Methods of adaptability and stability applied to eucalyptus breeding

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Abstract − The objective of this work was to evaluate the consistency of the methods of Annicchiarico, Lin & Binns, Wricke, and factor analysis in identifying eucalyptus clones with stability, adaptability, and high productive potential. Eight-four clones, with three years of age, from the genetic breeding program of the company CMPC Celulose Riograndense were used. Three field experiments were carried out in a randomized complete block design, in an 84x3 factorial arragement, with 20 replicates of one plant per plot. The clones were evaluated as to diameter at breast height, plant height, and volume of wood. The methods of Annicchiarico and Lin & Binns are highly correlated with each other, and their use together with the method of Wricke is a sound strategy for the evaluation of eucalyptus clones. The factor analysis identified broadly adaptable clones, and some of them were the same ones identified by the methods of Annicchiarico and Lin & Binns. The use of the mean classification of the clones, along with the factor analysis, is efficient to identify the most adapted, stable, and productive ones among a high number of genotypes.

Index terms: *Eucalyptus*, average ranking, experimental planning, factor analysis, selection.

Métodos de adaptabilidade e estabilidade aplicados ao melhoramento de eucalipto

Resumo − O objetivo deste trabalho foi avaliar a consistência dos métodos de Annicchiarico, Lin & Binns, Wricke e de análise fatorial na identificação de clones de eucalipto com estabilidade, adaptabilidade e alto potencial produtivo. Foram utilizados 84 clones, com três anos de idade, provenientes do programa de melhoramento genético da empresa CMPC Celulose Riograndense. Três experimentos de campo foram realizados em delineamento de blocos ao acaso, em arranjo fatorial 84x3, com 20 repetições de uma planta por parcela. Os clones foram avaliados quanto a diâmetro à altura do peito, altura da planta e volume de madeira. Os métodos de Annicchiarico e Lin & Binns são altamente correlacionados entre si, e seu uso em conjunto com o método de Wricke é uma estratégia apropriada para avaliação de clones de eucalipto. A análise fatorial identificou clones amplamente adaptáveis, e alguns deles foram os mesmos identificados pelos métodos de Annicchiarico e Lin & Binns. O uso da classificação média dos clones, juntamente com a análise fatorial, é eficiente para identificar os mais adaptados, estáveis e produtivos, entre um elevado número de genótipos.

Termos para indexação: *Eucalyptus*, ranque médio, planejamento experimental, análise de fatores, seleção.

Introduction

Eucalyptus breeding programs are usually based on selection among and within half-sibling progenies, in order to identify the best clones in the final breeding period (Resende et al., 2012). For this, such clones are evaluated in different environments before final selection and commercialization. Some studies have shown the occurrence of genotype x environment interaction (G×E) in eucalyptus clones (Nunes et al., 2002; Rocha et al., 2006; Rosado et al., 2012) and, therefore, it is important to carry out studies aiming at identifying specific clones for each environment.

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Traditionally, the process of investigating G×E interactions has been through the analysis of variance (Anova) in groups (sites) of experiments; however, the simple analysis of this component of variance does not provide detailed information about the behavior of each clone in each environmental condition (Cruz et al., 2012). In this sense, the analyzes of adaptability and stability based on the Anova, such as those of Annicchiarico (1992) and Wricke (1965), and in a nonparametric analysis, such as that of Lin & Binns (1988), allow to identify clones with predictable behavior and responsive environmental conditions. In addition, the factor analysis, proposed by Murakami & Cruz (2004), comprehends the analysis of adaptability and grouping of homogeneous environments.

The use of more than one method in the assessment of adaptability and stability has been a common practice and has shown that some methods are somewhat redundant (Lin & Binns, 1991; Silva & Duarte, 2006; Pereira et al., 2009; Carvalho et al., 2014).

In *Eucalyptus* breeding, due to the long cycle of the species, high operational costs, and to the use of vast and heterogeneous areas, the adopted strategies for the selection of clones must be the most sound and precise ones. Therefore, studies regarding the phenotypic adaptability and stability of this species are essential.

The objective of this work was to evaluate the consistency of the methods of Annicchiarico (1992), Lin & Binns (1988), Wricke (1965), and factor analysis (Murakami & Cruz, 2004) in identifying eucalyptus clones with stability, adaptability, and high productive potential.

Materials and Methods

Three field experiments were carried out in 2012 in the areas of the company CMPC Celulose Riograndense, in the municipalities of Eldorado do Sul (Boa Vista horticultural forest), Butiá (Morro Vermelho horticultural forest), and São Gabriel (Cerro do Batovi horticultural forest), all located in the state of Rio Grande do Sul, Brazil. The experiments were planted in a 3.50x2.14-m spacing and conducted according to the company's operating procedures. Information on the three environments where the tests were implemented are shown in Table 1.

Eighty-four Eucalyptus clones were evaluated in each environment (Table 2). A randomized complete block design was used, in a factorial arrangement 84x3, arranged in 20 replicates, with one plant per plot. The clones were assessed in the third year with measurements of diameter at breast height (DBH, cm), total plant height (PH, m), and volume of wood (VOW, m^3). DBH was measured with a diameter tape, and the total height was obtained with the relascope. The VOW, with the bark, was estimated according to the model of Leite et al. (1995):

$$\mathrm{VOW} = 0.000048 \times \mathrm{DHB}^{1.720483} \times \mathrm{PH}^{1.180736} \times \exp^{(-3.00555)\times(\mathrm{tx}/\mathrm{DBH})} \times \left[0 - (\mathrm{d}/\mathrm{DHB})^{1+0.228531\times \mathrm{d}}\right] + \varepsilon$$

where DBH is the diameter at 1.3 m from the soil; PH is the total height; tx is equal to 0, for volume estimates with bark, and to 1 for estimates without bark; d is the upper commercial diameter; and ε is the experimental error.

The data were tested for homogeneity of variances and heteroscedasticity of residues. Afterwards, a joint analysis of variance was performed using Snedecor's F-test, at 5% probability. The averages of the genotypes were grouped by the Scott-Knott test, also at 5% probability.

The evaluations for adaptability and phenotypic stability of DBH, PH, and VOW were performed with

Table 1. Geographic location and soil and climatic conditions of the environments evaluated in the state of Rio Grande do Sul, Brazil.

Descriptor	Boa Vista	Morro Vermelho	Cerro do Batovi
Municipality	Eldorado do Sul	Butiá	São Gabriel
Geographic coordinates	- 30.0689; - 51.4470	- 30.2750; -52.1005	- 30.4470; - 54.5342
Altitude (m)	75	188	139
Previous occupation	Forest	Forest	Native field
Soil type	Ultisol	Ultisol	Ultisol
Mean temperature (°C)	18.2	18.2	20.2
Absolute minimum temperature (°C)	2.21	2.21	0.3
Absolute maximum temperature (°C)	34.9	34.9	37.3
Frost risk	Low	Low	High
Relative humidity (%)	82.2	82.2	72.4
Rainfall (mm)	1570	1570	1965

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the methods of: Annicchiarico (1992) and Wricke (1965), based on the Anova; Lin & Binns (1988), based on the nonparametric analysis; and factor analysis, proposed by Murakami & Cruz (2004). The stratification (clustering) of the environments was performed according to the magnitude of the factorial loads obtained after 50 rotations with the "varimax" method. The scores were plotted in relation to the factors, and it was possible to identify the clones with specific adaptability to the regions determined by the factors (quadrants II and IV of the graph), clones with wide adaptability (quadrant I), as well as clones with low performance (quadrant III).

For each studied variable, the association between the methods was evaluated by the correlation coefficient (Spearman) applied to the rank of each genotype, considering the parameters and the concept of adaptability and stability of each method. In the methods of Wricke and Lin & Binns, rank 1 was assigned to the clone with the lowest estimate of ω_i and P_i, respectively, successively, until the last rank, which presented the largest of these estimates. In the method of Annicchiarico, contrastingly, rank 1 was attributed to the clone with the highest estimate of ωi; afterwards, the average of the ranking of the four methods studied and the productive ranking of the clones were established. This average was ranked, and the clones with the ten best averages were presented. All statistical procedures were performed using the Genes software (Cruz, 2013).

Table 2. Description of the *Eucalyptus* clones analyzed in three environments, with their respective species and crosses.

No.	Species	Number of clones	Total no. of clones (%)
1	*E.* (*grandis x urophylla*) x not informed	31	36.90
2	*E. urophylla* x *E. globules*	21	25.00
3	*E.* (*grandis x urophylla*) x *E. globulus*	12	14.29
4	*E. saligna* x not informed	4	4.76
5	*E.* (*grandis* x *urophylla*) x *E.* (*urophylla* x *globulus*)	3	3.57
6	*E.* (*grandis* x *saligna*) x notinformed	2	2.38
7	*E. grandis* x *E.globulus*	2	2.38
8	*E.* (*grandis* x *urophylla*) x *E.maidenii*	2	2.38
9	*E.* (*grandis* x *urophylla*) x *E.viminalis*	2	2.38
10	*E. urophylla* x not informed	1	1.19
11	*E.* (*dunnii* x *grandis*) x *E.* (*urophylla* x *globulus*)	1	1.19
12	*E.* (*dunnii* x *grandis*) x *E.viminalis*	1	1.19
13	*E. saligna*	1	1.19
14	*E.* (*dunnii* x *grandis*) x not informed	1	1.19
Total		84	100.00

Results and Discussion

The analysis of joint variance revealed a significant interaction of clones and environments for DBH, PH, and VOW. The G×E interaction hampers giving a standard recommendation for all sites (Rosado et al., 2012).

According to the Scott-Knott test, six groups were formed for DBH. The group with the highest averages (A) was composed of 18 clones (21%) (Table 3). Plant height showed high variability, revealing the potential of this trait for the selection of superior clones. Four groups were formed for PH. The group with the highest averages (A) was composed by 21 clones (25%). For VOW, six groups were formed, with the highest averages only in five clones (5%).

Clones 9, 59, and 72 had the highest DBH, PH, and VOW averages (Table 3). A previous study with 21 clones, 36 months old, from the Cenibra breeding program, showed averages of 11 cm, 16.5 m, and 0.07 m^3 for these same traits, respectively (Rosado et al., 2012). The results found, therefore, revealed clones with high productive potential for selection, which can be used as a source of genetic variation for *Eucalyptus* breeding programs.

The most stable material for DBH, identified by the method of Annicchiarico, was clone 59 (Table 4). According to the methods Lin & Binns and Wricke, however, clones 9, 26, and 3 showed the best stability and adaptability results. Genotype 59 was ranked first, regarding stability, with the second highest DBH. Moreover, this genotype was classified as the first, second, and tenth most adapted and stable by the methods of Annicchiarico, Lin & Binns, and Wricke, respectively.

Clone 59 also presented the highest PH values (Table 5), and it was classified as the first most adapted and stable according to the methods of Annicchiarico and Lin & Binns. As for VOW, this clone once more had the best results, being classified as the first and second most adapted and stable, according to the methods of Annicchiarico and Lin & Binns, respectively (Table 6). It is important to highlight that clone 59 also showed the second highest average of VOW. In a study with sugarcane (*Sacharum officinarum* L.), Paula et al. (2013) identified that the methods of Lin & Binns and Annicchiarico were similar as to their classification of genotypes, with 100% of agreement for the first 10 ranking positions.

Of the 30 analyzed correlation pairs, 83% were significant at 1% probability. For the three studied variables, a high association (r_s>0.90) was observed between genotype rank for the evaluated traits and their classification regarding the parameters of adaptability and stability of the methods of Annicchiarico and Lin & Binns (Table 7). These results indicate that these methods can be used as tools for identifying stable clones among the most productive ones. The positive correlation (r_s>0.90) between these methods, however, shows that their joint use should be optional, since their results converge to a common point. Similar findings were observed by Silva & Duarte (2006) and by Pereira et al. (2009), who found high positive associations between them.

Although the methods of Annicchiarico and Lin & Binns are based on different statistical principles, the genotypic classification for the three variables analyzed was similar (Tables 4, 5, and 6). For example, clone 59 was classified as the most stable by these two methods regarding PH (Table 5), but as the first and second, respectively, regarding VOW (Table 6). These results may be associated with the higher average values observed for this clone (Table 3), since both methods use the superiority of the clone, in relation to the maximum average response of each environment, as a principle for determining adaptability and stability (Cruz et al., 2012).

The parameters of adaptability and stability of the method of Wricke showed relatively low associations (r_s<0.50) with the production averages of DBH, PH, and VOW (Table 7). The methods of Annicchiarico and Wricke were lowly correlated to each other. Thus, the joint use the methods of Annicchiarico or Lin & Binns with the Wricke method must be favored by the breeders, since their parameters can reveal detailed information, which could aid in choosing the best strategy for selection.

In the average ranking of the three evaluated variables, clone 59 occupied the first order (Table 8).

Table 3. Genotype grouping[1] according to their averages for diameter at breast height, plant height, and volume of wood.

Group	Highest average	Lowest average	Genotype[2]
			Diameter at breast height (cm)
A	17.614	15.790	9, 59, 64, 15, 72, 62, 11, 10, 58, 65, 68, 83, 75, 77, 71, 1, 34, 82
B	15.494	13.460	16, 74, 76, 12, 63, 13, 8, 26, 69, 67, 66, 30, 33, 46, 2, 51, 79, 52, 60, 84,40,29,54, 4, 14, 17, 32, 20, 70, 78
C	13.311	12.002	55, 31, 24, 73, 56, 53, 18, 61, 47, 7, 35, 50, 80, 21, 39, 27, 42, 81
D	11.641	11.021	5, 3, 41, 43, 57, 28, 36
E	10.807	9.850	49, 22, 19, 6, 48
F	9.581	8.140	25, 37, 23, 44, 45, 38
			Plant height (m)
A	17.768	16.336	59, 9, 77, 30, 13, 14, 62, 72, 83, 34, 29, 70, 40, 67, 12, 81, 46, 8, 69, 74, 71
B	16.221	14.853	58, 82, 16, 60, 84, 51, 75, 54, 26, 1, 24, 20, 31, 4, 11, 64, 65, 68, 61, 10, 47, 15, 70, 17, 32, 7, 73, 78, 55, 52, 18, 2, 3, 63, 56, 33, 66
C	14.771	13.071	22, 53, 39, 76, 41, 27, 35, 43, 36, 21, 50, 42, 57, 28, 80, 37, 19, 5, 25
D	12.822	10.966	49, 48, 23, 6, 44, 38, 45
			Volume of wood (m^3)
A	0.215	0.188	9, 59, 72, 64, 66
B	0.183	0.161	62, 15, 77, 83, 10, 58, 65, 11, 34, 68, 75, 71, 74, 1
C	0.156	0.134	30, 16, 13, 46, 12, 82, 67, 69, 79, 26, 8, 63, 24, 84, 40, 76, 29, 60, 2, 51
D	0.127	0.118	54, 33, 52, 17, 4, 14, 73, 70, 18, 32, 42
E	0.115	0.081	53, 20, 31, 78, 47, 35, 81, 55, 39, 21, 61, 56, 27, 41, 22, 7, 43, 36, 80, 50, 3, 5
F	0.071	0.032	28, 57, 49, 19, 37, 48, 6, 23, 25, 44, 45, 38

[1]The groups were formed according to the Scott-Knott test, at 5% probability. [2]The order of the genotype in each group is presented according to their decreasing average ranking for each variable.

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Table 4. Estimates of the adaptability and phenotypic stability parameters for diameter at breast height (DBH, cm) of 84 *Eucalyptus* genotypes (G) for the methods of Annicchiarico (ANN), Lin & Binns (L&B), and Wricke (W), as well as their respective ranks (C) according to their adaptability and stability classification in each method.

G	DBH		ANN		L&B		Wricke		G	DBH		ANN		L&B		Wricke	
	Average	C	Ωi	C	Pi	C	ωi	C		Average	C	ωi	C	Pi	C	ωi	C
1	15.99	16	101.3	16	4.67	17	73.36	34	43	11.31	70	73.08	50	27.1	69	8.538	4
2	14.65	33	100.1	21	8.23	29	18.5	7	44	9.029	82	12.74	82	57.3	81	954.5	83
3	11.55	68	77.26	47	25.90	68	18.83	9	45	8.32	83	12.32	83	63.3	84	840.4	81
4	14.08	42	93.43	33	11,00	42	28.68	14	46	14.76	32	70.38	54	9.06	34	331.8	68
5	11.64	67	53.46	66	25.20	66	175.2	59	47	12.42	57	59.72	64	20.1	54	176.9	61
6	10.16	77	40.95	74	41.40	78	391.5	72	48	9.85	78	65.3	61	39.8	77	33.44	19
7	12.41	58	77.10	48	21,00	56	64.25	30	49	10.81	74	32.36	78	39.2	76	699.9	79
8	15.11	25	90.12	37	7.85	27	103.5	41	50	12.33	60	62.11	62	23.5	63	237.9	66
9	17.61	1	111.6	4	0.95	1	125.4	46	51	14.62	34	94.74	29	8.41	31	49.65	24
10	16.47	8	108.3	9	2.49	7	63.59	29	52	14.57	36	101	18	8.72	32	8.101	3
11	16.48	7	105.1	11	2.60	8	89.77	37	53	12.75	54	42.31	73	20.1	55	510.4	76
12	15.32	22	100.4	20	5.67	21	45.89	23	54	14.13	41	92.42	35	10.4	41	32.76	18
13	15.11	24	95.07	28	6.46	23	69.47	32	55	13.31	49	46.45	70	22.8	61	714.6	80
14	14	43	78.92	46	13.20	45	140.1	52	56	12.75	53	72.39	52	19.7	52	131.7	48
15	17.21	4	115.40	2	1.410	3	26.29	13	57	11.26	71	69.55	56	28.8	71	71.34	33
16	15.49	19	104.10	12	5.40	19	32.51	17	58	16.42	9	108.7	8	2.78	9	55.72	26
17	13.91	44	91.02	36	12.10	43	32.32	16	59	17.36	2	120.5	1	0.97	2	20.11	10
18	12.65	55	48.34	69	19.80	53	377.8	71	60	14.42	37	87.59	40	9.43	38	96.62	39
19	10.68	76	51.39	68	35.70	75	256.5	67	61	12.54	56	83.72	44	19	51	18.52	8
20	13.73	46	72.37	53	15.10	46	211.1	64	62	16.57	6	109.9	6	2.28	6	58.75	28
21	12.26	62	65.83	59	21.20	57	137.9	49	63	15.12	23	87.66	39	8.26	30	169	58
22	10.75	75	26.98	79	33.60	74	453	75	64	17.31	3	104.1	13	1.52	4	183.8	63
23	9.131	81	7.484	84	58.60	83	1207	84	65	16.35	10	98.78	25	3.75	15	143.6	53
24	12.91	51	26.55	80	22,00	59	928.3	82	66	14.87	29	86.24	41	9.28	36	110.8	43
25	9.581	79	24.63	81	49.6	80	697	78	67	15	28	92.86	34	7.06	26	90.98	38
26	15.03	26	105.10	10	6.95	25	3.243	1	68	16.29	11	104.1	14	3.41	12	76.35	35
27	12.16	64	69.40	57	23.30	62	125.5	47	69	15.02	27	98.84	24	6.68	24	40.3	21
28	11.12	72	60.80	63	31.10	72	157.8	55	70	13.65	47	65.5	60	17	49	377	70
29	14.34	40	99.94	22	9.52	39	8.694	5	71	16.02	15	113.1	3	3.52	14	14.94	6
30	14.86	30	85.93	42	7.88	28	139.1	51	72	17.18	5	98.72	26	1.97	5	235	65
31	13.25	50	76.32	49	16.80	48	117.7	44	73	12.9	52	85.67	43	17.3	50	26.15	12
32	13.9	45	83.24	45	13.10	44	99.37	40	74	15.38	20	110.1	5	5.47	20	6.592	2
33	14.81	31	89.50	38	9.14	35	88.18	36	75	16.17	13	109.6	7	3.16	10	36.73	20
34	15.82	17	93.77	32	4.87	18	162.4	56	76	15.36	21	101.1	17	5.8	22	44.87	22
35	12.33	59	37.19	77	23.60	64	580.3	77	77	16.16	14	100.8	19	3.45	13	107.1	42
36	11.02	73	37.27	76	32.40	73	425.2	74	78	13.46	48	72.78	51	16.3	47	176.1	60
37	9.449	80	42.79	72	43.70	79	138.8	50	79	14.6	35	93.97	31	8.76	33	54.56	25
38	8.14	84	44.11	71	58,0	82	149.8	54	80	12.32	61	66.9	58	22.4	60	179.3	62
39	12.2	63	58.77	65	21.50	58	165.8	57	81	12	66	52.27	67	25.4	67	359.8	69
40	14.37	39	96.72	27	9.41	37	24.11	11	82	15.79	18	102.1	15	4.67	16	57.71	27
41	11.36	69	69.75	55	28,00	70	68.17	31	83	16.26	12	99.71	23	3.2	11	124.8	45
42	12	65	40.65	75	24.4	65	421.1	73	84	14.41	38	94.17	30	9.82	40	31.76	15

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Table 5. Estimates of the adaptability and phenotypic stability parameters for plant height (PH, m) of 84 *Eucalyptus* genotypes (G) for the methods of Annicchiarico (ANN), Lin & Binns (L&B), and Wricke (W), as well as their respective ranks (C) according to their adaptability and stability classification in each method.

G	PH		ANN		L&B		Wricke		G	PH		ANN		L&B		Wricke	
	Average	C	Ωi	C	Pi	C	ωi	C		Average	C	ωi	C	Pi	C	ωi	C
1	16.01	31	104.90	32	3.04	30	9.85	9	43	14.30	66	93.64	66	8.43	63	4.69	3
2	15.07	53	99.47	50	6.86	54	112.67	54	44	11.77	82	79.02	82	26.77	80	415.32	78
3	15.03	54	98.59	54	5.99	49	16.62	15	45	10.97	84	74.89	83	37.19	84	897.63	84
4	15.88	35	104.01	34	3.67	34	77.22	46	46	16.42	17	106.15	21	1.98	17	108.27	52
5	13.37	76	86.79	76	12.49	74	51.84	38	47	15.55	42	99.85	49	4.35	40	187.57	68
6	11.91	81	80.55	81	27.10	81	532.18	81	48	12.63	79	83.03	79	17.38	78	58.33	40
7	15.40	47	100.90	45	4.55	42	1.44	1	49	12.82	78	85.66	78	20.01	79	386.82	76
8	16.40	18	107.68	16	2.59	27	65.07	42	50	14.16	69	93.91	64	10.77	71	125.91	58
9	17.73	2	115.02	3	0.32	3	94.59	50	51	16.12	27	104.32	33	2.53	26	89.75	49
10	15.59	41	98.64	53	7.37	57	691.42	82	52	15.11	51	98.14	55	5.10	45	25.10	20
11	15.85	36	103.84	36	3.78	36	50.73	36	53	14.71	60	94.70	62	6.69	52	121.89	57
12	16.53	15	107.71	15	1.58	13	17.84	16	54	16.07	29	105.52	26	2.90	28	7.96	6
13	17.15	5	111.74	7	0.75	7	45.96	33	55	15.11	50	100.12	47	8.33	60	240.52	71
14	17.14	6	111.83	6	0.90	8	54.09	39	56	14.99	56	99.02	51	6.81	53	60.58	41
15	15.52	43	101.57	43	4.16	37	1.67	2	57	14.08	71	92.86	68	10.25	70	75.31	45
16	16.19	24	105.36	27	2.23	20	21.65	18	58	16.22	22	105.91	23	2.33	21	13.80	14
17	15.49	45	101.28	44	4.19	38	9.10	7	59	17.77	1	116.21	1	0.19	1	11.10	12
18	15.10	52	96.76	58	5.92	48	232.55	70	60	16.18	25	105.76	24	2.51	24	34.30	27
19	13.38	75	89.35	74	15.86	76	265.91	73	61	15.62	40	102.60	38	4.26	39	29.54	26
20	15.93	33	105.21	29	4.39	41	109.59	53	62	17.13	7	111.90	5	0.98	11	49.52	35
21	14.16	68	93.27	67	10.15	69	120.34	56	63	14.99	55	97.92	56	8.65	65	330.27	74
22	14.77	59	93.70	65	8.65	64	495.84	80	64	15.83	37	102.33	39	3.48	32	131.85	59
23	12.13	80	81.12	80	28.26	82	860.93	83	65	15.77	38	103.19	37	3.58	33	27.68	24
24	15.94	32	101.64	42	4.93	44	451.45	79	66	14.85	58	98.65	52	8.75	66	178.60	66
25	13.07	77	87.20	75	17.02	77	219.54	69	67	16.59	14	108.36	14	1.60	14	27.67	23
26	16.02	30	105.29	28	3.14	31	10.10	11	68	15.71	39	103.85	35	4.74	43	68.96	44
27	14.46	64	95.29	60	8.38	61	35.37	28	69	16.39	19	106.96	18	1.87	15	9.34	8
28	13.85	72	92.14	69	12.79	75	177.85	65	70	15.49	44	101.83	40	6.92	55	265.06	72
29	16.95	11	110.69	10	0.95	10	10.00	10	71	16.34	21	105.55	25	2.17	18	117.60	55
30	17.25	4	112.17	4	0.58	4	50.82	37	72	17.11	8	111.45	8	0.74	6	38.54	31
31	15.92	34	104.91	31	3.73	35	27.60	22	73	15.25	48	100.04	48	5.71	46	65.25	43
32	15.48	46	101.82	41	7.97	59	372.54	75	74	16.36	20	106.74	19	1.96	16	11.81	13
33	14.97	57	97.55	57	5.89	47	26.85	21	75	16.09	28	105.00	30	2.49	23	7.32	5
34	16.97	10	110.42	12	0.91	9	43.03	32	76	14.67	62	94.30	63	7.13	56	172.53	64
35	14.36	65	92.01	70	8.43	62	180.12	67	77	17.67	3	115.20	2	0.30	2	48.32	34
36	14.17	67	91.24	71	9.53	68	168.33	63	78	15.18	49	100.46	46	6.48	50	79.38	47
37	13.45	74	86.31	77	12.49	73	149.49	61	79	16.82	12	110.68	11	2.17	19	82.58	48
38	11.12	83	74.64	84	31.06	83	398.57	77	80	13.79	73	91.05	72	11.89	72	105.34	51
39	14.70	61	95.43	59	6.59	51	37.90	30	81	16.52	16	107.15	17	2.44	22	145.13	60
40	16.64	13	108.81	13	1.51	12	6.21	4	82	16.21	23	106.10	22	2.51	25	22.10	19
41	14.51	63	94.95	61	7.92	58	35.96	29	83	17.09	9	111.38	9	0.72	5	29.11	25
42	14.15	70	90.65	73	9.02	67	151.29	62	84	16.16	26	106.18	20	2.93	29	18.31	17

Clone 62 was also ranked among the first ten clones, and it is noteworthy that both clones 59 and 62 composed group A, with the best averages, and were classified among the most adapted and stable.

Table 6. Estimates of the adaptability and phenotypic stability parameters for volume of wood (VOW, m^3) of 84 *Eucalyptus* genotypes (G) for the methods of Annicchiarico (ANN), Lin &Binns (L&B), and Wricke (W), as well as their respective ranks (C) according to their adaptability and stability classification in each method.

G	VOW		ANN		L&B		Wricke		G	VOW		ANN		L&B		Wricke	
	Average	C	Ωi	C	Pi	C	ωi	C		Average	C	ωi	C	Pi	C	ωi	C
1	0.16	19	99.03	21	0.004	19	0.05	49	43	0.09	67	91.11	36	0.012	62	0.01	14
2	0.13	38	82.89	52	0.006	29	0.00	4	44	0.04	82	46.41	80	0.025	83	0.23	83
3	0.08	70	91.46	35	0.014	68	0.01	11	45	0.04	83	25.34	84	0.025	84	0.20	79
4	0.12	43	90.02	37	0.008	45	0.02	18	46	0.15	24	88.38	41	0.004	24	0.11	67
5	0.08	72	72.10	63	0.013	64	0.01	9	47	0.11	55	74.11	59	0.009	51	0.01	15
6	0.05	78	43.97	82	0.021	79	0.16	74	48	0.05	79	72.72	61	0.019	77	0.05	46
7	0.09	66	98.41	24	0.013	65	0.03	23	49	0.06	76	52.36	77	0.020	78	0.22	81
8	0.14	30	94.52	31	0.007	37	0.04	41	50	0.08	71	75.92	57	0.015	71	0.09	61
9	0.22	1	101.61	12	0.000	1	0.18	76	51	0.13	39	87.60	44	0.006	33	0.02	20
10	0.17	10	48.23	79	0.002	5	0.14	70	52	0.13	42	88.06	42	0.007	41	0.00	3
11	0.17	12	92.11	34	0.003	10	0.05	48	53	0.12	51	72.11	62	0.008	48	0.06	51
12	0.15	23	102.33	10	0.004	20	0.02	21	54	0.13	40	99.66	19	0.007	42	0.01	6
13	0.16	21	101.83	11	0.004	21	0.04	39	55	0.10	58	71.88	64	0.014	70	0.24	84
14	0.12	45	100.61	17	0.008	46	0.03	27	56	0.09	62	85.74	48	0.013	67	0.06	54
15	0.18	7	99.16	20	0.002	6	0.01	12	57	0.07	74	80.59	54	0.017	75	0.05	45
16	0.16	22	98.42	23	0.004	22	0.03	29	58	0.17	11	101.19	14	0.003	12	0.06	52
17	0.12	44	96.42	27	0.007	38	0.00	2	59	0.20	2	113.33	1	0.001	2	0.04	36
18	0.12	48	66.80	70	0.007	39	0.05	50	60	0.14	37	96.38	28	0.006	34	0.03	25
19	0.06	75	63.94	73	0.018	76	0.09	63	61	0.10	61	93.66	32	0.012	63	0.01	16
20	0.11	52	87.63	43	0.010	52	0.07	55	62	0.18	6	101.05	15	0.002	7	0.04	40
21	0.10	60	77.39	55	0.012	60	0.04	42	63	0.14	31	69.07	67	0.007	43	0.16	73
22	0.09	63	49.49	78	0.011	57	0.01	10	64	0.19	4	81.35	53	0.001	3	0.12	69
23	0.05	80	31.87	83	0.022	80	0.19	78	65	0.17	14	94.79	30	0.003	13	0.05	47
24	0.14	32	61.73	76	0.005	25	0.14	71	66	0.19	5	73.73	60	0.003	14	0.18	75
25	0.05	81	63.73	74	0.023	81	0.20	80	67	0.14	26	100.30	18	0.005	26	0.04	38
26	0.14	28	98.23	25	0.006	30	0.00	1	68	0.17	15	88.59	40	0.003	15	0.04	43
27	0.09	64	85.96	47	0.013	66	0.04	37	69	0.14	27	103.20	6	0.005	27	0.01	17
28	0.07	73	69.28	66	0.017	73	0.08	60	70	0.12	47	74.52	58	0.010	56	0.22	82
29	0.14	36	108.00	2	0.006	31	0.01	8	71	0.16	17	86.78	45	0.003	16	0.03	33
30	0.16	20	102.90	7	0.004	23	0.08	58	72	0.20	3	102.75	9	0.001	4	0.15	72
31	0.11	53	93.48	33	0.010	53	0.04	35	73	0.12	46	86.44	46	0.008	49	0.01	7
32	0.12	49	69.44	65	0.009	50	0.08	59	74	0.16	18	102.86	8	0.003	17	0.03	24
33	0.13	41	89.22	39	0.008	47	0.05	44	75	0.17	16	101.41	13	0.003	18	0.01	13
34	0.17	13	100.96	16	0.003	11	0.10	64	76	0.14	35	67.77	69	0.006	35	0.03	32
35	0.11	56	65.97	71	0.010	54	0.11	66	77	0.18	8	105.64	3	0.002	8	0.10	65
36	0.08	68	68.47	68	0.014	69	0.12	68	78	0.11	54	84.50	50	0.011	58	0.06	53
37	0.06	77	62.43	75	0.017	74	0.03	28	79	0.14	29	95.16	29	0.006	36	0.03	26
38	0.03	84	44.14	81	0.024	82	0.09	62	80	0.08	69	76.66	56	0.015	72	0.07	56
39	0.10	59	82.89	51	0.010	55	0.02	19	81	0.10	57	89.68	38	0.011	59	0.18	77
40	0.14	34	105.44	4	0.006	32	0.00	5	82	0.15	25	98.53	22	0.005	28	0.03	34
41	0.09	65	85.32	49	0.012	61	0.03	30	83	0.18	9	104.54	5	0.002	9	0.07	57
42	0.12	50	64.85	72	0.007	40	0.03	31	84	0.14	33	97.10	26	0.007	44	0.02	22

According to the factor analysis, for the three variables studied, only one eigenvalue presented magnitude above 1 (Table 9). As the first factor explained relatively a small part of the variance, the second factor was considered to represent the variability of the data. Thus, the percentage of variance accumulated in the first two factors was above 80% for the three studied variables. By analyzing the factors after rotation, it was possible to group sites 1 and 3 in the first factor, leaving site 2, isolated in the second factor. With the identification of similar environments, the breeder has the potential to establish different breeding strategies for each group of environments, which can allow obtaining greater success in the selection process (Elias et al., 2016).

The clones present in quadrant I had wide adaptability, since they presented good performance in subregions 1 and 2 (Figure 1). The clones present in quadrant II showed specific adaptability for the sub-region 2 – or for environment 2 –, while the clones in the quadrant IV showed specific adaptability for subregion 1, with environments 1 and 3. Clones present in quadrant III presented low performance and could not be indicated.

Some disagreements around wide adaptation still remain in plant breeding programs. Baranski (2015) reported that genotypes should have as wide an adaptation as possible, meaning high and stable yields across different environments, and that this wide adaptation could be achieved by selecting only plants that do well in high fertility and irrigated environments. In agreement with this, Gallais & Hirel (2004) reported that the selection in an ideal environment is more

Table 7. Spearman correlation coefficients of the adaptive and stability ranks of *Eucalyptus* clones, determined with the methods of Annicchiarico (ANN), Lin & Binns, and Wricke (upper matrix), and Pearson correlation coefficient between the analyzed variables (lower matrix).

Variable	Method			Variable	
	ANN	Lin & Binns	Wricke	Plant height	Volume of wood
		Average rank			
Plant height	0.991**	0.979**	0.510**	-	-
DBH	0.905**	0.994**	0.443**	-	-
Volume of wood	0.673**	0.985**	0.096^{ns}	-	-
		Annicchiarico rank			
Plant height	-	0.970**	0.543**	-	-
DBH	-	0.926**	0.744**	-	-
Volume of wood	-	0.657**	0.419**	-	-
		Lin & Bins rank			
Plant height	-	-	0.609**	-	-
DBH	-	-	0.488**	-	-
Volume of wood	-	-	0.155^{ns}	-	-
		Person correlation analysis			
Plant height		-	-	0.845**	0.966**
DBH		-	-	1	0.846
Volume of wood		-	-		1

* and **Significant by the t-test, at 5 and 1% probability, respectively. DBH, diameter at breast height.

Table 8. Average ranking (μ_r) of the ten first *Eucalyptus* clones (C) considering the ranking of the averages (μ), and the adaptability and stability ranks of the methods of Annicchiarico (I_i), Lin & Binns (P_i), and Wricke (ω_i), for the evaluated variables.

Rank	Diameter at breast height						Plant height						Volume of wood					
	C	μ	I_i	P_i	ω_i	μ_r	C	μ	I_i	P_i	ω_i	μ_r	C	μ	I_i	P_i	ω_i	μ_r
1	59	2	1	2	10	3.75	59	1	1	1	12	5	59	2	1	2	36	9.4
2	15	4	2	3	13	5.5	62	7	5	11	35	12.6	15	7	20	6	12	15.8
3	71	15	3	14	6	9.5	83	9	9	5	25	14.6	62	6	15	7	40	16.6
4	62	6	6	6	28	11.5	72	8	8	6	31	15	74	18	8	17	24	17.4
5	74	20	5	20	2	11.75	13	5	7	7	33	17	83	9	5	9	57	17.4
6	75	13	7	10	20	12.5	12	15	15	13	16	17.2	12	23	10	20	21	20.4
7	58	9	8	9	26	13	14	6	6	8	39	18.2	11	12	34	10	48	22.4
8	10	8	9	7	29	13.25	69	19	18	15	8	18.2	75	16	13	18	13	22.6
9	11	7	11	8	37	15.75	40	13	13	12	4	19.6	58	11	14	12	52	23.8
10	68	11	14	12	35	18	67	14	14	14	23	20	1	19	21	19	49	24.2

efficient, due the reduction of the genetic variability usually observed in nonideal environments. However, it seems logical that, although it might be possible to eventually define the characteristics of ideal plants, adapted to a specific environment, it would be much more difficult to define all possible combinations of a range of characteristics necessary to provide good adaptability in several environments (Rawlings, 2005).

Among the 84 evaluated clones, three (9, 59, and 72) stood out for having the highest average values of DBH, PH, and VOW (Table 3). These results indicate the presence of variability in the clone bank tested, as well as the existence of superior clones, which can be maintained in the breeding program if they present productive stability and wide adaptability, responding to the improvement in the environment (Rosado et al., 2012).

Each evaluated method classified the clones into distinct ranks, which makes their recommendation a difficult task. According to the average ranking (Table 8), however, it can be inferred that clones 59 and 62 stood out as the most stable and adapted. The factor analysis reinforced this statement. Both clones were located in quadrant I, which characterizes them as broadly adaptable. Furthermore, they had the highest averages for the analyzed variables (DBH, PH, and

Table 9. Subgroups of environments for the variables diameter at breast height, plant height and volume of wood, according to the factor analysis method, considering 84 *Eucalyptus* clones and three growing environments.

Eigen values		Factor scores after rotation		
(%)	Accumulated	Environment	Factor 1	Factor 2
Diameter at breast height				
63.149	63.149	1	0.9052	-0.2904
30.078	93.228	2	0.4487	0.8924
6.772	100.0	3	0.9348	-0.1472
Plant height				
56.092	56.092	1	0.9062	0.1161
32.848	88.940	2	-0.1890	0.9819
11.059	100.0	3	0.9088	0.0884
Volume of wood				
61.527	61.527	1	0.9377	0.0246
29.802	91.330	2	0.1164	0.9908
8.669	100.0	3	0.9057	0.2111

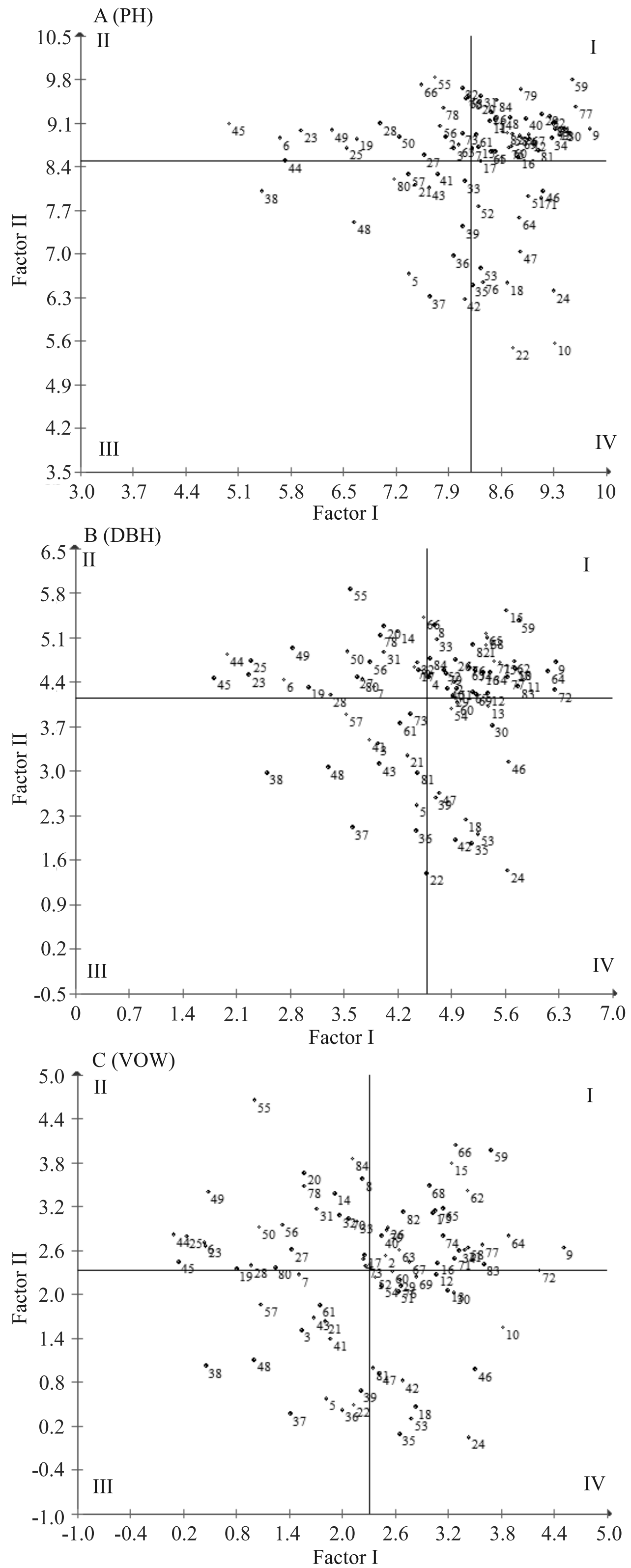

Figure 1. Distribution of factor analysis scores for the variables diameter at breast height (A), plant height (B), and volume of wood (C), considering 84 *Eucalyptus* clones evaluated in three environments.

VOW). Therefore, these clones can contribute to the breeding program, showing wide adaptability, stability, and productive potential.

Conclusions

1. The methods of Annicchiarico and Lin & Binns are highly associated with each other, and their use together with the method of Wricke is a sound strategy for the stability evaluation of *Eucalyptus* clones.

2. The use of the mean classification of the clones, along with factorial analysis, is efficient to identify the most adapted, stable, and productive ones among a high number of genotypes.

References

ANNICCHIARICO, P. Cultivar adaptation and recommendation from alfalfa trials in Northern Italy. **Journal of Genetics and Breeding**, v.4, p.269-278, 1992.

BARANSKI, M.R. Wide adaptation of green revolution wheat: international roots and the indian context of a new plant breeding ideal, 1960-1970. **Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences**, v.50, p.41-50, 2015. DOI: 10.1016/j.shpsc.2015.01.004.

CARVALHO, A.D.F. de; SILVA, G.O. da; PEREIRA, R.B. PINHEIRO, J.B. Análise de fatores e regressão bissegmentada no estudo da adaptabilidade e estabilidade de cenoura. **Revista Ceres**, v.61, p.932-940, 2014. DOI: 10.1590/0034-737X201461060007.

CRUZ, C.D. GENES: a software package for analysis in experimental statistics and quantitative genetics. **Acta Scientiarum. Agronomy**, v.35, p.271-276, 2013. DOI: 10.4025/actasciagron.v35i3.21251.

CRUZ, C.D.; REGAZZI, A.J.; CARNEIRO, P.C.S. **Modelos biométricos aplicados ao melhoramento genético**. 4.ed. Viçosa: Ed. da UFV, 2012.

ELIAS, A.A.; ROBBINS, K.R.; DOERGE, R.W.; TUINSTRA, M.R. Half a century of studying genotype × environment interactions in plant breeding experiments. **Crop Science**, v.56, p.2090-2105, 2016. DOI: 10.2135/cropsci2015.01.0061.

GALLAIS, A.; HIREL, B. An approach to the genetics of nitrogen use efficiency in maize. **Journal of Experimental Botany**, v.55, p.295-306, 2004. DOI: 10.1093/jxb/erh006.

LEITE, H.G.; CAMPOS, J.C.C.; PAULA JUNIOR, G.G.P. Emprego de um modelo de programação dinâmica para conversão de troncos em multiprodutos da madeira. **Revista Árvore**, v.19, p.447-465, 1995.

LIN, C.S.; BINNS, M.R. A superiority measure of cultivar performance for cultivar × location data. **Canadian Journal of Plant Science**, v.68, p.193-198, 1988. DOI: 10.4141/cjps88-018.

LIN, C.S.; BINNS, M.R. Genetic properties of four types of stability parameter. **Theoretical and Applied Genetics**, v.82, p.505-509, 1991. DOI: 10.1007/BF00588606.

MURAKAMI, D.M.; CRUZ, C.D. Proposal of methodologies for environment stratification and analysis of genotype adaptability. **Crop Breeding and Applied Biotechnology**, v.4, p.7-11, 2004.

NUNES, G.H. de S.; REZENDE, G.D.S.P.; RAMALHO, M.A.P.; SANTOS, J.B. dos. Implicações da interação genótipo x ambientes na seleção de clones de eucalipto. **Cerne**, v.8, p.49-58, 2002.

PAULA, R.R.; REIS, G.G.; REIS, M.G.F.; OLIVEIRA NETO, S.N.; LEITE, H.G.; MELIDO, R.C.N.; LOPES, H.N.S.; SOUSA, F.C. Eucalypt growth in monoculture and silvopastoral systems with varied tree initial densities and spatial arrangements. **Agroforestry Systems**, v.87, p.1295-1307, 2013.

PEREIRA, H.S.; MELO, L.C.; DEL PELOSO, M.J.; FARIA, L.C. de; COSTA, J.G.C. da; DÍAZ, J.L.C.; RAVA, C.A.; WENDLAND, A. Comparação de métodos de análise de adaptabilidade e estabilidade fenotípica em feijoeiro-comum. **Pesquisa Agropecuária Brasileira**, v.44, p.374-383, 2009. DOI: 10.1590/S0100-204X2009000400007.

RAWLINGS, D.E. Characteristics and adaptability of iron- and sulfur-oxidizing microorganisms used for the recovery of metals from minerals and their concentrates. **Microbial Cell Factories**, v.4, p.1-15, 2005. DOI: 10.1186/1475-2859-4-13.

RESENDE, M.D.V.; SILVA, F.F.; LOPES, P.S.; AZEVEDO, C.F. **Seleção Genômica Ampla (GWS) via Modelos Mistos (REML/BLUP), Inferência Bayesiana (MCMC), Regressão Aleatória Multivariada (RRM) e Estatística Espacial**. Viçosa: Universidade Federal de Viçosa, Departamento de Estatística, 2012. 291p.

ROCHA, M. das G. de B.; PIRES, I.E.; ROCHA, R.B.; XAVIER, A.; CRUZ, C.D. Avaliação genética de progênies de meio-irmãos de *Eucalyptus grandis* por meio dos procedimentos REML/BLUP e da ANOVA. **Scientia Forestalis**, v.71, p.99-107, 2006.

ROSADO, A.M.; ROSADO, T.B.; ALVES, A.A.; LAVIOLA, B.G.; BHERING, L.L. Seleção simultânea de clones de eucalipto de acordo com produtividade, estabilidade e adaptabilidade. **Pesquisa Agropecuária Brasileira**, v.47, p.964-971, 2012. DOI: 10.1590/S0100-204X2012000700013.

SILVA, W.C.J. e; DUARTE, J.B. Métodos estatísticos para estudo de adaptabilidade e estabilidade fenotípica em soja. **Pesquisa Agropecuária Brasileira**, v.41, p.23-30, 2006. DOI: 10.1590/S0100-204X2006000100004.

WRICKE, G. Zur Berechnung der Ökovalenz bei Sommerweizen und Hafer. **Pflanzenzüchtung**, v.52, p.127-138, 1965.

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