf.embrapa.br/apps/socioeconomia/index.htm

[8] Brasil (2006) Normative Ruling No. 25 of May 23, 2006. Annex I. Minimum requirements for determining the value for cultivation and use of common bean (Phaseolus vulgaris) for inclusion in the National Register of cultivars-RNC. Official Gazette of the Federative Republic of Brazil, Brasilia. http://extranet.agricultura.gov.br/php/snpc/index.php

[9] Pereira, H.S., Melo, L.C., Faria, L.C., Del Peloso, M.J. and Wendland, A. (2011) Complex interaction between genotypes and growing seasons of carioca common bean in Goiás/Distrito. *Crop Breeding and Applied Biotechnology*, **10**, 207-215.

[10] Pereira, H.S., Melo, L.C., Faria, L.C., Del Peloso, M.J., Díaz, J.L.C. and Wendland, A. (2010) Indication of common bean cultivars based in joint evaluation of different growing seasons. *Pesquisa e Agropecuária Brasileira*, **45**, 571-578.

[11] Cruz, C.D. (2007) Genes Program: Computational application in genetics and statistics. http://www.ufv.br/dbg/genes/genes.htm

[12] Ferreira, D.F. (2008) Stability application. University Federal of Lavras. http://www.dex.ufla.br/~danielff/softwares.htm

[13] Cruz, C.D. and Castoldi, F. (1991) Simple and complex decomposition in parts of the genotypes x environments interaction. *Revista Ceres*, **38**, 422-430.

[14] Annicchiarico, P. (1992) Cultivar adaptation and recommendation from alfafa trials in Northern Italy. *Journal of Genetics and Plant Breeding*, **46**, 269-278.

[15] Cruz, C.D. and Regazzi, A.J. (2001) Biometric models applied to genetic improvement. 2nd Edition, UFV, Viçosa.

