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Implications of the number of years assessment on recommendation of common bean cultivars

Ricardo Augusto Diniz Cabral Ferreira[1,4], Magno Antonio Patto Ramalho[2], Fernando Henrique Ribeiro Barrozo Toledo[3] and Angela de Fátima Barbosa Abreu[2]

[1]Federal University of Viçosa-Bioagro, Viçosa, MG, Brazil 36570-00; [2]Federal University of Lavras, Lavras, MG, Brazil 370200-000; [3]"Luiz de Queiroz" College of Agriculture, São Paulo University, Piracicaba, SP, Brazil 13400 - 970; [4]Corresponding author, E-mail: ricardo.cabral.agronomia@gmail.com

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Abstract

In the common bean crop in Brazil, the requirement of the value for cultivation and use trials is that these experiments must be conducted over two years in three locations per region. Information in regard to the necessary number of years to ensure precision in cultivar recommendation and the influence of evaluated years in the estimation of the GE interaction are still scarce. Using grain yield of five check varieties assessed over 11 years in three sowing seasons per year, the aims of this study are as follows: to measure the relative contribution of the GE interaction, evaluating the implication of the number of years in the estimates of the GE interaction, and infer how many years are needed to ensure precision in cultivar recommendation. For instances, analysis of variance was carried out involving all environments and also combinations of years. The results showed that the GE interaction was greater than all other cross-effects involving lines. The use of at least two years allows good coincidence in cultivar recommendation compared to the whole period. Increasing the evaluation time is a good strategy, especially when it is difficult to grow three different sowing seasons.

Key words: quantitative genetics — genotype × environment interaction — prediction — plant breeding

To recommend cultivars in Brazil, it is necessary to carry out experiments called value for cultivation and use (Valor de Cultivo e Uso – VCU) (Brasil 2006). These experiments are indispensable for registration of cultivars. The regulations for these VCUs vary among crops and were established by a group of breeders and researchers that work with each species.

In the case of common bean, among the VCU requirement is that these experiments must be conducted over 2 years in three locations per region (Brasil 2006). Indications are that the decision in regard to the number of years was based on the experience of the group of breeders that work with the crop. Even though there are studies with respect to the line × year interaction, references were not found in regard to the number of years necessary to represent the future years in which the potential cultivar will be used by farmers. Some information in this respect was reported for temperate climate conditions in other species (Cross and Helm 1986, Gellner 1989, Yan and Rajcan 2003, Ma and Stützel 2014).

The Universidade Federal de Lavras (Federal University of Lavras), Lavras, MG, Brazil, has assessed common bean lines for some decades in its breeding programme. In these experiments, most of the lines are substituted for others after 2 years of testing. However, there is a group of common controls that were assessed for several consecutive years. Using data from these controls, the aim of this study was (i) to make inferences in regard to the relative contribution of the interactions involving lines, years, locations and sowing times; (ii) to check the implications of the number of years in the relative contribution of the line × year interaction; and (iii) to check how many years are necessary to have assurance in recommendation of a new cultivar.

Materials and Methods

We used data from experiments for the assessment of advanced lines from the common bean breeding programme of the Universidade Federal de Lavras carried out in the period from 2002 to 2012, with three crop seasons per year.

These experiments were carried out at three locations in the state of Minas Gerais, Brazil: Patos de Minas (18°34′S 46°31′W), Lavras (21°14′S and 45°59′W) and Lambari (21°50′S, 45°21′W). These three locations differed in regard to physical and chemical properties of the soil and also in regard to climate. The years in which the data were obtained at each location and in each crop season (sowing dates) are shown in Table 1.

In these experiments, the number of lines assessed varied from year to year; however, it was always >25. Every 2 years, new lines were assessed; however, five lines were continually used as common check varieties – they were 'Talismã', 'Carioca', 'Carioca MG', 'Pérola' and 'Ouro Negro'. A lattice or randomized block experimental design was used, with three replications. The experimental plots consisted of two rows of four metre length, spaced at 0.5 m.

Analyses of variance were carried out per experiment. For the statistical analyses of this study, the adjusted mean values of the five control cultivars obtained in the analyses of each experiment were used. With the mean values of these five lines in each experiment, combined analysis involving all the experiments was carried out. The Cochran (1957) method was adopted to adjust the degrees of freedom, due to the heterogeneity of the errors.

With the analyses of variance, the relative contribution of each source of variation (SV) to total variation (R^2) was estimated, except for the error, using the following estimator.

$$R^2 = \left(\frac{\mathrm{SQ}_{\mathrm{FV}i}}{\sum_{i=1}^{n} \mathrm{SQ}_{\mathrm{FV}i}}\right) \times 100,$$

where $\mathrm{SQ}_{\mathrm{FV}i}$ is the sum of square of the variation source i.

The Scott–Knott (1974) test was also carried out at the level of 5% probability for the cultivars in each crop season within each location, in the mean of the three crop seasons in each location and in the mean of all the environments.

All the combinations of combined analyses were also carried out varying the number of years. The number of analyses varied according to the location and the crop season. In all, 11 157 simulations were carried out (Table 1). In these analyses of variance, emphasis was directed to

Table 1: Number of years the experiments were carried out in Lavras, Lambari and Patos de Minas, MG, Brazil, in three crop seasons (sowing dates)

Location	Sowing dates	Years[1]	Combinations[2]	No combinations[3]
Lavras	October/ November	11	Taken 2 until 10 at time	2035[4]
	February/ March	11	Taken 2 until 10 at time	2035
	July/August	10	Taken 2 until 9 at time	1012
Lambari	October/ November	10	Taken 2 until 9 at time	1012
	February/ March	11	Taken 2 until 10 at time	2035
	July/August	9	Taken 2 until 8 at time	501
Patos	October/ November	8	Taken 2 until 7 at time	246
	February/ March	11	Taken 2 until 10 at time	2035
	July/August	8	Taken 2 until 7 at time	246
Total	Experiments	89	Combinations	11 157

[1]Total no. of years in which the experiments were assessed.
[2]Combinations made with the total no. of years in which the experiments were assessed.
[3]Sum of the total of simulations involving all the combinations of years.
[4]$\sum_{p=2}^{10} C_{10}^{p}$, where p is the number of years involved in each analysis.

estimation of the contribution of the line × year interaction (L × Y) in relation to the others.

After identification of the two best lines from the analyses involving all environments, two possible coincidences were estimated:

Coincidence type I: Coincidence of having at least one of the best lines in the two best places for each combination of years:

$$\text{Percentage of coincidence of the type I} = \left(\frac{\text{Number of situations in which had coincidence of having at least one of the best lines in the two best places}}{\sum_{p=2}^{10} C_{10}^{p}}\right) \times 100.$$

Coincidence type II: Coincidence of the two best lines being in the two best places for each combination of years:

$$\text{Percentage of coincidence of the type II} = \left(\frac{\text{Number of situations in which had coincidence of having two of the best lines in the two best places}}{\sum_{p=2}^{10} C_{10}^{p}}\right) \times 100.$$

where $\sum_{p=2}^{10} C_{10}^{p}$ is the sum of the combination taken two until 10 at time and p is the number of years involved in each analysis.

Results

The results of combined analysis of variance for grain yield (g/plot) involving the experiments carried out in the three locations, in the three crop seasons per year from 2002 to 2012, show the existence of variation among the lines ($P \leq 0.01$) (Table 2). The interactions involving lines were all significant ($P \leq 0.05$), except for the triple interaction involving lines, locations and crop season and the quadruple interaction involving all the factors. The interactions among the environmental factors, that is crop seasons, locations and years, were all significant ($P \leq 0.01$) (Table 2).

Observe that the line SV contributed only 1.55% to the variation. As for the environmental effects of crop season (S), year (Y) and location (E), individual explanation was >10%. Among the SV involving interaction, the lowest R^2 was for S × Y (Table 2).

In the experiments using different combinations of years, ranging from two up to the maximum number of years in which the experiments were carried out minus one, it was possible to observe that the amplitude of variation of R^2 was large, especially when the simulations involved a smaller number of years (Table 3). Another notable result in the effect of the number of years involved in estimates of the L × Y interaction was the fact of considering the analyses per crop season or in their mean value. Observe that when the mean of the three crop seasons is considered, regardless of the location, the amplitude of variation of the contribution of the L × Y interaction to the total variation (R^2) is reduced. It can be seen that when the goal is estimating the L × Y interaction, using data from three crop seasons allows more reliable estimates.

In particular, in experiments in the final stages of the breeding programme, the main interest is in identifying one or two lines to recommend to farmers as cultivars. Normally, the decision is made considering the overall mean of the experiments. However, it should be highlighted that, although interactions involving lines were significant, in most cases, 'Ouro Negro' and 'Pérola' were in the group of the best lines. When the mean value of the combined analyses of the three locations and crop seasons in the 11 years was considered, once more, these two constituted the group of the best lines, according to the Scott–Knott test (1974) (Table 4).

The combinations of analyses considering different numbers of years also allowed evaluating the implications of these numbers in classification of the lines. For better visualization, the two best lines ('Ouro Negro' and 'Pérola'), identified in the mean value of the three locations in the three crop seasons in each of the 11 years, were used as a reference. As the results were very similar among the locations, only those obtained in Lavras will be shown. The coincidence of one of these two lines in first or second place (coincidence type I) was always high (Fig. 1). Observe that considering only two years, the percentage of coincidence was >80%. It is clear that in two years, it would be possible to identify at least one of the desired lines.

Furthermore, the percentage of coincidence of having the two best ('Perola' and 'Ouro Negro') simultaneously in the first two

Table 2: Analysis of variance of grain yield (g/plot), involving the check cultivars (lines), locations, seasons and years, obtained in the evaluation of bean lines in the period 2002–2012

SV	df	MS	P-value	R^2 %[1]
Line(L)	4	402 012.80	≤0.01	1.55
Season (S)	2	5 865 297.41	≤0.01	11.34
Year (Y)	10	1 124 774.76	≤0.01	10.88
Location (E)	2	6 199 120.13	≤0.01	11.99
L × S	7[2]	61 466.24	≤0.01	0.42
L × Y	32[2]	132 741.46	≤0.01	4.11
L × E	7[2]	110 392.32	≤0.01	0.75
S × Y	16[2]	1 068 592.84	≤0.01	16.53
E × S	4[2]	1 162 639.37	≤0.01	4.50
E × Y	16[2]	779 967.78	≤0.01	12.07
L × S × Y	80	56 585.23	≤0.01	4.38
Lx E × S	16	27 726.42	0.69	0.43
E × S × Y	30	465 676.13	≤0.01	13.51
L × Y × E	80	46 017.15	0.03	3.56
L × E × S × Y	120	34 447.03	0.51	4.00
Mean square error	4201	27 336.21		100.00

[1] $\left(SS_{svi}/\sum_{i=1}^{n} SS_{svi}\right) \times 100$ where: SS_{svi} is the sum of squares of the source variation *i*.

[2] Degrees of freedom adjusted using the Cochran (1957).

places (Coincidence type II) was <30% (Fig. 2). It is noteworthy, however, that when the mean value of the crop seasons in each location is considered, the coincidence of the best lines increases substantially with an increase in the number of years.

Discussion

The use of controls in experiments for the assessment of progeny and/or lines has the advantage of allowing comparison of groups of treatments in different environments, years and/or locations (Petersen 1994). Unfortunately, in a large number of cases, these controls are substituted at very short intervals, which makes data analysis involving a greater amplitude of conditions difficult. In addition, a very small number of controls is normally used, generally one or two (Tai 1969, Besag and Lane 1986, Kempton and Talbot 1988). In this study, five controls were used for 11 consecutive years. In comparison of the mean values of the lines involving all the environments (89 experiments – combination of the three locations, sowing times and all the years of assessment), two groups were formed. Variation among the lines was necessary to achieve the goal of the research.

Table 3: Amplitude of variation of the estimates of the coefficient of determination (R^2) for the L × Y interaction. Estimates obtained in the different combinations of number of years in analyses of variance, per crop season and combined. Data obtained in Lavras, Lambari and Patos de Minas, MG, Brazil

	Lavras				Patos				Lambari			
Combination of years	Rainy	Winter	Dry	Average	Rainy	Winter	Dry	Average	Rainy	Winter	Dry	Average
2 by 2	79.77	87.59	87.21	26.09	83.23	59.40	60.73	12.61	75.05	78.67	70.91	32.68
3 by 3	81.22	81.06	88.27	22.92	76.86	40.84	70.48	11.47	77.69	63.81	79.85	26.95
4 by 4	80.38	77.30	79.44	20.43	58.88	31.14	53.96	11.22	71.66	66.37	71.54	24.77
5 by 5	72.46	69.00	65.62	19.12	46.88	18.83	44.48	8.45	64.99	55.44	51.00	22.05
6 by 6	52.09	59.18	60.44	16.23	38.35	8.47	32.48	7.21	51.33	44.21	42.55	19.16
7 by 7	45.02	52.88	42.37	11.59	27.31	3.83	24.93	4.79	37.26	25.19	34.06	15.40
8 by 8	35.78	30.65	30.60	8.05	0.00	0.00	15.55	3.17	26.74	11.56	27.71	12.21
9 by 9	27.64	16.65	20.95	5.89	X	X	7.90	2.26	18.41	0.00	16.13	9.53
10 by 10	18.34	0.00	9.06	2.69	X	X	4.02	1.58	0.00	x	7.36	5.11
11 by 11	0.00	X[1]	0.00	0.00	X	X	0.00	0.00	x	x	0.00	0.00

[1] The number of years is not enough years to make the combination of years (see Table 1).

Table 4: Mean values of grain yield (g/plot) of the common bean lines assessed in the experiments carried out in the period from 2002 to 2012. Data shown per location and crop season (sowing dates) in the mean value of the crop seasons for each location (mean value) and involving all the environments

		Bean lines				
Location	Sowing dates	'Carioca'	'Carioca MG'	'Ouro Negro'	'Pérola'	'Talismã'
Patos de Minas	October/November	747a[1]	703a	706a	761a	693a
	February/March	693b	691b	810a	730b	705b
	July/August	964a	975a	996a	933a	930a
	Mean	789b	779b	834a	799b	768b
Lavras	October/November	789a	855a	873a	896a	900a
	February/March	990a	967a	1059a	1034a	1027a
	July/August	1048a	1086a	1117a	1072a	976b
	Mean	939b	966b	1013a	999a	967b
Lambari	October/November	527c	606b	712a	616b	545c
	February/March	765b	879a	936a	875a	886a
	July/August	760b	940a	970a	893a	84b
	Mean	685d	806b	872a	794b	751c
Combined		808b	855b	911a	869a	834b

[1] Means followed by the same letter in each row belong to the same group by the Scott–Knott (1974) at the 5% level of probability.

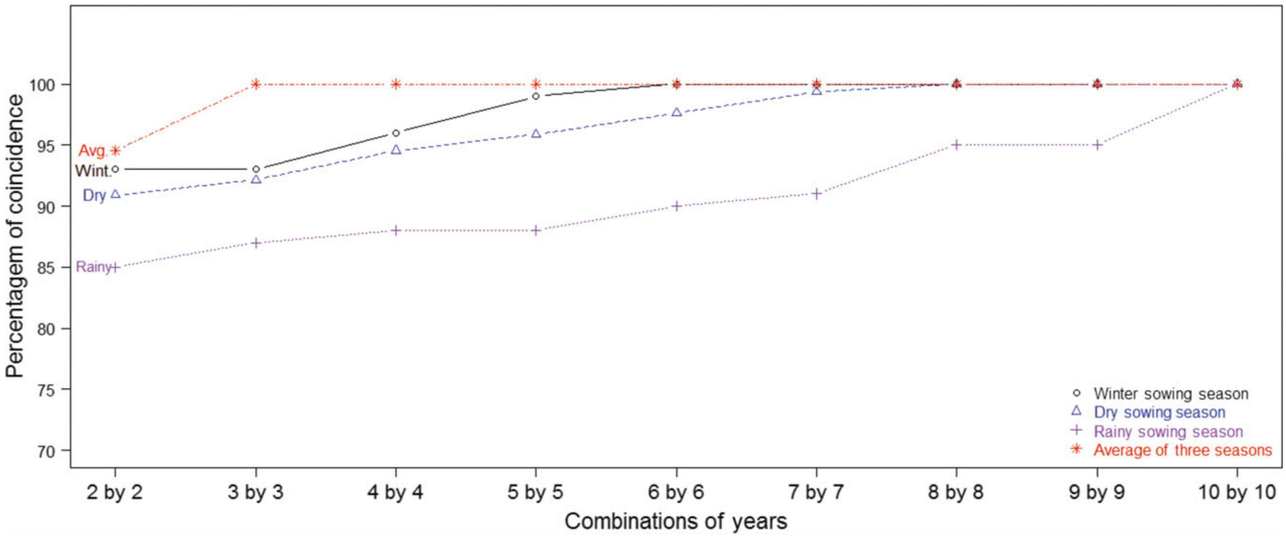

Fig. 1: Percentage of cases in which the line 'Pérola' or 'Ouro Negro' occurred in the first two places. Estimates obtained in the different combinations of number of years, considering the crop years separately or together. Data obtained in Lavras, MG, Brazil

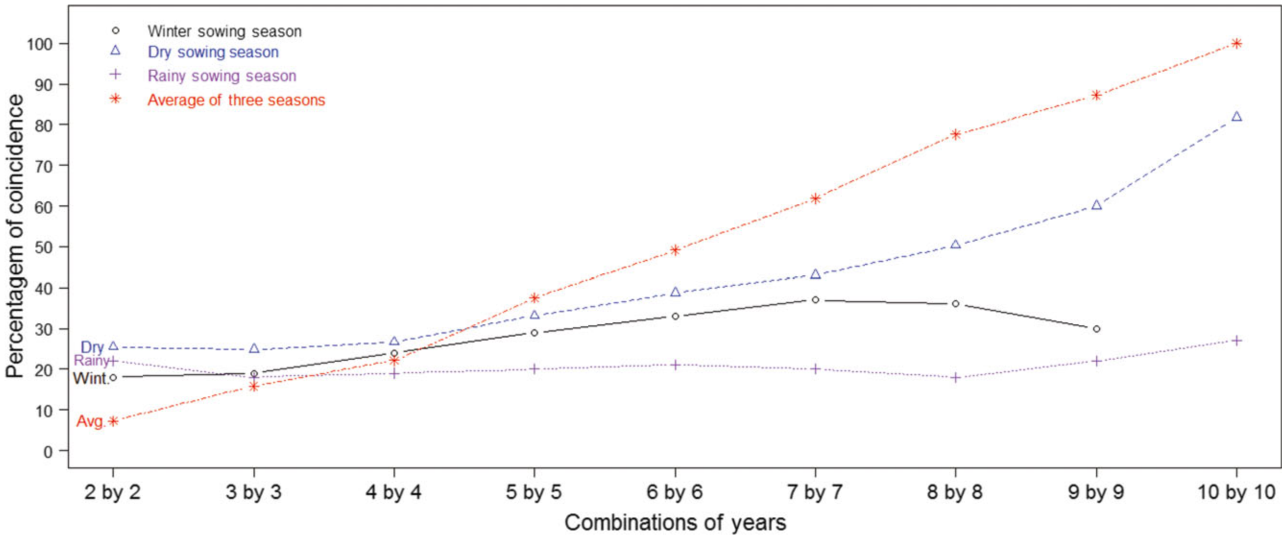

Fig. 2: Percentage of cases in which the line 'Pérola' and 'Ouro Negro' occurred in the first two places. Estimates obtained in the different combinations of number of years, considering the crop years separately or together. Data obtained in Lavras, MG, Brazil

In many regions of Brazil, especially in the state of Minas Gerais, common bean may be sown practically throughout the year. To facilitate exchange of information, the sowing months are grouped into some seasons (Vieira et al., 2005). Considering the three locations in which the experiments were conducted, there are what is called the dry season – sowing in the months of February/March, the fall/winter season – sowing in July/August, and the rainy season – sowing in October/November. The climatic conditions in these three crop seasons are quite distinct. The dry season coincides with the end of the period of intense rains and higher temperatures. In the vegetative phase of the fall/winter season, there is practically no rain and the crop is fully irrigated. In the rainy season, rainfall is normally intense and the relative humidity and temperature are high. These differences among crop seasons were confirmed in the analysis undertaken (Tables 2 and 4). In numerous other studies for the assessment of lines carried out in these same three locations, differences in the mean yield of the lines among the three crop seasons are common (Matos et al. 2007, Lima 2014). The effect of years is very common in the studies carried out in the region (Ramalho et al. 1998, Matos et al. 2007).

Although all the individual sources of variation were significant, as has already been mentioned, their relative contribution to total variation (R^2) was different (Table 2). In the mean of the three environmental factors, crop season, year and location, the contribution was 11.4%. This value was 7.4 times greater than that of the line factor (R^2 = 1.55%). In experiments with the common bean crop, and even in other species in which progeny/lines are assessed, the contribution of the sources of variation involving environments is almost always more expressive than the genotypes (Ramalho et al. 1998, Pereira et al. 2010, Silva et al. 2011).

For Allard and Bradshaw (1964), the effect of years is unpredictable; that is, the climate conditions and occurrence of biotic factors from one year to another are unpredictable. The experiments carried out are actually a way of predicting what will occur in farmers' fields (Gauch and Zobel 1988). Thus, when these results are extrapolated to what will occur on farmers' properties in future, all these factors must be important.

The greatest challenge to be overcome by researchers, especially for crops under tropical conditions, is mitigating the effect of the genotype × environment interaction. In this study, as all the individual sources of variation were significant, it was expected that if there were interaction, it would be expressed. Of the 11 types of interaction possible, in only two, L × E × S and L × E × S × Y, was the level of significance >5% (Table 2). In addition, it was verified that the contribution of the interactions to the total variation, estimated by R^2, showed large divergence, ranging from 0.42% (L × S) to 16.53% (S × Y) (Table 2). It is noteworthy that the sum of the contribution to total variation of the seven interactions involving lines corresponds to only 17.5%. In the literature, the reports on the contribution of the interactions are not always in agreement. Meyer et al. (2011) and Laidig et al. (2008) working with cultivars from 30 different crops reported that the contribution of the Genotype × Year and Genotype × Environment interaction varies among the crops. Ramalho et al. (1998) and Silva et al. (2011) observed that the L × E and L × S interactions contributed less than the L × Y interaction, as occurred in this study. However, Matos et al. (2007) and Torga et al. (2013) found that the L × E interaction was of a magnitude greater than or equal to the L × S and L × Y interactions. It should be highlighted that, in these studies, the number of years involved was small.

The problem in using few years to estimate the line × year interaction (L × Y) may be clearly seen in Table 3. Note that when 2 years are used, the amplitude of variation of the contribution of the L × Y interaction is large. Increasing the number of years, the contribution of the L × Y interaction decreased, as expected. Another important point is that when this interaction is estimated using the mean data of the three crop seasons, the amplitude of variation of R^2 is less than that using only one crop season. Thus, even without there being an L × S interaction, it is important that the experiments be carried out in the three crop seasons because that way it is possible to have better estimates of the L × Y interaction.

The approach of the experiments for the assessment of lines and/or hybrids, as is the case of the VCU, is to identify the genotypes that will continue with the best performance in farmers' fields (Gauch and Zobel 1988). In Brazil, these experiments are required by law to recommend a cultivar, and one of the rules is that these experiments be conducted over at least two years (Brasil, 2006). However, the question arises if two years are enough for the recommendation to be able to reflect the relative performance of the lines in future.

Seeking to give an answer to this inquiry, experiments were simulated involving various combinations of years. The coincidence of the two best lines assessed in the 11 years with the best ones identified in the different combinations of years was not high, regardless of the number of years, locations and crop seasons. This reflects the line × environment interaction. The important thing for the breeder is not to have perfect coincidence, but that at least one of the lines is in the group of the best lines. Observe that in this case, the percentage of coincidence is much greater, above 80%, even with only two years (Fig. 1).

Note, moreover, that the combinations of analyses made in the mean value of the three crop seasons almost always had greater coincidence, once more indicating that it is important to assess in more than one crop season per year. This is an advantage of the common bean crop in relation to other annual species because, as it has a short cycle, it allows the assessment of the lines in three crop seasons in a single year, increasing the number of replications in obtaining the mean values. Troyer (1996) comments that the best way of choosing a hybrid or line with broad adaptation, that is mitigating the effect of the interaction, is to assess the genotypes with the greatest number of replications possible. Clearly, it is difficult to extend the number of years as this delays recommendation of the cultivar, which is undesirable. As was seen, two years proved to be sufficient, especially when considering the mean value of the three crop seasons in the three locations.

The probability of identifying one of the two lines with the best performance in the 11 years was above 90%. Thus, 2 years would already be sufficient for identifying at least one of the best lines. As already mentioned, in the standards of the VCU experiments for common bean and for other annual species, it was apparently established without any scientific grounding that two years would represent the future years that the recommended cultivar(s) would encounter on farmers' properties. In the case of common bean, as observed in this study, the decision was correct.

In the common bean crop, there are no studies assessing the number of years in recommendation of lines. But for other crops, such as soybean, corn and wheat, there are some reports (Cross and Helm 1986, Yan and Rajcan 2003, Ma and Stützel 2014). In general, the results were consistent with those reported above; that is, that two years would already be sufficient. However, it is important to highlight that these studies were carried out with an unbalanced database, where the number of cultivars that were replicated from 1 year to the next was small.

Questioning that could be made of the results of this study is that the number of lines assessed was small and that the coincidence obtained could be explained by chance. In principle, the argument is valid. However, consideration was made (data not shown) as to what the coincidence of the lines classified in the group of the worse lines occupies the first places in the different combinations of the number of years. There was no consistency in the results when the number of years was increased, as occurred when involving only the best lines. Thus, the coincidence obtained in this study must not be simply a random event.

In summary, the results showed the relative magnitude of the line × year interaction was greater than all the other interactions involving lines. The use of two years is viable for recommendation of new cultivars for the common bean crop. However, especially when it is not possible to carry out three crop seasons annually, the use of more years is a good strategy.

References

Allard, R. W., and A. D. Bradshaw, 1964: Implications of genotype-environmental interactions in applied plant breeding. Crop Sci. **4**, 503—508.

Besag, J., and M. Lane, 1986: Statistical analysis of field experiments using neighbouring plots. Biometrika **42**, 231—251.

Brasil, 2006: Instrução Normativa n° 25 Requisitos mínimos para determinação do valor de cultivo e uso de feijão (*Phaseolus vulgaris*) para a inscrição no registro nacional de cultivares. Available at: http://extranet.agricultura.gov.br/sislegisconsulta/servlet/VisualizarAnexo?id=11376 (last accessed on December 11, 2014).

Cochran, W. G., and G. M. Cox, 1957: Experimental Designs. J. Wiley, Oxford.

Cross, H. Z., and J. L. Helm, 1986: Hybrid maize selection strategies based on state yield trials. J. Agro. Educ. **15**, 110—113.

Gauch, H. G., and R. W. Zobel, 1988: Predictive and postdictive success of statistical analyses of yield trials. Theor. Appl. Genet. **76**, 1—10.

Gellner, J., 1989: Predicting superior yielding spring wheat an oat cultivars using past yield data. Agron. J. **81**, 194—197.

Kempton, R. A., and M. Talbot, 1988: The development of new crop varieties. J. R. Stat. Soc. **151**, 327—341.

Laidig, F., T. Drobek, and U. Meyer, 2008: Genotypic and environmental variability of yield for cultivars from 30 different crops in German official variety trials. Plant Breed. **127**, 541—547.

Lima, L. K., Ramalho, M. A. P., A. F. B. Abreu, F. H. R. B. Toledo, and R. A. D. C. Ferreira, 2014: Implications of predictable and unpredictable environmental factors in common bean VCU trials in Minas Gerais. Crop Breed. and Appli. Biote. **14**, 146—153.

Ma, D., and H. Stützel, 2014: Prediction of winter wheat cultivar performance in Germany: At national, regional and location scale. Eur. J. Agron. **52**, 210—217.

Matos, J. W., M. A. P. Ramalho, and Â. F. B. Abreu, 2007: Thirty two years of common bean breeding in Minas Gerais state José. Ciênc. Agrotec. **31**, 1749—1754.

Meyer, U., et al., 2011: Optimization of number of trials in official VCU trial series of Germany. Biuletyn Oceny Odmian, Zeszyt **33**, 73—82.

Pereira, H. S., L. C. Melo, L. D. Faria, M. J. Del Peloso, J. L. C. Díaz, and A. Wendland, 2010: Indication of common bean cultivars based in joint evaluation of different growing seasons. Pesq. Agropec. Bras. **45**, 571—578.

Petersen, R. G., 1994: Agricultural Field Experiments: Design and Analysis. CRC Press, New York.

Ramalho, M. A. P., Â. F. B. Abreu, and J. B. Santos, 1998: Interações genótipos × épocas de semeadura, anos e locais na avaliação de cultivares de feijão nas regiões sul e Alto Paranaíba em Minas Gerais. Ciênc. Agrotec. **22**, 176—181.

Scott, R. J., and M. Knott, 1974: A cluster analysis method for grouping mans in the analysis of variance. Biometrics **30**, 507—512.

Silva, C. A., A. F. B. Abreu, M. A. P. Ramalho, and J. E. Carneiro, 2011: Implications of the origem of bean lines in the magnitude of the interaction with environments. Pesq. Agropec. Bras. **46**, 720—728.

Tai, G. C. C., 1969: Genotypic stability analysis and its application to potato regional trials. Crop Sci. **11**, 184—190.

Torga, P. P., P. G. S. Melo, H. S. Pereira, L. C. de Faria, M. J. Del Peloso, and L. C. Melo, 2013: Interaction of common beans cultivars of the black group with years, locations and sowing seasons. Euphytica **189**, 239—248.

Troyer, A. F., 1996: Breeding widely adapted, popular maize hybrids. Euphytica **92**, 163—174.

Vieira, C., 2005: Melhoramento do feijão. In: A. Borém (ed.), Melhoramento de espécies cultivadas, 233—247. UFV, Viçosa.

Yan, W., and I. Rajcan, 2003: Prediction of cultivar performance based on single-versus multiple-year tests in soybean. Crop Sci. **43**, 549—555.