Combining ability effects of clonal rootstocks and scions in rubber trees (*Hevea)*

Paulo de Souza Gonçalves*[1] and Antonio Lucio Mello Martins[2]
[1]Embrapa/Instituto Agronômico (IAC), Centro de Análise e Pesquisa Tecnológica do Agronegócio do Café, Caixa Postal 28, CEP 13001-970, Campinas, SP, Brazil; [2]IAC, Pólo Regional de Desenvolvimento Tecnológico do Centro Norte, Caixa Postal 24, CEP 15830-000, Pindorama, SP, Brazil. (* Corresponding Author. E-mail: paulog@iac.sp.gov.br)

ABSTRACT

Rootstocks and scions combinations of five rubber tree [*Hevea brasiliensis* (Willd. ex Adr. de Juss.) Muell-Arg.] clones were evaluated for rubber yield and growth vigor to detect the rootstock with the best general combining ability (GCA) and the best specific combining ability (SCA), using the method 1, suggested by Griffing. The clones (scions) involved were: IAN 873, RRIM 600, RRIM 701, PB 235 and GT 1 grafted in five different rootstocks from illegitimate seeds of the same clones. The ANOVA mean squares for GCA and SCA reciprocal effects were highly significant for both characters. The general GCA: SCA ratios were 24:1 and 4:1 for rubber yield and growth vigour, respectively. The rootstock of the RRIM 600 clone was the best general combiner for rubber yield (g_i = 8.25), followed by the PB 235 (g_i = 5.20).Although negative, the rootstock of the RRIM 600 clone showed the best GCA (g_i = -0.0354) for growth vigour, followed by rootstock of the GT 1 clone which presented a g_i = -0.5194 value. The maximum SCA effects for rubber yield (s_{ij} = 5.55) was obtained by IAN 873 rootstocks combined with the RRIM 600 clone as scion, followed by the PB 235 (rootstock) combined with the RRIM 600 scions (s_{ij} = 3.06). For growth vigour, the best specific combining ability effect of s_{ij} = -1.64 was obtained by the IAN 873 clone in combination with the RRIM 701 clone, with their respective rootstock and scion. As for rubber yield, the RRIM 600 rootstocks were classified as the best general combination. In addition, the IAN 873 rootstocks combined with the RRIM 600 scion showed the best specific combining ability.

KEY WORDS: *Hevea brasiliensis,* rubber tree, rootstock, scion, general combining ability, specific combining ability.

INTRODUCTION

The budded rubber tree [*Hevea brasiliensis* (Willd. ex Adr. de Juss.) Muell.-Arg.] plant comprises a root system provided by the stock plant and a shoot system supplied by the scion plant. Early observations showed that the average yield of a clone budded on seedling rootstocks was usually somewhat inferior to that of its mother tree, which led to an investigation of the stock effects and of the possibility of selecting superior rootstocks to improve scion performance. In a programmed planting, clones are carefully selected to be used as scions. However, limited attention is paid to the selection of rootstocks. The rootstock can influence the growth and rubber yield of the scion to varying degrees. Usually the type of rootstock is not considered important as long as they are seedlings of buddable size. Availability rather than the particular type of seedling dictates the selection of the rootstock used for budding. This situation arises not because there is no experimental information on rootstocks, but because the role of the rootstock has not been well emphasized and its benefits not clearly illustrated.

A number of experiments compared illegitimate seedlings on different clones as rootstocks (Schweizer 1938; Schmöle 1941; Paardekooper 1954; Campaignole and Bouthillou 1995; Buttery 1961; Combe and Gener 1977; Abbas and Ginting 1981). Most of these trials showed marked stock effects on scion growth (Cramer 1930; Yahampath 1968). Differences between the rubber yield of a scion clone on different rootstocks up to 20 % were reported by Schemöle (1941) and up to 18 % by Paardekooper (1954). On the other hand, in five Malaysian experiments carried out between 1931 and 1941, which included a number of scion clones and illegitimate seedlings families as rootstocks, a significant rootstock influence on girth and yield of scions obtained was evident in two of the trials (Buttery 1961). Later, Ng et al. (1981) showed that rootstock influenced significantly the growth and yield of the scion, but there was no rootstock interaction. Selection of good rootstocks is therefore

important to obtain high yield in scions. Monoclonal seedlings rootstocks from popular clones planted in São Paulo State are being used in the present rootstock scion experiment (Gonçalves, et al., 1994; Martins et al., 2000.) This study is expected to throw some light on the combining ability for rubber yield and growth vigour and on the process of choosing better rootstocks among the existent clonal rootstock material for future exploitation.

MATERIAL AND METHODS

Five clones of rubber tree *viz*. RRIM 701, PB 235, IAN 873, GT 1, RRIM 600 were used as rootstock and scion to give a diallel type of budding design. Parentage and places of origin of these clones are in Table 1. The illegitimate seeds for rootstocks were collected in the middle of monoclonal blocks of size above 2,0 hectares and the scions were collected from the budwood stock nursery at the Pindorama Experimental Station in São Paulo State, Brazil. The seeds were germinated in the pre-nursery and transferred to the polybags. One year later, the rootstocks (seedlings) raised in the polybags were budgrafted with the clonal (scions) materials, following the pattern given by the diallel method, consisting of three types of clonal combinations, according to the Griffing´s approach, method 1 (Griffing, 1956). The clonal combinations turned into self-buddings such as the RRIM 600 scion budded onto an RRIM 600 rootstock, with similar self-buddings for RRIM 701, PB 235, IAN 873 and GT 1. There were clonal combinations consisting of main clonal and reciprocal clonal combinations.

This design of 25 rootstock/scion combinations was tested in the field following a split-plot randomized block design with four replications. Five treatments (rootstocks) and five sub-treatments (scion) were built up with 30 and six trees. The experiment was set up at the Pindorama Experimental Station (latitude 21º 13´5 longitude 48º 56´W and altitude of 560 m) with red-yellow podizolic soil of medium texture, which was TB eutrophic, deep, abrupt and well dry drained (Lepesch and Valadares, 1976). The climate is tropical continental, with a wet summer and a dry winter period with reduced temperatures and rainfall. The mean annual temperature is 22.2ºC, with a maximum of 28.9ºC and a minimum of 16.6ºC. The mean annual rainfall is 1,390mm. The period from October to April usually has a favorable precipitation for growth and production. Low precipitation and temperatures occur from May to September. The girth (circumference in cm) of each tree was measured annually from the date of planting. Pre-tapping girth measurements were taken at 1.20cm above the highest point of the bud union. Seven years later, trees that reached a girth of 45.0cm or more were opened for tapping at a height of 1.20 above the union. Attempts were made to record one girth measurement (girth at opening) and one-year yield measurement. The trees were tapped on a half spiral four day, by a tapping system that is seven times / month for 11 months/ year (as tapping was not done in July), on days when normal tapping, which starts around 7:30 AM, was possible. After tapping, the latex was collected in plastic cups provided for each recording tree. Once the latex flow stopped, the rubber was coagulated in the cup itself by adding 2 % of acetic acid solution and stirring it well. The coagulated rubber in each cup was then made into a “biscuit”, which were dried and tied to each tree for about 30 days. Then it was weighed and the dry rubber content for each tree was recorded. General and specific combining ability comparisons between the rootstock and the scion combinations were made by evaluating the magnitude of the general and specific combining ability effects obtained from the diallel analysis. Experimental method 1 of the diallel analysis, generalized by Griffing (1956), was applied to the study, which includes the analysis of variance for general, specific and reciprocal combining abilities and the estimation of their effects. In this case, the statistical is expressed by the following equation:

$Y_{ijk} = m + g_i + s_{ij} + r_{ij} + r_k + e_{ijk}$ where m is the mean value of i rootstock combined with j^{th} scion; g_i are the values for general combining ability effect for the i^{th} rootstock sij is the value for specific combining ability effect for the combination between i^{th} and ^{jth} rootstock and scion respectively; r_{ji} are the values for reciprocal effects for the combination between i^{th} rootstock and jth; rk is the

Table 1. List of rubber clones, parentage and places of origin.

Clone[1/]	Parentage	Origin
GT 1	Primary clone	Indonesia
IAN 873	PB 86 x FA 1717	Brazil
RRIM 701	44/553 x RRIM 501	Malaysia
PB 235	PB 5/51 x PB S.78	Malaysia
RRIM 600	Tijir 1 x PB 86	Malaysia

[1/] GT: Godang Tapen; RRIM: Rubber Research Institute of Malaysia; IAN: Instituto Agronômico do Norte; PB: Prang Besar; Tijr: Tijirandji and FA: Ford Acre.

value for replication effect for the k^{th} block and e_{ijk} is the value for the error.

RESULTS AND DISCUSSION

The means for the rootstocks and scion combinations and their reciprocal for rubber yield are presented in Table 2. The values for the scions and rootstocks combinations of the same clone are in the diagonal, starting at the upper left side. Except for IAN 873 (23.75 g / tree / tapping), the yields obtained from the clonal rootstocks that received the scion of the same clones, such as GT 1, PB 235, RRIM 701 and RRIM 600, were very good, ranging from 41.25 to 58.84 g / tree tapping compared to 22.65 to 67.25 g / tapping for combinations arising from possible rootstocks combined with different clone scion. The average rubber yield for rootstock, combined with the same scion, had almost the same value as the combinations of clone rootstocks with different clones scion.

A similar or slightly lower values for growth vigour (Table 3) were observed for the five clonal rootstock combined with the same clone scion compared with rootstocks combined on different clone scions. The IAN 873 (rootstock) x RRIM 600 (scion) combinations were more vigorous ($\bar{x}$ = 57.85) compared to the reciprocal RRIM 600 x IAN ($\bar{x}$ = 52.47). Among the combinations of rootstock with scions there was variability for rubber yield among growth vigour characters. Rubber yield appeared to be the most variable character (CV = 20.06%) and growth vigour (CV = 6.66%) was the least variable character. Combining ability analyses of clonal rootstock combined with clonal scions in a complete diallel for the characters rubber yield and growth vigour are shown in Table 4. General combining ability (GCA) and reciprocal specific combining ability (REC) mean squares effects for both characters were highly significant. This agrees with previous studies on yield and sieve tube size where the GCA, SCA and reciprocals were significant (Tan and Subramanian 1975; Olapade, 1988). In this study the variance due to GCA was higher then the variance due to SCA. This demands a wide scale determination of clonal yield to determine specific compatible rootstocks clones, suitable for the budding of high yielding clones.

The relative magnitude of general (GCA) and specific combining abilities (SCA) is also indicated by the GCA: SCA mean square ratio (Table 4). Both characters showed that the GCA effect was at least four times higher than the SCA in contributing to the variations of rootstock/scion combinations differences. Similarly, the reciprocal effect has the same SCA effect importance in contributing to the total variance.

The GCA values for rubber yield and growth vigour among the combination of five rootstocks and the five scions studied are summarized in Tables 5 and 6. For rubber yield (Table 5), the RRIM 600 showed to be the best rootstock (g_i = 8.2478), followed by the PB 235 with g_i = 5.1968. Although negative, the same ranking of combinations was observed for growth vigour (Table 6). Rootstocks from the RRIM 600 clone showed to be the best with g_i = -0.0354 followed

Table 2. Means and standard deviations for rubber yield (g/tree/tapping) among combinations of five different clonal rootstocks and five different scions in rubber tree (*Hevea*).

	Scions					
Rootstocks	GT 1	IAN 873	PB 235	RRIM 701	RRIM 600	General means
GT 1	47.22	27.58	52.70	41.58	55.73	44.96
	±8.86	±10.85	±17.03	±11.51	±11.86	±12.02
IAN 873	47.57	23.75	45.85	40.08	67.25	44.90
	±12.47	±12.12	±15.59	±10.02	±11.88	±12.42
PB 235	52.72	26.90	58.84	37.78	65.97	48.44
	±13.20	±10.93	±26.93	±13.83	±28.29	±18.64
RRIM 701	40.81	22.65	50.15	41.25	54.48	41.86
	±7.95	±6.34	±17.53	±6.82	±11.22	±9.97
RRIM 600	49.47	31.89	58.25	43.80	55.86	47.85
	±7.81	±13.02	±20.91	±11.13	±7.42	±12.06
General means	47.56 ±10.06	26.55 ±10.65	53.16 ±19.60	40.90 ±10.66	59.85 ±14.13	

by the GT 1 with g_i = -0.5194. There was a higher rootstock influence on rubber yield rootstock and scion. Thus, yield is influenced more by the ability of the rootstock to receive and integrate the scion into its own system. This is more so as the rootstock and scion interact. The scion is explants whose survival depends largely on the rootstock. Rubber yield showing overall SCA effects of the individuals combinations studied are shown in Tables 5.

The estimated SCA showed the best values for the rootstock from IAN 873 combined with the scion of the clone RRIM 600 (s_{ij} = 5.5952) followed by the combination of PB 235 rootstock with RRIM 600 as scion (s_{ij} = 3.0622), indicating that these combinations were more productive than expected. The high SCA effects between IAN 873 is a reflection of the close genetic relationship between the two clones, since rootstock and scion have the PB 86 clone as the same parental. Conversely, rootstocks from IAN 873 combined with scion of PB 235 (s_{ij} = -4.5488) and PB 235 rootstocks combined with RRIM 701 (s_{ij} = -2.6098) were considerably less productive than expected. Growth vigour combinations (Table 6) with the best SCA values were the rootstock from IAN 873 combined with scions from RRIM 600 with value s_{ij} = 1.6384, followed by rootstock from RRIM 701 combined with scion from the RRIM 600 clone (s_{ij} = 1.0414), while the lowest values were shown by the PB 235 (rootstock) combined with scions from RRIM 701 and the GT 1 (rootstock) combined with scions

Table 3. Means and standard deviations for girth (circumference in cm) among combinations of five different clonal rootstocks and five different scions in rubber tree (*Hevea*).

Rootstocks	Scions					General means
	GT1	IAN 873	PB 235	RRIM 701	RRIM 600	
GT 1	53.03	54.22	54.79	50.43	54.05	53.30
	±4.81	±4.44	±5.94	±3.47	±4.45	±4.62
IAN 873	50.50	52.69	55.48	51.67	57.85	53.64
	±4.48	±5.22	±4.57	±4.61	±5.61	±4.90
PB 235	51.45	55.05	55.00	49.70	54.70	53.18
	±3.92	±5.12	±7.46	±2.96	±7.79	±5.45
RRIM 701	50.12	52.95	53.55	50.00	55.06	52.34
	±3.07	±4.29	±4.47	±3.60	±3.38	±3.82
RRIM 600	50.29	52.47	53.53	49.56	49.62	51.09
	±3.03	±4.76	±6.10	±2.32	±4.46	±4.13
General means	51.08 ±3.86	53.48 ±4.77	54.47 ±5.77	50.27 ±3.39	54.26 ±5.14	

Table 4. Mean square of the analysis of variance for general and specific combining abilities among combinations of rootstock and five different scions for rubber yield and growth vigour in rubber tree (*Hevea*).

Source of Variation	D.F.	Rubber yield (g/t/t)[1/]	Growth vigour (cm)
Treatment	24	611.2626 [2/]	20.9117 [2/]
GCA	4	2108.5432 [2/]	42.0588 [2/]
SCA	10	87.9668n.s.	10.0771n.s.
REC.	10	535.6461 [2/]	23.2873 [2/]
Error	60	59.9845	6.9392
General		45.6032	52.7104
GCA:SCA		24:1	4:1

[1/] Grams/tree/tapping; [2/] $p<0.01$ and [n.s.] not significant.

Table 5. Estimates of general combining ability (GCA), and specific combining ability (SCA, upper diagonal) and reciprocal (REC., lower diagonal) effects among combinations of five different clonal rootstocks and five different scions for yield (g/tree/tapping) in rubber tree (*Hevea*).

Rootstocks	Scions					GCA effects
	SCA effects					
	GT 1	IAN 873	PB 235	RRIM 701	RRIM 600	
GT 1	0.3032	1.1912	1.2532	-0.8398	-1.9078	0.6568
IAN 873	-9.9950	-2.1008	-4.5488	-0.1368	5.5952	-9.8762
PB 235	-0.0100	9.4750	2.8432	-2.6098	3.0622	5.1968
RRIM 701	0.3850	8.7150	-6.1850	4.0972	-0.5108	-4.2252
RRIM 600	3.1300	17.6800	3.8600	5.3150	-6.2387	8.2478

Table 6. Estimates of general combining ability (GCA) and specific combining ability (SCA, upper diagonal) and reciprocal (REC., lower diagonal) effects among combinations of five different clonal rootstocks and five different scions for girth (circumference in cm) in rubber tree (*Hevea*).

Rootstocks	Scions					GCA effects
	SCA effects					
	GT 1	IAN 873	PB 235	RRIM 701	RRIM 600	
GT 1	1.3584	-0.6776	-0.1856	-0.5095	0.0144	-0.5194
IAN 873	1.8600	-1.7136	0.5934	0.1594	1.6384	-0.8465
PB 235	1.6700	0.2150	0.604	-0.7936	0.3254	-1.1146
RRIM 701	0.1550	-0.6400	-1.9249	0.1024	1.0414	-1.4064
RRIM 600	1.8799	2.6899	0.5850	2.7500	-3.0195	-0.0354

from IAN 873 with values as s_{ij} = -0.7936 and s_{ij} = -0.6776, respectively.

An important consideration in evaluating reciprocal effects is the magnitude of the effects or their deviation from zero rather than the relationships between effects. Estimated reciprocal combination effects for rubber yield and growth vigour were found to have an overall significance as shown by the low diagonal line on Tables 5 and 6. Many of these effects were high. The highest effects for rubber yield were found in the rootstocks of RRIM 600 combined with scions from IAN 873 (s_{ij} = 17.6800), followed by the PB 235 rootstock on the scion from IAN 873 (s_{ij} = 9.4750) and RRIM 701 combined with the IAN 873 scion (s_{ij} = 8.7150).

Conversely, considerably less yield than the expected was obtained by the scion from the IAN 873 rootstock on the scion GT 1 (s_{ij} = 9.9950). In this investigation, the combinations of the rootstocks with the scion from the same clones were generally poor in rubber yield. Only vigorous trees suitable for tapping were used as experimental materials. Comparisons between the two groups of combinations for rubber yield performance, however, showed that combinations rootstocks with scions of the same clone were, generally, very much inferior to the rootstock combined with scion from different clones. The combining ability studies for rootstock/clone relationship have revealed the importance of GCA for rubber yield and growth vigour characters. Although specific and reciprocal effects were detected for a few combinations, for both characters, they were evidently less important. For instance, the specific

combining ability and reciprocal effects for growth vigour were only $^1/_4$ and $^1/_2$ of that accounted for by the general combining ability. On the other hand, the SCA and reciprocal effects were relatively larger in relation to rubber yield.

CONCLUSIONS

RRIM 600 rootstocks were the best general combiner followed by the PB 235 for rubber yield in relation to all clone scions studied.

Rootstock influence was higher than the scion influence regarding the compatibility of rootstock and scion.

Clones scion high rootstock effect such as those from the RRIM 600 and PB 235 clones can be largely used as rootstocks to bud high yielding clones, thus ensuring high rubber yield success.

The best specific combining ability effect for rubber yield was obtained by the IAN 873 rootstock combined with scions of the RRIM 600.

ACKNOWLEDGEMENTS

The authors are grateful to Mr. Valdir Cabreira, for the statistical analysis; Miss Graziela dos Santos Lima and Miss Mariana Negrão de Oliveira for their help in preparing this paper, and to the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP).

RESUMO

Capacidade Combinatória de Enxerto com Porta-Enxertos Clonais de Seringueira

Produção e vigor da combinação de porta-enxertos com enxertos de cinco clones de seringueira [*Hevea brasiliensis* (Willd. ex Adr. de Juss.) Müell-Arg.] foram avaliados para obter a capacidade geral de combinação (CGC) do melhor porta-enxerto com todos os enxertos (clones) estudados e a capacidade específica da combinação (CEC) do porta-enxerto com enxerto específico utilizando o método 1, sugerido por Griffing, 1956. Os clones utilizados foram IAN 873, RRIM 600, RRIM 701, PB 235 e GT 1, enxertados em cinco diferentes porta-enxertos provenientes de sementes ilegítimas dos referidos clones combinados em um dialelo 5 x 5. As análises de variância revelaram que os efeitos de CGC e seus recíprocos, foram altamente significativos para os caracteres estudados. A relação dos CGC:CEC foi 24:1 para produção e 4:1 para vigor. Para produção de borracha, porta-enxertos obtidos de sementes do clone RRIM 600 seguidos de porta-enxertos do PB 235 (g_i = 5,20) foram os melhores para CGC. Para vigor, embora negativo, porta-enxertos do clone RRIM 600 (g_i = -0,03), seguido do GT 1 (g_i = -0,52) foram os melhores em CGC. Os efeitos de CEC para produção (s_{ij} = 5,55 e s_{ij} = 3,06) foram obtidos pela combinação dos porta-enxertos IAN 873 seguido pelo PB 235, ambos combinados com enxertos do clone RRIM 600. O melhor efeito da CEC para vigor (s_{ij} = 1,64) foi obtido da combinação do porta-enxerto do clone IAN 873 com enxerto do clone RRIM 600. Conclui-se, que porta-enxertos do clone RRIM 600 foram os que apresentaram melhor CGC para produção de borracha, enquanto que porta-enxertos do clone IAN 873 em combinação com enxertos do clone RRIM 600 apresentaram a melhor CEC.

REFERENCES

Abbas, B.S. and Ginting, S. 1981. Influence of rootstock and scion on girth increment in rubber trees. Bulletin Balai Penelitian Perkebunan Medan. 12:145-52.

Buttery, B.R. 1961. Investigations into relationship between stock and scion in budded trees of *Hevea brasiliensis*. Journal of the Rubber Research Institute of Malaysia. 17:46-76.

Campaignole, J. and Bouthillou, J. 1995. Alliance clone-sujet. Institute Recherches Caoutchouc Indochine Rapport.

Combe, J.C. and Gener, P. 1977. Effect of the stock family on the growth and production of grafted *Hevea*. Journal of the Rubber Research Institute of Sri Lanka. 54:83-92.

Cramer, P.K.S. 1930. The budgrafting of rubber. p.380-385. In: Proceedings Northern International Congress, London, 1930.

Gonçalves, P. de S.; Martins, AL.M. and Bortoletto, N.1994. Avaliação do crescimento de seis diferentes populações de porta-enxertos de seringueira: uma avaliação preliminar. Pesquisa Agropecuária Brasileira. 29:553-560.

Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing system. Australian Journal Biological Sciences. 9:463-493.

Lepsch, I.F. and Valadares, J.M.A.S. 1976. Levantamento pedológico detalhado da Estação Experimental de Pindorama SP. Bragantia. 35:13-40.

Martins, AL.; Ramos, N.P.; Gonçalves, P. de S. and Val, K.S. 2000. Influência de porta-enxertos no crescimento de clones de seringueira no Estado de São Paulo. Pesquisa Agropecuária Brasileira. 35:1473-1750.

Ng, A.P.; Ho, C.Y.; Sultan, M.O; Ooi, C.B.; Lew, H.L. and Yoon, P.K. 1981. Influence of six rootstocks on growth and yield of scion clone of *Hevea brasiliensis*. p.134:149. In: Proceedings Rubber Research Institute of Malaysia Planter´s Conference. Rubber Reseach Institute of Malaysia, Kuala Lumpur.

Olapade, E.O.1988. General and specific combining abilities for latex yield in *Hevea brasiliensis*. p.423:430. In: Proceedings Coloque Hevea, Montpllier. IRRDB, Paris.

Paardekooper, E.C. 1954. Resultaten van twee onderstamproeven bij *Hevea*. De Bergcultures, Batavia. 551:553.

Schmöle, J.F. 1940. De invloed van denonderstam op de productive van oculaties. Archief voor de Rubbercultuur in Nederlandsch – Indië. 24:305-314.

Schmöle, J.F. 1941. *Hevea brasiliensis* and *Hevea spruceana* hybrids as stocks for bud-grafs. Archief voor de Rubbercultuur in Nederlandsch – Indië. 25:159-167.

Schweizer, J. 1938. Over den wederzijdschen involued van bovenen onderstam bij *Hevea brasiliensis*. De Bergecultures.12:773:775.

Tan, H. and Subramanian, S. 1975. A five parent diallel cross analysis for certain characters of young *Hevea* seedlings. p.13-26. In: Proceedings International Rubber Conference, Kuala Lumpur. Rubber Research Instiute of Malaysia, Kuala Lumpur.

Yahampath, C. 1968. Growth rate of PB 86 on different *Hevea* rootstocks. Quartely Journal Rubber Research Institute of Ceylon. Agualawatta. 44:27-35.

Received: December 04, 2001;

Accepted: December 11, 2002.