

Correlation Studies on Photosynthetic Rates, Girth and Yield in Hevea brasiliensis

Z. SAMSUDDIN*, H. TAN* AND P.K. YOON*

Correlation studies were carried out using photosynthetic rates (PR) of two-whorl buddings raised from budded stumps in a controlled growth chamber and yield and growth parameters of mature buddings from field trials. Positive correlations between PR and yield over five years (MY) were found. No correlations were, however, detected between PR and mature growth parameters i.e. girth at opening (GO), girth at fifth year of tapping (GC) and girth increment (GI).

The correlations between MY and GI or GC were negative and significant. Among the growth parameters, significant positive correlations were found between GO and GC, GC and GI but there was no correlation between GO and GI.

Multiple regression studies of PR on MY, GO, GC or GI suggest that MY was the only dominant and significant variable accounting for 22% of the variation in PR. Growth parameters do not appear to give significant positive predictive power for PR. When MY was used as the dependent variable, with GO, GC and GI as the independent variables, the coefficients of multiple determination (R^2) varied from 0.31 to 0.57. PR showed some additional contribution (significant at $P < 0.1$) when considered together with growth parameters to account for MY.

The significance of these results is discussed in relation to the usage of PR in early selection for yield in Hevea.

Photosynthetic rates (PR) of *Hevea brasiliensis* have been shown to be significantly different in seedlings¹ and in clones². However, there is conclusive evidence available on the relationship between PR and productivity. Samsuddin *et al.*³ studied PR in a hand pollinated seedling population produced through the breeding programme of the Rubber Research Institute of Malaysia and found significant variation in PR, nursery yield (early test-tapping) and growth parameters among individual seedlings and families. However, there was no significant correlation between PR and nursery yield. Only when combined with other growth characters, did PR show some contribution to variation in nursery yields. This paper extends the study using buddings of clones of known field performance but planted in a controlled environment chamber. It deals with the variations and

inter-relationships of PR of buddings and their mature yields and growth performance. It also discusses the potentials of PR as an additional criterion for early culling in rubber breeding.

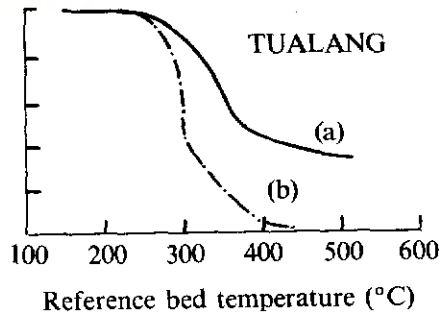
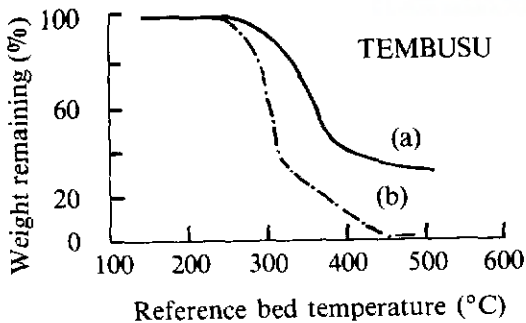
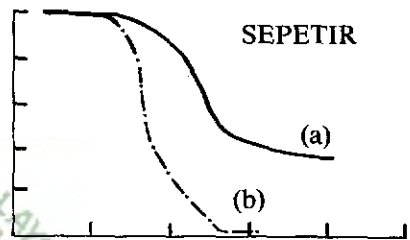
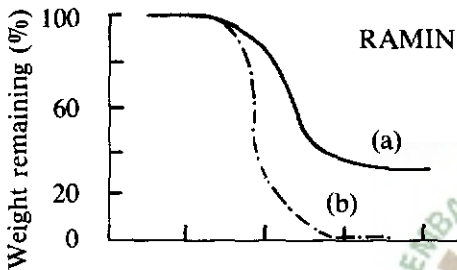
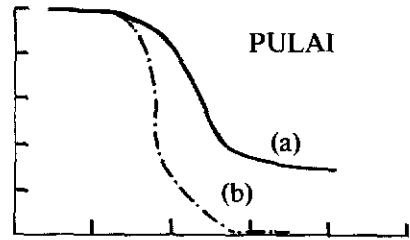
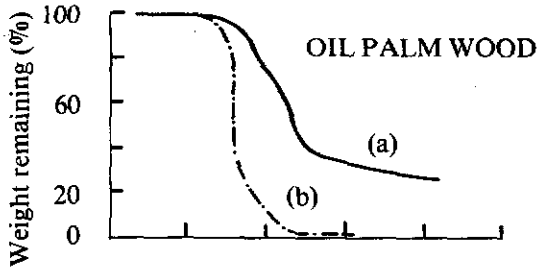
MATERIALS AND METHODS

Budded stumps of uniform sizes were prepared in Malaysia and despatched to Belgium. They were planted in polybags (25 × 55 cm, lay-flat measurement). These plants were raised in a Weiss controlled growth chamber (at the Department of Biology, Universitaire Instelling Antwerpen, Belgium) having day temperature of 27°C, relative humidity (R.H.) 70% and irradiance 480 $\mu\text{Em}^{-2}\text{s}^{-1}$ measured at plant height. At night (12 h) the temperature was 25°C and R.H. 90%. At one-whorl leaf stage

*Rubber Research Institute of Malaysia, P.O. Box 10150, 50908 Kuala Lumpur, Malaysia

APPENDIX B (CONTD)

THERMOGRAVIMETRY CURVES OF SOME MALAYSIAN WOOD SPECIES:
(a) IN NITROGEN GAS AND (b) IN AIR



the leaves were sprayed with a mixture of foliar feed and a zinc-based contact fungicides. Compound fertiliser containing NPK was given when they reached the two-whorl stage. Micro-elements were supplied weekly through nutrient solution following that of Hoagland's⁴, but water was given daily.

Photosynthetic rates of the clones were measured on mature⁵ intact leaves of the second whorl. A leaf was placed in an assimilation chamber (Sirigor, Siemens, West Germany) that had a constant temperature of 27°C and R.H. of 70%. This chamber was arranged in an open pneumatic circuit to a differential infra-red gas analyser (Maihak, UNOR, West Germany). Air having *circa* 340 cm³ m⁻³ CO₂ from outside the laboratory was sucked into a 1 m³ plastic container before passing through the chamber. Three high pressure sodium lamps (giving irradiance up to 1500 μEm⁻² s⁻¹ in the 400–700 nm bands) placed at a height of 1.5 m above the chamber were used as the irradiance source. To reduce the heat load from the lamps reaching the chamber, a 5-cm water filter was placed at a distance of 15 cm below the lamps.

Irradiance was measured using a quantum sensor (Lambda Instrument, USA). The PR of interest were at saturated irradiance (> 1000 μEm⁻² s⁻¹)⁶. The course of PR under this irradiance saturated condition was monitored by an analogue recorder. Once equilibrium was attained, the data were printed out by digital data logger connected in parallel to the infrared gas analyser. Leaf area was measured using a portable leaf area meter (Lambda Instrument, USA). Five to ten plants were used for PR measurements. Three to five leaves were measured from each of these plants.

Photosynthetic rates were calculated following:

$$PR = [(C_i - C_o) f] / A$$

where C_i and C_o are the concentrations of CO₂ (mg dm⁻³) going into and coming out of the chamber, respectively; f is the air flow rate (dm³ s⁻¹) into the chamber and A is the leaf area (m²).

Yield and girth data of the clones were obtained from records of large-scale clone trials

(LSCT) conducted in various locations and environments in Peninsular Malaysia. Tapping of these trees commenced when 50% or more of the trees reached a circumference of 50 cm at the height of 1.5 m from the union. The half-spiral alternate daily (½S d/2) tapping system was used. Yield was measured once a month. Girth measurements (circumference of trunks) were made at a height of 1.5 m from the union. Girth at the opening of tapping (GO) was measured just before tapping commenced and GC was the girth at the fifth year of tapping. Girth increment (GI), was calculated as the difference between GC and GO. Yield (MY) was calculated as yearly means in grammes per tree per tapping for five years. The means of the variables (MY, GO, GC and GI) of the clones planted in various environmental conditions were calculated and used in the present study. As mature yield and growth performance of clones were derived from LSCT which were planted in various environments, it is assumed that the average values from these trials would be reasonable estimates for their genetic expressions. The trials from which mean performances were calculated are shown in *Table 1*.

Means (\bar{x}), standard deviations (s) and simple correlations among the parameters were calculated. Step-wise regression studies were also carried out to determine the contributions of various parameters, singly or in combinations, to variations in PR and MY. For graphical representation, the various classes of the parameters referring to low, $<(\bar{x} - s)$, below average \bar{x} to $(\bar{x} + s)$, and high, $>(\bar{x} + s)$ were used. The upper limits of the low and above average classes are presented in *Figure 1*; thus, forming the boundaries of the carpets and the boxes in the *XY* and *YZ* planes, respectively.

For comparison of the common clones based on groupings of PR and MY, the five classifications considered were: $\bar{x} + 2s$, $\bar{x} + 1s$, \bar{x} , $\bar{x} - 1s$ and $\bar{x} - 2s$.

RESULTS

Means and Variations

The means of the parameters studied are shown in *Table 1*. MY has means that range

TABLE 1. MEANS AND STANDARD DEVIATION FOR LEAF PHOTOSYNTHETIC RATES, MATURE YIELD AND GIRTH PARAMETERS OF *HEVEA* CLONES

Clone	Photo-synthetic rate (mg CO ₂ m ⁻² s ⁻¹)	Range	No. of trials	Large-scale clone trial							
				Mean yield (g/tree tapping)	Range	Girth at opening (cm)	Range	Girth after 5 years of tapping c (cm)	Range	Girth increment (cm)	Range
RRIM 600	0.538	0.455-0.609	13	35.1	29.7-60.1	48.1	40.1-56.9	67.1	54.3-80.1	19.0	13.0-20.2
PB 28/59	0.526	0.426-0.572	9	39.0	26.7-51.1	48.8	41.2-54.2	61.2	59.4-64.6	12.4	9.1-13.9
PB 235	0.454	0.334-0.573	4	39.8	37.8-43.1	58.7	57.0-60.1	72.3	72.0-72.7	13.6	12.2-15.7
RRIM 703	0.490	0.471-0.521	8	38.7	31.9-44.4	49.8	47.2-52.4	64.4	62.7-67.6	14.7	12.4-15.7
RRIM 701	0.473	0.380-0.524	9	28.1	21.8-32.9	53.7	50.9-58.6	68.8	68.1-71.2	15.1	12.4-16.1
PB 260	0.452	0.360-0.518	4	39.8	33.7-54.2	52.2	50.9-55.0	66.9	66.6-69.8	14.7	12.2-17.7
RRIM 712	0.445	0.301-0.511	5	38.6	34.7-43.7	47.3	46.7-48.8	61.1	59.4-63.6	13.8	11.5-15.1
AVROS 2037	0.428	0.375-0.474	6	24.3	18.1-36.1	55.8	47.2-66.1	74.8	71.2-84.8	19.0	17.8-21.1
PR 255	0.424	0.328-0.462	7	5.4	28.8-43.0	50.8	44.5-57.2	68.0	65.3-72.7	17.2	13.4-19.2
PB 255	0.420	0.319-0.494	5	38.8	34.4-42.6	52.9	51.1-56.1	67.1	66.3-69.9	14.2	13.1-15.2
PB 217	0.414	0.303-0.506	7	25.5	18.1-27.0	49.5	45.8-51.8	69.2	66.2-72.0	19.7	16.5-20.4
RRIM 628	0.411	0.365-0.443	8	38.3	32.4-44.1	50.0	43.3-62.1	62.3	54.8-65.1	12.3	11.5-19.1
RRIM 623	0.411	0.373-0.440	8	29.0	25.4-41.0	55.1	49.7-60.6	73.3	66.1-78.0	18.2	15.2-20.0
RRIM 527	0.405	0.396-0.413	3	31.3	28.4-35.5	47.8	47.4-48.6	63.5	60.4-65.1	15.7	13.0-17.5
Ch 30	0.403	0.340-0.461	5	18.5	15.2-22.4	50.3	45.3-55.2	70.4	63.8-72.7	20.1	17.0-22.7
PB 5/51	0.395	0.303-0.540	5	29.0	25.5-38.1	49.4	43.0-53.4	65.3	61.8-67.1	15.7	12.9-16.5
RRIM 725	0.391	0.313-0.421	8	31.9	29.9-36.0	48.5	42.5-51.4	64.2	58.0-70.0	15.7	12.8-18.6
RRIM 501	0.381	0.303-0.461	9	33.2	28.7-42.1	50.6	39.6-55.4	62.0	51.0-68.2	11.5	7.0-13.7
PB 242	0.373	0.358-0.446	3	32.1	30.1-34.8	53.3	52.8-53.6	69.6	69.6-71.8	16.3	13.8-18.2
GT 1	0.365	0.320-0.422	8	25.5	21.4-31.8	51.7	47.6-59.3	68.8	62.6-77.1	17.1	12.8-17.8
RRIC 6	0.340	0.319-0.359	6	27.6	23.3-32.7	48.6	45.2-54.2	64.7	59.5-71.5	16.2	12.8-22.7
RRIM 612	0.337	0.329-0.351	6	19.7	15.0-27.6	52.0	49.5-57.3	74.1	70.5-78.9	22.1	19.1-25.4
PR 261	0.312	0.301-0.359	6	34.5	30.2-41.6	47.7	40.7-53.0	65.5	60.1-71.2	17.8	13.7-19.1
Mean	0.417			31.9		51.0		67.2		16.18	
S.D.	0.056			6.42		2.92		4.05		2.71	
C.V. (%)		13.40		20.10		5.70		6.00		16.90	

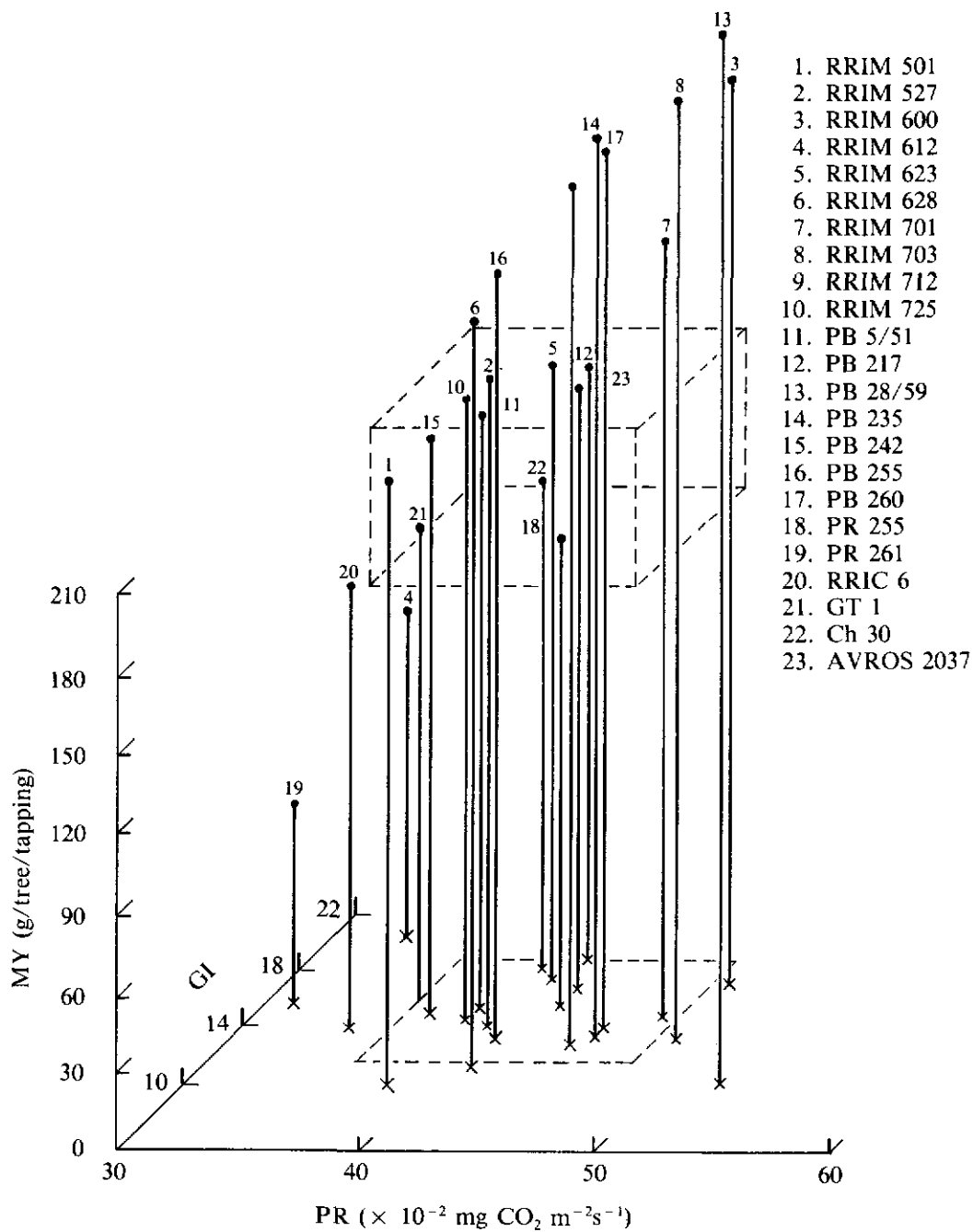


Figure 1. Relationship among leaf photosynthetic rates (PR), mean girth increment over five years (GI) and mean mature yield over five years (MY).

from 18.5 g per tree per tapping to 39.8 g per tree per tapping and shows the highest coefficient of variation (C.V.) (20.1%). The second highest C.V. is shown by GI (16.9%) that has means that range between 11.5 cm to 22.1 cm. This is followed by PR having C.V. of 13.4% and means that range between 0.312 mg CO₂ m⁻²s⁻¹ to 0.538 mg CO₂ m⁻²s⁻¹. GO and GC show low C.V. of 5.7% and 6% and have means that range between 47.7 cm to 58.7 cm and 61.1 cm to 74.8 cm, respectively. The C.V. suggest that the yield and the girth increment during tapping among the clones studied have higher variations than their girth at opening or at the fifth year of tapping. PR were also fairly variable among the clones studied.

Relationship Studies

Simple correlations. The simple correlation coefficients among the characters studied are shown in Table 2. The correlation coefficient between PR and MY is positive and significant but those between PR and GC and GI are negative and not significant. The correlation coefficient between PR and GO is, however, positive but not significant. The highly significant negative correlation between GI and MY (-0.754***, d.f. = 21) probably demonstrates the phenomenon of competition for the common assimilates⁷. It is evident that tapping has created a bigger sink compared to that of dry

matter accumulation as reflected by the girth increment.

Multiple regression. Two sets of multiple regressions were made (Table 3). One uses PR as the dependent variable to see how much the biomass (reflected by girth parameters⁸) and partition (reflected by yield of rubber) explain the variation of PR. The other uses MY as the dependent variable to see the contribution of PR in addition to the growth parameters.

In Equations 1, 2 and 3 of the step-wise multiple regressions where PR is the dependent variable, MY accounts for 22.0% of the variation in PR. The addition of GC and GO did not contribute significantly in accounting for the variation in PR.

In Equations 4, 5 and 6 where MY is the dependent variable, the growth parameters GO and GC jointly or GI singly was able to account for MY variation by about 57%. Inclusion of PR as an independent variable together with the growth parameters improve the predictive power for MY to some extent. An increase of about 7% to 13% in coefficients of determination was noted in the step-wise multiple regressions, suggesting that PR does play some part in determining MY.

Photosynthetic rates, girth increment and yield. A graphical presentation of the relation-

TABLE 2. SIMPLE CORRELATIONS AMONG LEAF PHOTOSYNTHETIC RATES, MATURE YIELD AND GIRTH PARAMETERS

Character	Correlation coefficient			
	MY	GO	GC	GI
Leaf photosynthetic rates (PR)	0.469*	0.061NS	-0.152NS	-0.293NS
Mean yield over 5 years (MY)		-0.070NS	-0.557*	-0.754***
Girth at opening (GO)			0.746***	0.038NS
Girth after 5 years of tapping (GC)				0.694**

Degrees of freedom = 21

*, **, *** = P < 0.05, 0.01, 0.001 respectively

NS = Not significant at P < 0.05

GI = Girth increment over five years of tapping

TABLE 3. STEPWISE MULTIPLE REGRESSIONS OF LEAF PHOTOSYNTHETIC RATES AND MATURE YIELD ON OTHER CHARACTERS STUDIED

Equation	Dependent variable	Independent variable	Intercept	R ²
1	PR	0.004*MY (0.002)	0.286	0.220
		0.005*MY + 0.002 ^{NS} GC (0.002) (0.003)	0.114	0.237
		0.005*MY + 0.003 ^{NS} GC - 0.001 ^{NS} GC (0.003) (0.006) (0.007)	0.108	0.238
2	PR	0.004*MY (0.002)	0.286	0.220
		0.004*MY + 0.002 ^{NS} GO (0.002) (0.004)	0.189	0.229
		0.005*MY + 0.002 ^{NS} GO + 0.003 ^{NS} GI (0.003) (0.004) (0.006)	0.108	0.238
3	PR	0.004*MY (0.002)	0.286	0.220
		0.005*MY + 0.002 ^{NS} GC (0.002) (0.003)	0.114	0.237
		0.005*MY + 0.002 ^{NS} GC + 0.001 ^{NS} GI (0.003) (0.004) (0.007)	0.108	0.238
4	MY	-0.881**GC (0.287)	91.088	0.310
		-1.786***GC + 1.685** GO (0.348) (0.483)	65.947	0.571
		-1.592**GC + 1.447** GO + 31.527 [#] PR (0.342) (0.471) (16.491)	51.903	0.640
5	MY	-1.790***GI (16.123)	60.855	0.569
		-1.602***GI + 30.933 [#] PR (0.335) (16.123)	44.913	0.636
		-1.447***GI + 31.527 [#] PR - 0.145 ^{NS} GC (0.471) (16.491) (0.304)	51.903	0.640
6	MY	-1.790***GI (0.340)	60.855	0.569
		-1.602**GI + 30.933 [#] PR (0.335) (16.123)	44.913	0.797
		-1.592***GI + 31.527 [#] PR - 1.450 ^{NS} GO (0.342) (16.491) (0.304)	51.903	0.800

PR = Leaf photosynthetic rates

MY = Mean yield over five years

GO = Girth at opening

GC = Girth after five years of tapping

GI = Girth increment over five years

NS = Not significant at P < 0.05

= P < 0.01; * = P < 0.05; ** = P < 0.01; *** = P < 0.001

Figures within brackets are the standard error of respective partial regression coefficients.

ships among PR and the means of GI and MY over five years of tapping is given in *Figure 1*. The box forms the boundaries for below average PR, GI and MY. The carpet is the projection of the lower surface of the box that encompasses clones with below average to above average PR and GI. Clones falling to the right of the box or the carpet have high PR. Clones that stand outside the carpet but to the distal boundary have high GI, whilst those outside the frontal boundary have low GI. In general, a good proportion of clones having high PR show high MY whilst those having low PR show low MY. For example, clones RRIM 703, PB 28/59 and RRIM 600 had high PR, average to above average mean girth increment over five years (GI) and high mean yield over five years (MY). On the other hand, clones RRIM 501, PR 261 and RRIC 6 that had low PR showed average to above average GI but low MY. Clones having PR that ranged between average to above average showed GI within the same limits but depending on their positions within the limits had MY that ranged between average to high. The phenomenon of competition between dry matter accumulation (as expressed by GI) and rubber yield that was apparent in the simple correlation study (*Table 2*) is also demonstrated in this graphical presentation.

Photosynthetic rates as selection criteria. The significant and positive though low correlation ($r = 0.469$) between PR and MY gives an indication that PR may be usefully used as a culling criterion. To assess this possibility, comparison of common clones on different groupings between PR and MY was carried out. PR and MY were ranked and the number of common clones falling into the corresponding groups (fractions) were scored and expressed as the percentage of the number of clones in the PR groupings (*Table 4*). When means of clones greater than the general mean were taken as the point of cut-off for the top fraction, the percentage of common clones was 80%. However, when the means of clones less than the general mean were taken as the point of cut-off for the bottom fraction, the percentage of common clones was 84.6%.

TABLE 4. NUMBER AND PERCENTAGE OF COMMON CLONES SELECTED OR CULLED USING PHOTOSYNTHETIC RATES AND MATURE YIELD

No. selected in fraction	No. of common clones	
	Top fraction	Bottom fraction
3	2 (66.7)	1 (33.2)
5	3 (60.0)	2 (40.8)
10	8 (80.0)	6 (60.0)
13	9 (69.2)	11 (84.6)

Top 10 is having $\bar{x} >$ means of clones.

Figures within brackets indicate percentage of selected common clones.

DISCUSSION

For a character to be genetically manipulated, it must have a sufficient degree of variation. Photosynthetic rates satisfy this condition. The broad sense heritability for PR in this study has a value of 44%⁹, suggesting that this character has sufficient genetic variability and is, therefore, amendable for genetic manipulation.

The significant but low correlation between PR and MY is of interest in this study. Samsuddin *et al.*³ who studied the correlations between PR and nursery yield (NY) and other nursery growth parameters *i.e.* girth at two years after field nursery planting (NGO), girth after the completion of nursery test-tapping (NGC) and girth increment during test-tapping (NGI) reported no significant correlation between PR and other nursery characters. The approach in these two studies is essentially similar. However, the main differences are that in the previous study PR data were collected on single plants and correlations were made between PR, test-tapping yield and growth parameters of young seedlings grown in field nursery, while the present results were obtained from multiple buddings grown in a controlled environment. Though the magnitude of PR collected in the field and the laboratory is of the same order, the measurement errors can be expected to be greater in the field due to environmental influence and the lack of replicates of the plants. Further, the correlation between NY and mature yield ranges from low to moderate¹⁰. It is, therefore, possible that the correlation between PR and NY was not

demonstrable because of the limitations of the technique even though some positive association may exist between them.

The significant correlation between PR and MY found here may be due to the better expression of PR in terms of total canopy photosynthates input as the leaf area index (LAI) of *Hevea* clones is similar in mature stand¹¹. This is not the case in nursery plants. As the plants in the nursery were young and planted at inter-plant distance of 1.8×1.8 m, giving a planting density of 3086 plants per hectare, the expression of the crown photosynthates input and its partitioning may not primarily be influenced by PR but confounded with the crown characteristics and inter-plant competition in the stand.

Leong¹² showed that the LAI of certain *Hevea* clones' canopies remained fairly constant after the fifth year of planting. Templeton¹¹ also showed that the LAI of a three-year-old AVROS 50 was 4.9 which was comparable to that of a seven-year-old RRIM 501. From these studies, it could be inferred that the LAI of *Hevea* canopies are fairly similar. Thus, it would appear that PR may play a positive role in determining yield of mature *Hevea* plants. Though the associations between PR and partition would be critical, they have yet to be ascertained.

Recognising the important role played by the canopy in mature stands, it would be advantageous if *Hevea* clones with good canopy architecture that effects maximum irradiance interception, thus resulting in a higher total photosynthetic inputs are identified. Conceptually, a good canopy should have leaves with ideal angles of display¹³ to capture maximum irradiance and low leaf area density especially at the lower stratum to minimise mutual shading. Satheesan *et al.*¹⁴ showed that due to mutual shading, the middle and lower strata of a *Hevea* canopy intercepted 13% and 6% of the total irradiance, respectively.

The high percentage of common clones falling into both corresponding groups of PR and MY is noteworthy. These results suggest that PR might be useful as a nursery culling criterion.

However, this finding has to be treated with caution because of the following limitations. First, the clones used for this study were not selected at random and the sample size was small. Second, the plots from where the yield data were collected were not specially designed for this study, thus the data may not be sufficiently precise. Hence, this study should only be considered as preliminary. Further work using random and larger samples would be necessary to confirm the above findings.

A character to be measured for screening purposes should satisfy the following criteria. It should be cheap, fast and reliable. Whilst PR measurements can be rapidly done using relatively inexpensive instruments, the plants used in this study were raised in a highly sophisticated growth chamber. This factor may be a limitation. One could construct suitable growth chambers at relatively low cost so that large number of young seedling or buddings could be screened in a relatively short time for selection. However, this may not be feasible if one deals with a large population. Alternatively, if the plants to be measured can be replicated (such a technique is now available)¹⁵ to minimise experimental error and/or confounding effect, it should reduce this limitation and PR measurement in field nursery would be worthwhile for inclusion as an additional early selection criterion.

CONCLUSION

Yield in *Hevea* is determined by many factors. This study shows that one of these factors is PR. The positive and significant but low correlation between PR and MY and the fair proportion of agreement of clones from the PR and MY groups are interesting. While this observation does not allow selection of good performers, it nevertheless suggests the possibility of using PR as a criterion for early culling of low yielders. This will effectively cut down the number of progeny to be tested, thus saving land, cost and effort. The speed and relative ease of screening for PR suggests that the use of this parameter may be practical if it is better than or complementary to nursery test-tapping yield that is currently used as one of the

important early selection criteria. However, further work to confirm this relationship should be carried out before the full potential of using PR in the rubber breeding programme can be determined.

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