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Genotype × Environment Interaction Studies in Rubber (Hevea) *Clones*[#]

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The importance and impact of genotype × environment (G×E) effects on Hevea *planting recommendations have been long recognised. However, studies on G×E interaction in rubber were initiated only in the seventies. This paper reviews previous studies on G×E in* Hevea *and examines the extent, nature and the major factors of G×E interaction.*

Data on girth and yield derived from two sets of clonal trials, namely, RRIM 700 series (16 clones tested in 6 locations) and 1954 foreign exchange clone trials (91 clones tested in 5 locations) were used in this study. The data were subject to various statistical analyses.

In general, the G×E interaction was present and significant for yield and girth. However, total variance of the G×E interaction was rather small, compared to clonal and environmental effects. The G×E variance components accounted for 12.6% and 11.4% to 19.3% for girth and yield, respectively. When the results from previous studies were combined, the contribution of G×E variance components over the total variance components for various characters of Hevea *was 15.7%.*

The nature of G×E interaction was studied using joint regression analysis. The results showed that differences in linear regression accounted for only a small proportion of the total G×E interaction effects, suggesting the non-linear nature of the G×E interaction for most of the characters in Hevea *and the involvement of more than one major environmental factor (probably wind damage and disease, in this study), causing the G×E interaction.*

Stability estimates of clones were carried out using various statistical techniques such as regression and deviation, coefficient of variation and variance, ecovalence and other stability variances. In general, all the above methods could help classify clones according to their stability or response toward the variation of environment as guideline for choice of clones for planting. Regression technique however needs some caution in application due to the non-linearity of the G×E interaction in Hevea. *In contrast, simple statistical parameters such as CV or variance and mean of genotypes over different trial sites can serve as practical and useful guides in clonal selection.*

One of the main tasks in *Hevea* breeding is the comparative evaluation of a series of clones, either bred locally or imported from other countries, over a wide range of environments in rubber planting areas. The testing of these planting materials in different environments is necessary because of the environmental influence on the yield and girth performance of rubber trees. In addition, it has also been observed that a particular clone which performs well in one environment may not perform as well in another environment relative to a given

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set of clones. This phenomenon of clone (genotype) – environment (GE) interaction effect can therefore make conclusive assessment of the value of individual clones for final clonal recommendation to the planting industry difficult.

In the past rubber breeders recommended the same set of planting materials to different rubber planting areas. After recognising the existence of GE effects, another approach known as regional planting recommendation in which certain recommended clones with known secondary defects are advised not to be planted in certain parts of the country which showed specific environmental constraints, such as severity of wind damage and incidence of major diseases[1-2]. In 1974, difficulties were encountered when demarcating boundaries of environmental constraints, and this led to the new concept[3] of 'Enviromax Planting Recommendation'. The principle underlying this planting recommendation is to maximise the yield potential in a particular locality, subject to the inhibitory influence of the environmental factors (including soil type, terrain, drought, *etc.*) through the choice of appropriate planting materials.

Although the importance of GE effects have been recognised and made use of in the late sixties, GE interaction studies began only in the early seventies in the Rubber Research Institute of Malaysia[4-5]. In Sri Lanka, GE studies started in 1975 by Jayasekera *et al.*[6-9]. Findings on GE studies in Indonesia[10], Nigeria[11] and India[12] are more recent.

This paper reviews previous reports on GE studies with special emphasis on the work carried out in the Rubber Research Institute of Malaysia. The extent and nature of GE interaction, stability estimates of clones and major factors causing GE interaction are also examined and highlighted.

Data Source

Two sets of trials, namely, RRIM 700 series (first selection) and 1954 foreign exchange clone trials were used for this study. The former *(Trial A)* consisted of sixteen locally bred clones, while the later *(Trial B)* consisted of ninety-one clones of diverse genetic and geographic origins, which were bred and selected by local and foreign institutions. These two sets of trials were sited in co-operating estates in different parts of Peninsular Malaysia representing certain environmental constraints such as leaf disease, wind severity and soil type in rubber growing areas. Lattice designs, which are resolvable into randomised block design, were used in these trials[13]. Experimental details of the trials have been described elsewhere by Paardekooper[14-19]. Some basic information of the trials are given in *Table 1*.

Two important economic characters, namely yield and girth, were emphasised in this study. For yield performance, yield/tree (g/tree/tapping), which reflects largely the yield potential of individual tree for a given clone, and yield/ha (kg/ha/year), which included the number of tapped stand and tapping intensity in yield estimation in a given area for a given clone, over a three- and/or seven-year period were considered. For girth performance, fourth year girth data was used.

Extent of GE Interaction

Conventional techniques on analyses of variance and variance components were used to detect the presence of GE interaction and its contribution in relation to the total variation. Yield and girth data from *Trial A* and *Trial B* were examined and were shown to have significant GE interaction effects, in addition to the large and significant main effects (clone or genetic and environmental). The respective variance components and their contributions

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TABLE 1. SOME INFORMATION ON THE TWO TRIALS USED IN THIS STUDY

	Trial A	Trial B
No. of clones	16	91
Location	6	5
Trial site	Selangor (2)	Selangor (2)
	N. Sembilan (1)	N. Sembilan (1)
	Malacca (1)	Malacca (2)
	Kedah (1)	
	Johore (1)	
Design	4 x 4 Balanced lattice	Simple lattice
Replication	5	2

Figures in parenthesis refer to number of trials.

TABLE 2. VARIANCE COMPONENTS FOR YIELD AND GIRTH PERFORMANCE AND THEIR RELATIVE CONTRIBUTIONS IN THE TRIALS

Variance component	Yield/tree	Yield/ha	Girth
Trial A			
Genetic (G)	22.86 (59.6)	48 835 (55.2)	8.48 (42.5)
Environmental (E)	9.36 (24.4)	18 777 (21.2)	8.53 (42.7)
G x E	4.70 (12.6)	17 095 (19.3)	2.52 (12.6)
Remainder	1.45 (3.8)	3 787 (4.3)	0.44 (2.2)
Trial B			
Genetic (G)	29.77 (45.5)	–	6.50 (28.6)
Environmental (E)	23.79 (36.4)	–	11.94 (52.6)
G x E	7.45 (11.4)	–	2.85 (12.6)
Remainder	4.40 (6.7)	–	1.40 (6.2)

Figures in parenthesis refer to percent contribution in relation to the total variance component.

to the total variance components are presented in *Table 2*.

Contribution of genetic variance component in relation to the total variance components for yield performance in both the trials are the highest (45.5% to 59.6%), followed by environmental variance component (21.2% to 36.4%). The GE variance component for yield, on the other hand, accounted for an average of 14.3% (range: 11.4% – 19.3%) of the total variance components. It is shown that GE variance component for yield/ha was higher than that for yield/tree. This is expected as yield/ha took into account factors arising from major environmental effects, for example, tree lost due to wind and diseases resulting in a lower tapping stand. For girth performance, both the genetic and environmental variance components jointly contributed 81.2% to 85.2% of the total variance components, with environmental variance component being larger in *Trial B*. The GE variance component accounted for 12.6% over the total variance components for the two trials.

Taking the two trials together, major variations of yield and girth performance over a set of environments are contributed mainly by the individual genetic and environmental effects. The contribution of GE effects, though significant, was small; its GE variance component recorded an average of 13.6% (range: 11.4% – 19.3%) of the total variance components.

Studies on GE contribution over the total variation for some *Hevea* characters have been made by researchers in other countries. Jayasekera *et al.*[6] who studied ten clones over eight locations, reported 16.8%, 7.5% and 37.9% of the total variance components are accounted for by the GE variance component with reference to first height, second height and survival rate, respectively. Aidi-Daslin *et al.*[1] in a study of twenty-three clones in two locations, reported 8.5%, 38.9%, 11.1%, 12.0%, 6.8% and 11.6% of the total variance components are accounted by GE variance component of yield, girth, bark thickness, dry rubber content, plugging index and number of latex vessel, respectively.

In general, the contribution of GE variance components to the total variance components for the various *Hevea* characters studied so far are small with an average of 15.7% (range: 7.5% for second height to 38.9% for girth).

Nature of GE Interaction

The nature of GE interaction has been studied using joint regression analyses[20,21]. In this approach, GE interaction can be further regressed on a measure of the environmental effect (usually environmental mean). The GE interactions are partitioned into two terms, namely, the heterogeneity of regression and deviations from regression. Each of these terms can be compared with the residual experimental error, and the heterogeneity of regression further compared with the deviations in order to see if it accounts for a significantly large part of the observed interaction. Although some limitations of this regression model have been mentioned[22], nevertheless this method has been used widely in GE studies.

Table 3 presents results of the joint regression analyses for yield and girth performance of clones in *Trial A* and *B*. It is noted that mean squares of heterogeneity of linear regression are not significant for yield performance in both the trials. On the other hand, significant mean squares for deviations from regression are detected for the same characters. For girth performance, a slightly different picture is obtained. A border-line significance ($P<0.10$) for *Trial A* and high significance ($P<0.01$) for *Trial B* for mean

TABLE 3. MEAN SQUARES OF JOINT REGRESSION ANALYSES FOR YIELD AND GIRTH IN TRIALS A AND B

Character	Clone (G)	Environment (E)	G × E	Linear regression	Deviations from regression	Remainder
Yield/tree						
Trial A	120.45 ***	155.86 ***	6.15 ***	3.75 NS	6.95 ***	1.45
	(15)	(4)	(60)	(15)	(45)	(300)
Trial B	160.68 ***	2176.51 ***	11.85 ***	12.91 NS	11.49 ***	4.40
	(90)	(4)	(360)	(90)	(270)	(483)
Yield/ha						
Trial A	265 059.6 ***	321 309.7 ***	20 881.8 ***	16 593.7 NS	22 311.2 ***	3 787.0
	(15)	(4)	(60)	(15)	(45)	(300)
Girth						
Trial A	53.81 ***	139.47 ***	2.96 ***	4.24 +	2.64 ***	0.44
	(15)	(5)	(75)	(15)	(60)	(360)
Trial B	36.76 ***	1 090.75 ***	4.23 ***	6.45 **	3.49 ***	1.40
	(90)	(4)	(360)	(90)	(270)	(483)

Figures in parenthesis refer to degrees of freedom

NS: Not significant at $P < 0.05$

+, **, ***: Significant at $P < 0.10$, 0.01 and 0.001 respectively squares due to heterogeneity of linear regressions are detected. The mean squares for deviations from regression are also large and highly significant for girth in both the trials.

The above results suggest that the nature of GE interaction for yield and girth performance could be largely non-linear although linear GE interaction is detected for girth performance to some extent.

Jayasekera[9] reported a similar nature of studies using a joint regression analysis of Perkins and Jinks[23]. The author suggested non-linear GE interaction for survival rate and two height measurements and mainly linear GE interactions for second year test-tapping yield and sixth year girth.

The finding of non-linear GE interactions for clonal performance with reference to the characters studied indicates the involvement of more than one major environmental factors in causing GE interaction and the differential clonal responses towards these environments.

Stability Estimates of Clones

Several statistical techniques are available to describe clonal response over a range of environments. Some of these require a priori assumption of linearity in response while others do not need this assumption. The subject on stability estimates has been reviewed by a number of researchers[24,25]. Some of these techniques used and the results obtained in this study are described below.

Regression and Deviation

Regression estimates of individual genotypes are usually estimated in conjunction with the regression method of studying GE interaction, like those described by Finlay and Wilkinson[20], and Eberhart and Russell[21]. While there may be a difference in the definition of stability, the meaning of regression in describing clonal response over environment is basically similar. Genotypes with regression coefficients, not significantly different from unity (one) are those performing almost similarly with the average performance of all clones in the environment tested. Genotypes with regression coefficients significantly higher than one are those which can adapt very well to good environment but perform poorly in unfavourable environment. Genotypes with regression coefficients significantly below one are those which are less sensitive to environmental changes, with relatively small fluctuation in performance in poor as well as in good environment.

Eberhart and Russell[21] regarded the first group ($b=1$) as genotypes with average adaptability/stability, the second group ($b>1$) as below average adaptability and the third group ($b<1$) as above average adaptability. Another statistics, *i.e.* deviation from regression, was incorporated as a second stability parameter to describe clonal stability[21]. A small deviation associated with the regression was considered more stable. These stability estimates are always considered together with average clonal performance to serve as a basis for clonal selection.

The three parameters (mean, regression coefficient and deviation from regression) were estimated for the clones involved in *Trial A* and *B* with regard to yield and girth performance. Clones with various degrees of adaptability/stability were identified and this information became useful as a supplementary guide for *Hevea* clonal selection[4,5].

The nature of regression estimates obtained from *Trial A* and *B* were examined in relation to its distribution into different classes. The results are summarised in *Table 4*.

TABLE 4. DISTRIBUTION OF REGRESSION COEFFICIENT (b) INTO GROUPS IN THE TRIALS

Character	b = 0 S / b = 1 NS	b = 0 S / b = 1 S	Total	
Yield/tree				
Trial A	4	0	4	(25.0)[a]
Trial B	40	2	42	(46.2)
Yield/ha				
Trial A	3	0	3	(18.8)
Girth				
Trial A	13	1	14	(87.5)
Trial B	54	7	61	(67.0)
Combined	114	10	124	(53.9)

[a]% Over total no. of regression in Trial A (N = 16) and Trial B (N = 91)
NS: Not significant at $P < 0.05$
S: Significant at $P < 0.05$

In *Trial A*, out of sixteen clones, only three to four clones had significant regression and all were shown to be not significantly different from unity (one) with reference to yield performance. For girth performance, fourteen out of sixteen clones showed significant regression and were not significantly different from unity (one), except for one case showing a significant difference.

In *Trial B*, forty-two out of ninety-one clones tested had significant regression coefficients for yield performance. Forty regression coefficients were not significant from unity (one) while two were significantly different from unity (one). An increased number of significant regression coefficients were noted for girth character; fifty-four cases were not significantly different from unity (one) while seven were significantly different from unity (one).

Combining all the regression estimates (230 cases) for yield and girth characters of both trials, 53.9% (124 cases) of the regression coefficients were shown to be significant; 92% (114 cases) were not significantly different from unity (one); 8% (10 cases) were significantly higher or below unity (one). This result implies that only a portion of clonal performance can be described by linear regression. Majority of the clones which can be described by linear regressions exhibited characteristics similar or close to average adaptability/stability. Only a few clones can be classified as above or below average adaptability. The result also agrees with earlier suggestion that GE interaction cannot be easily expressed by linear regression alone.

Table 5 presents the stability parameters of some selected clones. Most of these clones

TABLE 5. STABILITY PARAMETERS OF YIELD PERFORMANCE OF SOME SELECTED CLONES IN TRIAL B (EBERHART AND RUSSELL'S METHOD)

Clone	Mean yield (g/t/t)	Regression coefficient (b)	se(b)	Deviations from regression
RRIM 501	36.7	1.20	0.32	5.13
RRIM 513	28.7	0.62	0.24	1.03
RRIM 519	27.7	0.38*	0.19	0
RRIM 526	25.6	1.39	0.34	6.80
RRIM 605	32.6	1.39	0.39	10.17
RRIM 607	29.4	0.65	0.23	0.50
RRIM 623	33.9	1.07	0.16	0
PB 86	22.0	1.12	0.46	15.96
PB 5/51	31.3	0.79	0.24	1.04
PB 5/63	37.0	1.51	0.41	11.79
RRIC 6	30.5	0.89	0.22	0.07
LCB 1320	28.3	0.54 +	0.19	0
GT 1	29.9	0.93	0.19	0
PR 107	25.7	0.53	0.24	1.18
PR 251	34.6	1.02	0.37	8.54
PR 255	39.9	0.72	0.36	8.05
PR 261	40.7	0.66	0.53	22.32
Trial mean	28.7	1.00		
Range	16.5–41.0	0.24–2.15		

+, * : Significant from unity at $P < 0.10$ and 0.05 respectively

have been recommended as *Class I* and/or *Class II* clones at one time or another in the RRIM planting recommendations since 1952. They are generally characterised as having above average yield, regression coefficients hovering around unity (one) or below and small deviation from regression. A few clones such as RRIM 526 (b=1.39), RRIM 605 (b=1.39), and PB 5/63 (b=1.51), had higher regression coefficients [though not significant from unity (one)] and large deviation from regression. Clone PR 255 (b=0.72) and PR 261 (b=0.66) which still remain as *Class I* clones in the RRIM Planting Recommendation[26] had the highest yield, relatively low regression and large deviations from regression. Clone RRIM 519 (b=0.38) with below to average yield had the smallest regression coefficient and low deviation from regression. It should be pointed out that the regression estimates of these three clones are not significant from zero, thus unable to offer reliable interpretation of linear response across the environmental sites tested.

In other studies, Jayasekera *et al*[6] estimated regression coefficients for first height, second height and survival rate of ten clones with over eight sites. Suhendi[27] obtained regression estimates of sixteen clones tested in three locations. These authors illustrated the use of the information as a guide in clonal planting recommendation.

While useful information can be obtained from the above stability estimates, it deserves some comments in its use and interpretation. Firstly, rubber clone trials are usually conducted in a few sites or locations which at times fall into narrow environmental range. This would result in poor estimation of regression coefficients associated with individual clones, thereby unable to give meaningful and reliable interpretation. Secondly, linear component of GE interaction accounts for only a limited portion of the interaction. It is therefore prudent to caution the usage of linear regression coefficient as a basis for GE interpretation and stability studies.

CV and Variance

In view of the limitations mentioned above, *Hevea* breeders attempted other methods which need not require assumption of linear regression response. This approach makes use of conventional coefficient of variability as a stability measure as suggested by Francis and Kanenberg[28]. The CV and mean performance of individual clones over a number of environment tested were used for constructing a scattered diagram with mean and CV along the two axis. The average CV and grand mean performance of all clones were drawn on their corresponding axis to form four quarters. Thus, four groups of clones were identified:

- Group 1: High mean, small CV
- Group 2: High mean, large CV
- Group 3: Low mean, small CV
- Group 4: Low mean, large CV.

Depending on characters in question, some clones belonging to specific groups would be favoured in terms of clonal selection. In the context of clonal selection for yield, *Group 1* and *2* clones are considered promising candidates for selection as both groups have high average yield. *Group 1* is considered more stable with less fluctuation in performance over different sites while *Group 2* clones are more sensitive to environmental changes and may be better adapted to specific or certain environment. The method described above was used to assess clonal performance over different sites in *Trial A* and *B*.

Table 6 indicates results for some selected clones with reference to yield performance in *Trial B*. Most of these clones fall in *Group 1* and *2* as expected since they were recommended materials before. For instance, the present *Class I* clones PR 261 and PR 255 both fall into *Group 1* and *Group 2*, respectively.

A parallel approach as described by Jinks and Mather[29] has also been used[7]. Instead of CV, variance of a clone across environment was used as a measure of stability. A similar method of characterising various stability properties of clones for early height measurements and survival rates was demonstrated.

Ecovalence and other Stability Variance

Other stability parameters such as Wricke's ecovalence[30], Baker's variance[31] and Shukla's stability variance[32] were attempted in *Hevea*. These stability parameters for the ninety-one clones with reference to yield performance showing different degrees of stability were

TABLE 6. STABILITY PARAMETERS OF YIELD PERFORMANCE OF SOME SELECTED CLONES IN TRIAL B (FRANCIS AND KANNENBERG'S METHOD)

Clone	Mean yield (g/t/t)	CV (%)	Group
RRIM 501	36.7	17.6	1
RRIM 513	28.7	12.6	1
RRIM 519	27.7	8.8	3
RRIM 526	25.6	28.8	4
RRIM 605	32.6	23.3	2
RRIM 607	29.4	12.6	1
RRIM 623	33.9	16.0	1
PB 86	22.0	30.6	4
PB 5/51	31.3	14.0	1
PB 5/63	37.0	22.1	2
RRIC 6	30.5	15.4	1
LCB 1320	28.3	11.0	3
GT 1	29.9	16.2	1
PR 107	25.7	12.9	3
PR 251	34.6	17.0	1
PR 255	39.9	23.9	2
PR 261	40.7	13.6	1
Trial mean	28.7	20.7	
Range	16.5–41.0	8.9–37.4	

obtained[5]. A sample of these stability estimates for some selected clones is illustrated in *Table 7*. The information obtained from these three estimates were shown to be almost similar. When a clone had large Shukla's stability variance, it also had a large Wricke's ecovalence and a large Baker's variance. Both the highest yielding *Class I* clones PR 255 and PR 261 had relatively high stability variances.

Rajeswari Meenattoor *et al.*[12] used a very unconventional set of girth increment data during 'summer' and 'winter' seasons (as environments) over eight years in one trial, testing five rubber clones to carry out stability studies. The author's estimated ecovalence and Shukla's stability variance for the clones showed various degrees of stability (adaptability).

Possible Factors Causing GE Interaction

Systematic study on the factors underlying GE interaction has not been carried out so far for rubber tree performance. This is understandable because of the complexity of environmental factors in influencing yield performance and difficulties in isolating the specific factors for the study. However, from a number of observation and evaluation in field

TABLE 7. WRICKE'S, SHUKLA'S AND BAKER'S STABILITY VARIANCE FOR YIELD PERFORMANCE OF SELECTED CLONES IN TRIAL B

Clone	Wricke's ecovalence	Shukla's stability variance	Baker's variance
RRIM 501	32.4	8.2	8.1
RRIM 513	30.4	7.6	7.6
RRIM 519	46.5	11.8 *	11.6
RRIM 526	48.0	12.1 *	12.0
RRIM 603	28.2	7.1	7.1
RRIM 605	58.6	14.8 *	14.6
RRIM 607	26.4	6.6	6.6
RRIM 623	8.0	1.9	2.0
PB 86	62.6	15.9 **	15.6
PB 5/51	20.4	5.1	5.1
PB 5/63	73.4	18.6 **	18.4
RRIC 6	14.6	3.6	3.7
LCB 1320	30.9	7.8	7.7
GT 1	11.3	2.8	2.8
PR 107	37.4	9.4	9.4
PR 251	38.9	9.8	9.7
PR 255	44.7	11.3 *	11.2
PR 261	91.1	23.2 *	22.8

*, ** : Significant at $P < 0.05$ and 0.01, respectively

trials, two major factors have emerged as likely candidates in causing GE interaction. One factor is disease while the other factor is wind damage. These two factors can cause drastic differences in yield and girth performance in rubber clones. For example, RRIC 103 which is very susceptible to *Corynespora* could perform reasonably well in Kedah area where *Corynespora* leaf disease is not conducive or prominent. However, this clone can hardly grow to full maturity (up to tapping) and become the worst performer in the same set of trial in other states (*e.g.* Johore) where there is serious *Corynespora* leaf-disease problem. RRIM 703, a wind susceptible clone, can yield well (in kg/ha) in non-wind prone area but perform poorly in wind prone area, resulting a reverse in the ranking in a given set of clones tested in the same trials.

Although other factors such as soil type and terrain, climate, agronomic inputs, tapping system and intensity *etc.*, are known to influence rubber performance, their roles as major factors in GE interaction have not been demonstrated. Yew[33], who carried out a preliminary pot experiment involving different soil types and several clones, reported no evidence of soil x clone interaction in his early growth study. Chan and Pushparajah[34], on the other hand, reported certain type of soil may cause different types of wind damage. Perhaps, soil-type may exert their interaction effect through wind damage incidence of certain clones.

CONCLUSION

The following conclusions can be drawn from the fore-going studies:

- GE interaction exists in *Hevea*; it accounts for about 14% (range: 11% – 19%) of total variation in yield and girth performance in this study and an estimate of 16% (range: 8% – 39%) was obtained when combined with other studies.
- Differences in linear regression accounted only for a small proportion of the total GE interaction effects, suggesting that GE interaction is probably non-linear for most of the characters (yield, early height and survival rate) studied. Linear GE interaction however was detected for girth and test-tapping yield, but this linearity alone also cannot account for the total GE interaction.
- Relatively large and significant mean square deviation from regressions accounted for a major part of GE interaction effects, reinforcing the suggestion of non-linear GE interaction for most of the characters studied.
- Regression approach can be useful in the study of clonal performance over a set of environment. However, due to poor estimation of regression coefficient, partly due to small degrees of freedom in few tested sites in clone trials, its interpretation in GE interaction on the basis of linearity needs to be cautiously made.
- Statistical parameters such as CV or variance and mean of genotypes obtained over different trial sites can serve as practical and useful guides in clonal selection. Other parameters such as Wricke's ecovalence, Shukla's stability variance and Baker's variance can also provide information on clonal sensitivity over different environment.
- Disease and wind damage are the likely major factors causing GE interaction.
- For more effective evaluation of clones, choice of trial sites including various environmental constraints and an increased number of trial sites are important in providing suitable data for GE studies and improve efficiency of selection. This would therefore further refine rubber clonal recommendations.

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REFERENCES

1. HO, C.Y., NG, A.P. AND SUBRAMANIAM, S. (1969) Choice of Clones. *Plrs' Bull. Rubb. Res. Inst. Malaya No. 104*, 226.

2. RUBBER RESEARCH INSTITUTE OF MALAYA (1973) Planting Recommendations, 1973 - 1974. *Plrs' Bull. Rubb. Res. Inst. Malaya No. 125*, 33.

3. HO, C.Y., CHAN, H.Y. AND LIM, T.M. (1974) Environmax Planting Recommendation — a New Concept in Choice of Clones. *Proc. Rubb. Res. Inst. Malaysia Plrs' Conf. Kuala Lumpur 1974*, 293.

4. TAN, H. (1974) Stability Parameters of Growth Performance in *Hevea brasiliensis. Project Report 'Biometrical Genetics in* Hevea brasiliensis'. Kuala Lumpur: Rubber Research Institute of Malaysia.

5. RUBBER RESEARCH INSTITUTE OF MALAYSIA (1979) A Preliminary Report on Genotype-environment Interactions in *Hevea brasiliensis.* (Internal Report)

6. JAYASEKERA, N.E.M., SAMARANAYAKE, P. AND KARUNASEKERA, K.B. (1977) Initial Studies on the Nature of Genotype-environment Interactions in some *Hevea* Cultivars. *J. Rubb. Res. Inst. Sri Lanka*, **54**, 33.

7. JAYASEKERA, N.E.M. (1983) A Basis for Selecting *Hevea* Clones Stable to Unpredictable Agroclimatic Variability. *Silvae Genetica*, **32**, 181.

8. JAYASEKERA, N.E.M. AND KARUNASEKERA, K.B. (1984) Effect of Environment on Clonal Performance with Respect to Early Vigour and Yield of *Hevea brasiliensis. Proc. IRRDB Meeting on* Hevea *Physiology, Exploitation and Breeding, July 1984, Montpillier, France.*

9. JAYASEKERA, N.E.M. (1984) A Review of Studies on Genotype-environment Interactions in *Hevea. Proc. Int. Rubb. Conf. '75 Years of Rubber Research in Sri Lanka', Colombo, 17 – 19 Sept. 1984*, 111.

10. AIDI-DASLIN, ACHMAD BAIHAKI, TOHAR DANAKUSUMA, M. AND MURDANINGSIH HAERUMAN (1986) Interaksi Genotipe x Lingkungan pada Karet dan Peranannya di dalam Seleksi Klon. (Genotypes x Environment Interaction in Rubber and their Implications in Clonal Selection). *Bulletin Perkaretan*, **4(1)**, 23.

11. ONOKPISE, O.U., OLAPADE, O. AND MEKAKO, H.U. (1986) Genotype x Environment Interaction in *Hevea brasiliensis* (Mull Arg.). *Indian J. Genet.*, **46(3)**, 506.

12. RAJESWARI MEENATTOOR, J., VINOD, K.K., KRISHNAKUMAR, A.K., SETHURAJ, M.R., POTTY, S.N. AND SINHA, R.R. (1991) Clone x Environment Interaction during Early Growth Phase of *Hevea brasiliensis*. I. Clonal Stability on Girth. *Indian J. nat. Rubb. Res.*, **4(1)**, 51.

13. TAN, H. (1989) Some Aspects of Statistical Application in Rubber Breeding Trials. *Application of Statistics to Perennial Tree Crops*, 6. Kuala Lumpur: Palm Oil Research Institute of Malaysia.

14. PAARDEKOOPER, E.C. (1959) Report on the RRIM 'Exchange Clone' Trials (1954 Collection). I. *Rubb. Res. Inst. Malaya Res. Archs. Docum. No 11.*

15. PAARDEKOOPER, E.C. (1961) Report on the RRIM 'Exchange Clone' Trials (1954 Collection). II. *Rubb. Res. Inst. Malaya Res. Archs. Docum. No 14.*

16. PAARDEKOOPER, E.C. (1962) Report on Clone/tapping and RRIM 700 Series Clones Trials (1960-61). I. *Rubb. Res. Inst. Malaya Res. Archs. Docum. No 16.*

17. PAARDEKOOPER, E.C. (1964) Report on the RRIM 'Exchange Clones' Trials (Group B trials). III. *Rubb. Res. Inst. Malaya Res. Archs. Docum. No 25.*

18. PAARDEKOOPER, E.C. (1964) Report on Clone/tapping and RRIM 700 Series Clones Trials. II. *Rubb. Res. Inst. Malaya Res. Archs. Docum. No. 30.*

19. PAARDEKOOPER, E.C. (1965) Report on the RRIM 'Exchange Clones' Trials (Group B Trials). IV. *Rubb. Res. Inst. Malaya Res. Archs. Docum. No. 41.*

20. FINLAY, K.W. AND WILKINSON, G.N. (1963) The Analyses of Adaptation in a Plant Breeding Programme. *Aust. J. Agric. Res.*, **14**, 742.

21. EBERHART, S.A. AND RUSSELL, W.A. (1966) Stability Parameters for Comparing Varieties. *Crop Sci.*, **16**, 36.

22. FREEMAN, G.H. AND PERKINS, JEAN, M. (1971) Environmental and Genotype-environmental Components of Variability. VIII. Relation between Genotypes Grown in Different Environments and Measures of these Environments. *Heredity*, **27**, 15.

23. PERKINS, JEAN, M. AND JINKS, J.L. (1968) Environmental and Genotype-environmental Variability. III. Multiple Lines and Cross. *Heredity*, **23**, 339.

24. LIN, C.S., BRINNS, M.R. AND LEFKOVITCH (1986) Stability Analysis: Where do we stand? *Crop. Sci.*, **26**, 894.

25. BECKER, H.C. AND LOON, J. (1988) Stability Analysis in Plant Breeding. *Pl. Breed.*, **101**, 1.

26. RUBBER RESEARCH INSTITUTE OF MALAYSIA (1989) RRIM Planting Recommendations, 1989 – 1991. *Plrs' Bull. Rubb. Res. Inst. Malaysia No. 198*, 3.

27. SUHENDI DEDY (1989) Analisis Stabilitas Hasil Klon Karet (A Yield Stability Analysis of Rubber Clones). *Menara Perkebunan*, **57(1)**, 10.

28. FRANCIS, T.R. AND KANNENBERG, L.W. (1978) Yield Stability Studies in Short-season Maize. I. A Descriptive Method for Grouping Genotypes. *Can. J. Pl. Sci.*, **58**, 1029.

29. JINKS, J.L. AND MATHER, K. (1955) Stability in Development of Heterozygotes and Homozygotes. *Proc. Roy. Soc.*, **B143**, 561.

30. WRICKE, G. (1962) Uber eine Methode zur Erfassung der Okologischen Streubreite in Feldversuchen. *Z. Pflzucht.*, **47**, 92.

31. BAKER, R.J. (1969) Genotype - Environment Interactions in Yield of Wheat. *Can. J. Pl. Sci.*, **49**, 743.

32. SHUKLA, G.K. (1972) Some Statistical Aspects of Partitioning Genotype-environmental Components of Variability. *Heredity*, **29**, 237.

33. YEW FOONG KHEONG (1989) Soil/clone Relationship. Progress Report on Research Work on Soil Suitability for Rubber. (Internal Report). Kuala Lumpur: Rubber Research Institute of Malaysia.

34. CHAN, H.Y. AND PUSHPARAJAH, E. (1972) Productivity Potentials of *Hevea* on West Malaysian Soils: A Preliminary Assessment. *Proc. Rubb. Res. Inst. Malaya Plrs' Conf. Kuala Lumpur 1977*, 97.