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The Concept of Harvest Index as Applied to Hevea

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The concept of 'harvest index' for measuring productivity of Hevea *has not been generally used hitherto. In the present study, an attempt is made to obtain and compare values of harvest indices for various* Hevea *species, a series of* Hevea brasiliensis *clones and finally for a specific high-yielding* Class I *clone. Some physiological and structural parameters related to yield and hence ultimately to the harvest index are also considered.*

From the study, it is apparent that among the Hevea *species, the harvest index is highest for* Hevea brasiliensis. *Individuals in a population of seedling trees of* Hevea *also vary in their harvest indices. Clonal variation and annual variation are clearly evident. Variation due to age is also apparent. Competition between trees and the partition of assimilates between the competing physiological sinks within trees are factors which affect tree growth and hence productivity of rubber. The efficiency of the source may be assumed to be variable, especially as influenced by clonal character, age and perhaps other physiological parameters including those influencing tree-to-tree competition. It is noted that the variability of the sink may also influence these physiological parameters, through the influences on water turn-over and the variability in biosynthetic capacity of the laticiferous system. Exploitation procedures can also be expected to influence the behaviour of the sink and its efficiency.*

The concept of harvest index therefore might be a very useful property not only for comparison of clones but also to measure sensitivity of the clone to exploitation procedures and other environmental factors.

For cereals and other crops where the crop is harvested along with the whole plant, the concept of harvest index is applied to represent the proportion of economic crop harvested as a proportion of total dry matter[1,2,3].

For a perennial crop like *Hevea,* the concept may be expressed in more than one form. Previous researchers have used terms such as 'partition of assimilates' rather than 'harvest index' to represent the ratio between dry rubber yield and observed or calculated shoot weight[4,5]. This empirical ratio was further examined in relation to tapping experiments by Wycherley[6].

In one of the above studies, a group of tapped trees was compared with a group of untapped trees, before commencement of tapping and two years after tapping, to obtain data on 'shoot loss' due to tapping. In another study, the effects of tapping were systematically examined in a number of tapping trials distributed throughout the country and representing various frequencies of tapping and clone combinations, to arrive at a generalisation related to the physiological performance of clones of *Hevea.* Thus, in previous studies, the value of the regression equation relating shoot weight to girth of trees as originally obtained has been well established[7]. However, one important difference between the practice of the crop physiologists and the above studies is in the consideration of the calorific value term in the equation used in the calculation of harvest index as theoretically defined later[8].

It is well known that a crop is rarely limited in its yield by only a single environmental or genetic factor. The progressive improvement of economic yields in crops has been brought about by improvements in numerous co-limiting

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factors or phenomena such as improvement of genetic yield potential; improvement in management inputs and practices; introduction of chemical means of yield stimulation; improvement in chemical practices of pest and disease control; improvements in weed control; degree of response to fertiliser application, *etc.*

In rubber, it is generally claimed that yield improvement since the inception of rubber research in Malaysia is of the order of five- to seven-fold (unselected seedling yield compared to experimental yield of partly proven material) and there is a promise of a further 30%-60% increase from expectations in the next two decades[9]. No doubt the improvements have been due to the multiple factors mentioned earlier.

The vexing physiological question which is still unanswered is the proportion of the fixed carbon harvested in the economic crop yield compared to the total amount of fixed carbon. As the rubber tree yields liquid latex from its reservoir of the laticiferous system, and as at least 65% of the harvested matter is water, there is no doubt that the water relations of the tree influences production to a great extent. Furthermore, it has been abundantly shown that plugging indices influence latex flow pattern and ultimate yield[10]. It can be stated that while the solar energy is abundant in regions grown with rubber, it has not been shown whether the utilisation of solar energy by the clones of *Hevea* and the yield of economic crop are related in a manner that can be exploited for further yield improvement. In other words, whether efficiency of the source (photosynthesis) or efficiency of the sink (laticiferous system) is more important in realising genetic potential, has not yet been decided.

Templeton's earlier studies have shown that tapped trees undergo a 'shoot loss' of 2.3-45.5 kg/tree when compared to the increment of dry weights of 59.5-112.2 kg for the untapped trees amounting to percentage shoot losses of 4% to 52%. In the same populations, the percentage ratio of rubber weight to dry weight increment ranged from 3% to 11%. Wycherley observed that during the early years, there is a negative correlation between growth and yield, *i.e.* shoot loss is a function of yield between years and experiments. He further observed that tapping in itself, irrespective of yield, may depress growth, in addition to the shoot loss which is proportionate to the diversion of assimilates from accumulation of dry matter into yield.

This paper re-examines the efficiency of rubber extraction in the form of harvest indices, for a few *Hevea* species, a number of clones in large-scale trials (RRIM 700 series) and finally for a specific high-yielding clone, RRIM 600. Some other factors closely related to biomass production and economic (dry rubber) yield are further examined through simple correlations between some observed (structural, physiological and other yield related) properties, in a group of unselected seedlings and in RRIM 600.

EXPERIMENTAL

Various species of *Hevea* growing in *Field 67* of the RRIM Experiment Station at Sungai Buloh were used in their seventh year of tapping for the determinations on species. Data from the RRIM 700 series (second selections) were used for the comparisons of clones. Five age-classes of RRIM 600 were also utilised from the RRIM Experiment Station at Sungai Buloh (*Fields 64A, 53, 48C, 48E* and *69C*). Unselected seedlings in the fifth year of tapping, growing in *Field 68* of the RRIM Experiment Station at Sungai Buloh were used for some of the determinations.

Conventional techniques of yield recording and other physiological and structural measurements as currently practised in Malaysia were followed. The term 'micro-yield' denotes yield obtained from a 1 mm puncture on the bark[10].

Annual harvest index was derived as a percentage of the annual rubber harvest in calorific terms against the calculated shoot weight of the trees using the Shorrocks formula[7].

RESULTS

Figure 1 shows the frequency distribution of dry matter in an unselected seedling population which was in the fifth year of tapping. The population has a skewed distribution with a mode around 500 kg/tree. The range in values observed for the first year of observation (fifth year of tapping) was 104 kg to 1312 kg and for the second year of observation (sixth year of tapping) was 107 kg to 1630 kg. The dry matter increment varied from a low 1 kg value to a high 318 kg/tree/year. Although the high value coincided with that of the tree with the highest dry matter on first observation, the low value did not coincide with the tree with the lowest dry matter.

Table 1 shows the mean rubber yield per tapping, mean shoot weight and annual harvest index calculated from these figures for eighteen-year-old trees of seven species of *Hevea*. As expected, the highest harvest index was found in *H. brasiliensis,* despite its fifth ranking in shoot weight. This is due to the known higher yield potentials and partitioning coefficient in favour of economic yield.

Annual harvest index figures for clones in the fifth year of tapping, examined for the 700 series clone trial are given in *Table 2.* The above-average nature of RRIM 712 in this group of clones, for the whole period, is evident from the table. Annual harvest indices vary from about 2.2 to 9.3; there is an increasing trend with age upto the third or fourth year, and then there is a decline.

When the variability of annual harvest index was examined in relation to age classes within the same clone, RRIM 600 *(Table 3),* it was found that the indices declined from a high value of 16.2 in the first year to a low value of 4.7 in the tenth year. Furthermore, the differences between age-classes three, five, seven and ten years were not significant, indicating that the harvest index is a reliable property for evaluation purposes.

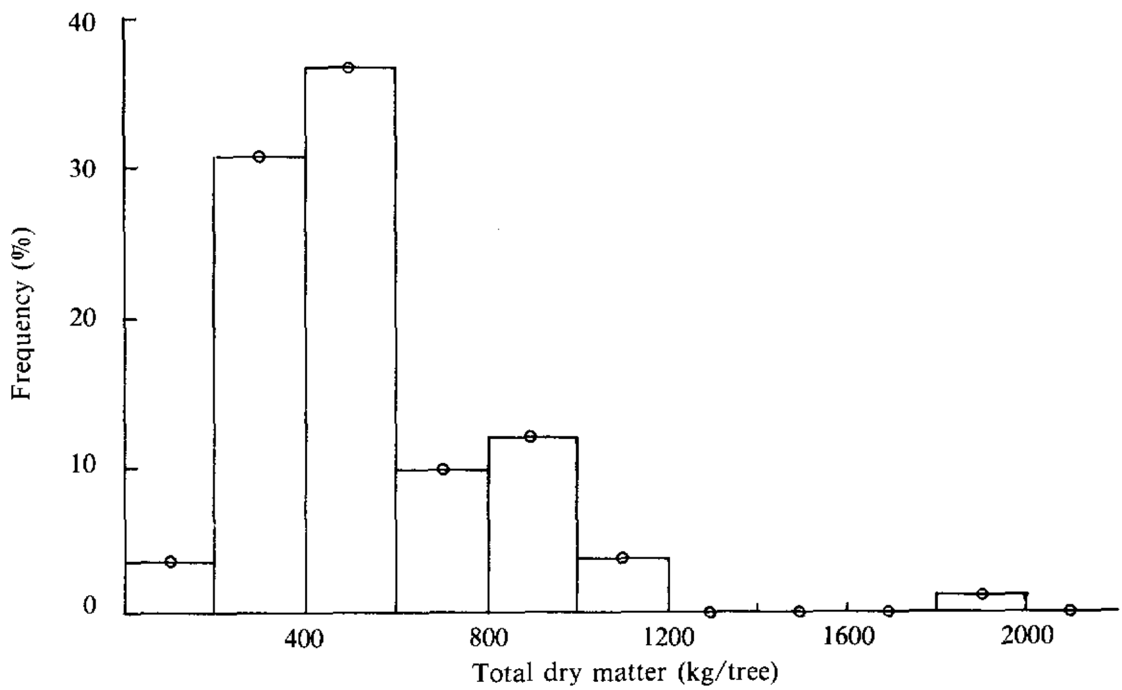

Figure 1. Dry matter distribution in unselected Hevea *seedlings.*

TABLE 1. YIELD, SHOOT WEIGHT AND ANNUAL HARVEST INDICES OF SEVEN SPECIES OF *HEVEA* (SEVENTH YEAR OF TAPPING)

Species	Mean yield (kg/tree/year)	Mean shoot weight (kg/tree)	Harvest index
H. brasiliensis (RRIM 605)	99.5	646	6.21
H. pauciflora	28.9	708	1.69
H. benthamiana	25.1	792	1.31
H. guianensis	5.3	380	0.45
H. rigidifolia	3.8	235	0.20
H. spruceana	2.4	1 009	0.20
H. nitida	1.1	802	0.14
S.E.	1.21	90.9	0.15
L.S.D.	3.36	263.3	0.45

TABLE 2. ANNUAL HARVEST INDICES FROM FIRST TO FIFTH YEAR OF TAPPING OF SOME CLONES IN LARGE-SCALE TRIALS (RRIM 700 SERIES — SECOND AND THIRD SELECTIONS)

Clone	Harvest index					Mean	S.E.
	1st year	2nd year	3rd year	4th year	5th year		
RRIM 709	3.60	6.61	7.88	6.87	5.42	6.07	0.73
RRIM 710	3.60	7.55	9.25	7.72	6.18	6.86	0.95
RRIM 711	3.49	5.33	6.28	5.66	4.70	5.09	0.48
RRIM 712	4.26	7.56	8.98	9.33	7.98	7.62	0.90
RRIM 713	3.79	4.80	4.98	4.65	3.49	4.34	0.30
RRIM 714	3.99	4.75	4.94	4.85	4.30	4.56	0.18
RRIM 715	2.53	3.07	3.22	2.85	2.60	2.85	0.13
RRIM 716	3.05	4.70	5.24	5.00	4.29	4.45	0.39
RRIM 717	5.43	6.61	6.08	5.35	4.70	5.63	0.33
RRIM 718	2.63	4.84	5.49	5.10	4.96	4.60	0.51
RRIM 719	3.19	4.43	5.28	5.45	5.19	4.70	0.42
RRIM 720	3.16	4.55	4.31	5.08	4.80	4.38	0.33
RRIM 721	4.15	6.72	7.46	6.44	5.15	5.98	0.59
RRIM 722	3.71	4.82	5.52	4.52	4.05	4.52	0.31
RRIM 723	2.31	3.44	4.68	4.53	4.24	3.84	0.43
RRIM 724	2.22	5.26	7.00	5.02	5.72	5.04	0.78
RRIM 725	3.42	5.79	6.76	5.95	4.70	5.32	0.58
Mean	3.44	5.34	6.07	5.55	4.85		
S.E.	0.19	0.31	0.40	0.35	0.28		

TABLE 3. YIELD, SHOOT WEIGHT AND ANNUAL HARVEST INDICES OF FIVE GROUPS OF RRIM 600 TREES AT DIFFERENT AGES[a]

Age (years)	Mean yield (g/tree/tapping)	Mean shoot weight (kg/tree)	Harvest index
1	4.9	5	16.2
3	9.7	45	5.3
5	20.6	105	4.8
7	72.1	251	4.7
10	89.0	302	4.7
S.E.	2.44	14.1	0.58
L.S.D.	6.76	39.7	1.63

[a]Yields of untapped stands were obtained by test tapping alternate daily for one month.

Simple Correlations between Yield and Some Yield-related Parameters

Simple correlations were derived for yield per centimetre of cut and annual harvest index, yield per centimetre of cut and latex vessel index, yield and dry matter, dry matter and dry matter increment, latex vessel ring number and dry matter, and plugging index and annual harvest index for unselected seedlings. These are given in *Table 4.* Most of the values are very highly significant. In this experiment, the yield per centimetre of cut and the latex vessel index were not significant; an unusual result.

TABLE 4. SOME SIMPLE CORRELATIONS BETWEEN OBSERVED PROPERTIES IN UNSELECTED SEEDLINGS (n = 53)

Correlation between	r
Yield/cm of cut and annual harvest index	0.6186***
Yield/cm of cut and latex vessel index	0.1834[NS]
Yield and dry matter	0.6007***
Dry matter and dry matter increment	0.7492***
Latex vessel ring number and dry matter	0.4335**
Plugging index and annual harvest index	−0.3878**

NS: Not significant
*P<0.05
**P<0.01
***P<0.001

Simple correlations were also computed for yield and micro-yield, yield and plugging index, micro-yield and micro-plugging index, yield and latex vessel ring number, micro-yield and latex vessel ring number and yield and dry matter, for five phases of growth of clone RRIM 600. The results are given in *Table 5.* The most consistent results are obtained for correlations between yield and dry matter for all the age-groups. Other results did not show clear trends.

Other Physiological Indicators

Table 6 gives details of physiological indicators which are linked to yield, and hence would be expected to be related to the harvest index, for the same groups of trees of RRIM 600. All three measures of yield show increasing trends with age, a property also reflected in the plugging index. Micro-plugging index, on the other hand, shows a reverse trend; dry rubber content (d.r.c.) shows a peak value before tappable age and then decreases, turgor pressure, bark thickness, latex vessel ring number, girth and dry matter show increasing trends.

DISCUSSION AND CONCLUSION

The desirability of having an index such as harvest index to measure the ratio between crop

TABLE 5. SIMPLE CORRELATIONS BETWEEN SELECTED PROPERTIES OF RRIM 600 FROM DIFFERENT PHASES OF GROWTH

Properties	Correlation				
	1 year	3 years	5 years	7 years	10 years
Yield and micro-yield	0.5764**	0.1837^{NS}	0.6214**	0.4930*	0.3050^{NS}
Yield and plugging index	-0.2482^{NS}	−0.5524*	−0.5109*	−0.8083***	−0.6488**
Micro-yield and micro-plugging index	−0.6027**	−0.6180**	−0.4509*	−0.6067**	−0.6212**
Yield and LVR number	0.4556	-0.0349^{NS}	0.4622*	0.4678*	0.5199*
Micro-yield and LVR number	0.4455*	0.2145^{NS}	0.7103***	0.1707^{NS}	0.4875*
Yield and dry matter	0.8804***	0.6031**	0.6535**	0.8657***	0.8564***

NS: Not significant
*P<0.05
**P<0.01
***P<0.001

TABLE 6. PHYSIOLOGICAL AND ANATOMICAL CHARACTERS OF RRIM 600 FROM DIFFERENT PHASES OF GROWTH[a]

Property	Value of property measured					S.E.	L.S.D.
	1 year	3 years	5 years	7 years	10 years		
Yield (ml)	4.9	9.7	20.6	72.1	89.0	2.44	6.76
Initial yield (ml)	0.5	4.8	9.5	16.0	25.2	0.36	0.99
Micro-yield (ml)	0.01	0.28	0.41	2.63	4.11	0.08	0.23
Plugging index	2.3	6.6	6.8	10.1	10.4	0.16	0.44
Micro-plugging index	70.3	44.9	44.0	30.4	30.3	0.7	1.9
D.r.c. (%)	39.5	47.7	54.9	44.5	44.5	0.34	0.93
Turgor pressure (atm)	0	8.7	10.4	11.4	12.8	0.09	0.25
Bark thickness (mm)	2.5	4.4	5.2	6.6	7.5	0.16	0.44
Latex vessel ring	3	5	8	16	21	0.6	1.8
Girth (cm)	14.5	32.4	44.2	60.6	64.6	1.40	3.94
Dry matter (kg)	5	45	105	251	302	14.1	39.7

[a]The untapped stands of one, three and five years were test-tapped on fifteen days during a month for determination of these values. Other determinations were obtained from one whole year of alternate day tapping.

harvested and dry matter production has been appreciated by crop physiologists around the world for many years. However, it is surprising that such an index has not been generally used in *Hevea* research since the inception of research on rubber as a crop. The partition of assimilates has been investigated earlier and a theoretical derivation of the concept of harvest index in *Hevea* has been available to us[8] since 1981. As far as the authors are aware, this is the first instance where experimental data have been utilised to compute harvest indices in

Hevea. The computations were based on certain assumptions and derived formulae of previous investigators[8,11], and they may be further improved and made more precise by future investigations. Nevertheless, the values obtained in the present work indicate some very pertinent trends.

It has been demonstrated in this study that individuals in a population vary in their harvest indices. Clonal variation and annual variation are also features clearly evident. Variation due to age is also apparent. Competition between trees and competition within trees (*i.e.* through partition of assimilates) are factors which affect tree growth and consequently productivity. Assuming that efficiency of the source is variable, as influenced by clonal character and age and perhaps other physiological factors related to tree-to-tree competition, it has also to be admitted that the sink is also variable because the latex flow characteristics are affected by water turn-over and biosynthetic capacity of the laticiferous system and by the demands made on this capacity by the exploitation procedures. Therefore, computations of harvest indices would be very useful for measuring the sensitivity of clones to exploitation regimes which in practice may be varied as much as four-fold in intensity. Hence, breeders and selectors would be advised to consider the value of employing harvest indices to compare not only the performance of genotypes *per se,* but also the genotype-environment interactions which affect performance.

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