Euphytica (2007) 156:67–75
DOI 10.1007/s10681-006-9352-8

Age of yield stabilization and its implications for optimising selection and shortening breeding cycle in rubber (*Hevea brasiliensis* Muell. Arg.)

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Received: 12 September 2006 / Accepted: 29 December 2006 / Published online: 21 January 2007

Abstract With the objective to explore the possibility of optimising selection for reducing the number of years of yield recording that could be sufficient enough to establish the lowest risk tapping-age for selecting the potential clones from field-level clone trials, long-term yield data (13–16 years) from eight clone evaluation trials were subjected to formal graphical/statistical analytical techniques. Non-linear curves were fitted to yield data and the year of start of upper asymptotic phase was worked out. Correlations were worked out between mean yield of all the years' data and cumulative mean yield over 3–10 years of tapping. Success rate achieved in the selection of high yielding clones from the third year of tapping was worked out. The mean maximum d*y*/d*x* (first derivative of the curve) across all trials ranged from 3 to 7 years of tapping with mean maximum d*y*/d*x* at 4 years. Correlations observed from the sixth year of tapping were highly significant in most of the trials. Considering the results from all the three analytical techniques, it was concluded that six years of yield recording would be required for optimising selection of top yielding clones from large-scale clone trials. The possible use of these results is discussed in the framework of a global selection scheme with a view to shorten the breeding cycle of *Hevea brasiliensis*.

Keywords *Hevea* breeding · Yield stabilization · Optimising selection · Shortening breeding cycle

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Introduction

Hevea brasiliensis (Willd. ex. Adr. de. Juss.) Muell. Arg., is one of the important industrial tree crops grown mainly in the tropical climates between 12° latitude on either side of the equator. It is the major source of 'natural rubber', a product used in the manufacture of thousands of products of which the pneumatic tyre is the most popular. Rubber trees belong to the genus *Hevea* under the family Euphorbiaceae. Though ten species have been recognized in the genus, *Hevea brasiliensis* is the only species cultivated (Webster and Paardekooper 1989). Like in other tree crops, in *Hevea* also, breeding, evaluation and release of clones is long, laborious and time consuming (Subramaniam 1980; Tan 1987; Simmonds 1989). Each cycle of hand pollination programme involves several crosses to generate few hundred to several thousand new genotypes. The first stage evaluation of these genotypes is carried out in seedling nurseries that reduce the number of potential individuals to a manageable level. Further reduction in number takes place when the selected seedlings are cloned and evaluated in clonal nurseries. Both seedling and clonal nursery are planted at a higher density than the normal spacing of the plantations (500 trees per hectare). Even after two stages of screening at the nursery level, there will still be many genotypes involved, which have to be evaluated in field-level tests. In *Hevea* breeding, small-scale and large-scale field trials are very important intermediary trialing stages and the total duration of both stages last for over 30 years. In these trials, selections from the nursery level tests are evaluated in normal commercial scale spacing to further reduce the number of selections to much smaller number which are worth passing forward to onfarm trials (Simmonds 1989).

In the current practice at the Rubber Research Institute of India, the small-scale trials are planted in RCB design with 25–50 entries in plot sizes of 4–5 ramets in three replications. In large-scale trials 10–15 entries are tested in plot sizes of 16–25 ramets following RCB design with three replications. The clones included in these trials are normally evaluated for yield for over 20 years (excluding immature period of about 6–7 years) to decide on the selections that are carried to onfarm trials. Both the trialing stages span over 30 years of evaluation period. In order to bring out the pipeline clones to limelight, breeding cycle needs to be shortened for increasing the number of potential clones that can be carried forward to onfarm trials. Thus, it is of high importance to explore the possibilities of reducing the number of years of yield recording for optimising the selection of potential clones without compromising the safer side of the decision. In *Hevea* even though a lot of literature is available on breeding and evaluation (Dijkman 1951; Polhamus 1962; Panikkar et al. 1980; Tan 1987; Simmonds 1989; Varghese 1992; Ong et al. 1994; Varghese and Mydin 2000; Saraswathyamma 2002; Priyadarshan and Clement-Demange 2004) no attempt has been made to find out the minimum number of years of yield data required to select the high yielding clones that are to be carried forward to onfarm trials. The objective of this study is to present the age of yield stabilization and to discuss its implications for optimising selection and shortening breeding cycle in *Hevea brasiliensis*.

Materials and methods

Data sets

Data sets used in this study come from eight clone evaluation trials conducted by the Rubber Research Institute of India at different locations. The trials and their details are summarized in Table 1. Among the eight trials, seven were conducted in the state of Kerala under the traditional rubber growing zone (8–12°N) and one at Agartala in the North East India under the non-traditional zone (23°N). All the trials conducted in the traditional rubber growing zone were tapped after about 8 years of immature growth while the trial at Agartala was tapped after 10 years of immature growth.

Graphical approach

Non-linear curves were fitted to yield data and the year of start of upper asymptotic phase was worked out. The non-linear equation fitted was the Morgan-Mercer-Flodin (MMF) model (Morgan et al. 1975; Saber and Wild 1989) that takes the following form:

$$y = \frac{ab + cx^d}{b + x^d}$$

where a is the value of the lower asymptote, b is the scaling parameter, c is the value of the upper asymptote and d is a parameter that

Table 1 Details of the clone trials from which data were used

Trial code	Location	Year of planting	Field lay-out			Current status	No. of clones	No. of years of yield data	Published information
			Design	Replications	Trees per plot				
CT1	PCK Estate, Chandanappally	1965	RBD	3	25	Concluded	10	16	Joseph et al.1986,1992
CT2	CES, Chethackal	1968	RBD	3	25	Concluded	10	15	Joseph et al. 1991
CT3	CES, Chethackal	1968	RBD	3	25	Concluded	10	15	Mercykutty et al. 1995
CT4	CES, Chethackal	1971	RBD	3	25	Concluded	10	15	Unpublished
CT5	CES, Chethackal	1973	RBD	3	25	Concluded	10	15	Unpublished
CT6	CES, Chethackal	1976	RBD	3	25	Concluded	10	13	Joseph and Premakumari, 1987
CT7	CES, Chethackal	1981	RBD	3	25	Concluded	10	13	Unpublished
CT8	RRS, Agartala[a]	1979	CRD	40	*Single tree plot*	Ongoing	12	13	Priyadarshan et al. 2000

PCK: Plantation Corporation of Kerala, CES: Central Experiment Station of the Rubber Research Institute of India, RBD: Randomized block design, CRD: Completely randomized design, RRS: Regional Research Station of the Rubber Research Institute of India in the North East India under the non-traditional zone.

[a]Three lowest yielding clones were excluded from analysis

controls the location of the point of inflection. Before choosing this model, many models were fitted to the data and it was found that in general MMF model fitted most of the data well, was easy to fit, fit statistics were robust and provided a discernible upper asymptote in most of the curves. Curve fitting was carried out using the software CurveExpert (version 1.38, http://curveexpert.webhop.biz). To exemplify understanding of the approach, graphs of fitted curves were drawn only for the top three clones of each trial. The first derivative of the fitted curve, dy/dx was worked out and the year of maximum dy/dx which is the time of highest increase in annual yield, was noted as the beginning of yield decrease and stabilization.

Correlation approach

Pearson's bivariate correlations were worked out between mean yield of all the years of tapping and progressively moving cumulative mean yield at different years of tapping. The correlations were worked out separately for each trial.

Decision approach

In this approach, starting from the third year of tapping, clones were selected based on progressively moving mean yield and the success rate for the selection of high yielding clones that would have been selected after 13–16 years of yield recording was worked out. Two methods of working out success rates namely, SR1 and SR2 were implemented. SR1 was worked out by unequal weighting of selections on a scale of 1–3 and the results were then converted to success rate. To differentiate the clone in weighting, ranks of the selections were reversed into their weightings. Thus the first, second and third ranked clones were assigned a weighting of three, two and one respectively. Other clones were weighted zero and hence did not contribute to success rate even if they were selected in a particular year. SR2 was worked out by equally weighting the top three clones with one and weighting the other clones with zero. Success rate was calculated as:

$$\text{Success rate} = \frac{\text{Actual total score due to selections in a chosen year}}{\text{Maximum total score that is achievable}} \times 100$$

Results

Graphs of fitted curves exhibited a discernible upper asymptotic phase in most of the clones (Fig. 1). The MMF model fitted the data well in majority of the cases. In general, high yielding clones gave better fits, while the low yielding clones showed dispersed scatter of yield points with poor fit parameters. Year of tapping at maximum d*y*/d*x* varied from 2 to 8 years (Table 2). The mean maximum d*y*/d*x* among the trials ranged from 2.5 to 7.0 years of tapping. Maximum d*y*/d*x* was observed at four years in the trials CT3, CT4, CT5, and CT6, at five in CT7, at six in CT2, at seven in CT1 and at eight in CT8.

In the initial years of tapping, bivariate correlations worked out between mean yield over all the years of tapping and the cumulative mean yield over three to 10 years of tapping varied among the trials (Table 3). The correlations

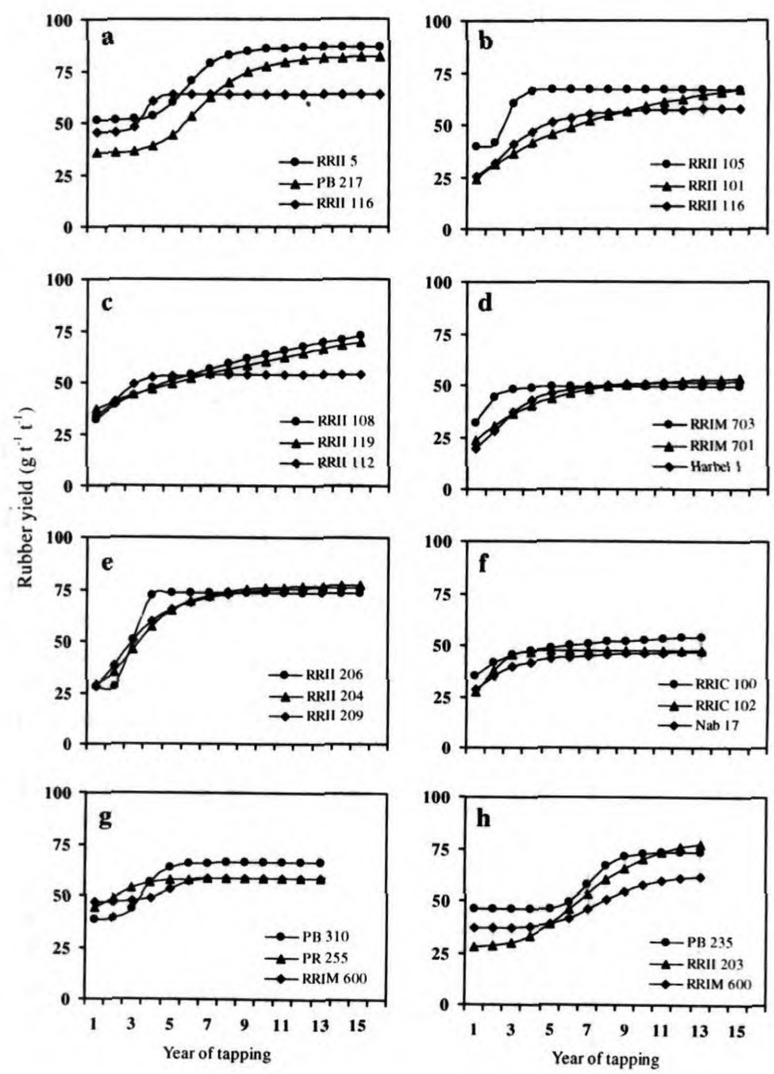

Fig. 1 Fitted curves of top three clones of trials CT1 to CT8 (**a**): CT1, (**b**): CT2, (**c**): CT3, (**d**): CT4, (**e**): CT5, (**f**): CT6, (**g**): CT7, (**h**): CT8

Table 2 Year of tapping at maximum dy/dx in different clones of *Hevea*

Clone[a]	Trial code							
	CT1	CT2	CT3	CT4	CT5	CT6	CT7	CT8[b]
1	6	3	2	2	3	2	4	7
2	7	2	2	2	3	2	3	7
3	4	3	3	3	3	2	5	8
4	5	5	4	4	4	2	3	7
5	6	5	3	2	3	4	4	3
6	5	2	NA	4	3	5	5	8
7	7	2	3	2	3	3	3	8
8	5	2	2	2	4	2	4	7
9	6	6	3	2	3	2	2	8
10	3	3	3	2	3	5	3	7
Mean	5.4	3.3	2.7	2.5	3.2	2.9	3.6	7.0

[a] In each trial clones are different

NA: It was not possible to work out the dy/dx values

[b] Three lowest yielding clones from this trial were excluded from analysis

Table 3 Simple correlation coefficients between mean yields over all the years of tapping with the cumulative mean yield over 3–10 years

Trialcode	Completed year of tapping							
	3	4	5	6	7	8	9	10
CT1	–0.19[ns]	–0.08[ns]	–0.07[ns]	0.42[ns]	0.53[ns]	0.64*	0.78**	0.87**
CT2	0.90**	0.92**	0.94**	0.96**	0.97**	0.98**	0.98**	0.98**
CT3	–0.15[ns]	0.03[ns]	0.22[ns]	0.59[ns]	0.64[ns]	0.77**	0.86**	0.92**
CT4	0.65*	0.71*	0.77**	0.81**	0.86**	0.88**	0.92**	0.96**
CT5	0.78**	0.91**	0.90**	0.95**	0.96**	0.98**	0.98**	0.99**
CT6	0.83**	0.84**	0.82**	0.90**	0.93**	0.95**	0.96**	0.98**
CT7	0.32 [ns]	0.40**	0.56[ns]	0.67*	0.80**	0.87**	0.90**	0.95**
CT8	0.86**	0.91**	0.92**	0.93**	0.95**	0.97**	0.98**	0.99**

$^*P < 0.05$; $^{**}P < 0.01$; ns = not significant

progressively increased with the advancing year of tapping. In trials CT2, CT5, CT6, and CT8, they were highly significant as soon as at year 3. A higher level of significance was achieved at year 5 for trial CT4, at year 7 for trial CT7, at year 8 for trial CT3, and at year 9 for trial CT1. Correlations observed in the early years of tapping did not show consistency across clone trials but they improved progressively from 6th year onwards culminating in highly significant values from 8th year of tapping.

In the decision approach, success rate achieved by SR1 method in selecting the three top clones by applying selection at different completed year of tapping (Table 4) was less than 70% at 3rd, 4th and 5th year of tapping. From sixth year of tapping, a success rate of more than 87% was observed. The success rate achieved in SR2 method was though similar to SR1, the values were slightly lower (Table 5). Individual probabilities of selecting the top three clones were identical in both SR1 and SR2. Probability of unselecting the top yielders in the 3rd, 4th and 5th year of tapping was very high with 13–37.5%. From sixth year onwards probability of unselecting the first ranker was nil while that of second and the third rankers was 25%. By the seventh year of tapping chances of loosing the third ranker was considerably lower (13%) while that of second ranker was still considerably higher (25%). In general, top yielding clones consolidated their position by the fourth year of tapping

Table 4 Success rate (probability) achieved in selecting the three top yielding clones at different completed years of tapping by unequal weighting (SR1) of selections

Trial code	Total years of data	Top clones	Yield(g t-1 t-1)[a]	Weighting	Completed year of tapping at selection							
					3	4	5	6	7	8	9	10
CT1	16	RRII 5	74.1	3	3	3	3	3	3	3	3	3
		PB 217	63.0	2	0	0	0	2	2	2	2	2
		RRII 116	60.3	1	0	1	1	1	1	1	1	1
CT2	15	RRII 105	62.7	3	3	3	3	3	3	3	3	3
		RRII 101	51.2	2	0	0	0	0	0	0	0	0
		RRII 116	50.8	1	1	1	1	1	1	1	1	1
CT3	15	RRII 108	56.9	3	0	0	3	3	3	3	3	3
		RRII 119	55.3	2	0	0	0	2	2	2	2	2
		RRII 112	51.2	1	1	1	1	1	1	1	1	1
CT4	15	RRIM 703	47.7	3	3	3	3	3	3	3	3	3
		RRIM 701	45.3	2	2	2	2	2	2	2	2	2
		Harbel 1	45.3	1	0	0	0	0	1	1	1	1
CT5	15	RRII 206	65.8	3	0	0	3	3	3	3	3	3
		RRII 204	65.6	2	0	0	0	0	0	0	0	0
		RRII 209	65.5	1	1	1	0	1	1	1	1	1
CT6	13	RRIC 100	49.0	3	3	3	3	3	3	3	3	3
		RRIC 102	44.8	2	2	2	2	2	2	2	2	2
		Nab 17	42.7	1	0	0	0	0	1	1	1	1
CT7	13	PB 310	58.7	3	0	0	0	3	3	3	3	3
		PR 255	54.7	2	0	2	2	2	2	2	2	2
		RRIM 600	54.0	1	1	1	0	1	0	0	0	0
CT8	13	PB 235	57.4	3	3	3	3	3	3	3	3	3
		RRII 203	52.0	2	0	0	2	2	2	2	2	2
		RRIM 600	47.5	1	1	1	1	1	1	1	1	1
Selection		Rankers selected	Total score for probability calculation		Probability of selecting the top yielders							
Individual		1	24		62.5	62.5	87.5	100.0	100.0	100.0	100.0	100.0
		2	16		25.0	37.5	50.0	75.0	75.0	75.0	75.0	75.0
		3	8		62.5	75.0	50.0	75.0	87.5	87.5	87.5	87.5
Combined		1 + 2	40		47.5	52.5	72.5	90.0	90.0	90.0	90.0	90.0
		1 + 2 + 3	48		50.0	56.3	68.8	87.5	89.6	89.6	89.6	89.6

[a] g/t/t: Grams per tree per tap

while the other two rankers kept on changing their positions before consolidating their respective rankings. From both the methods of calculating success rates it can be observed that at least six years of yield recording is necessary for getting the maximum increase in success rate (Fig. 2).

Discussion

Graphical approach (d*y*/d*x* approach) to delineate the year of maximum yield increase indicated the necessity of yield recording for a period of three to seven years. The variability observed in year of maximum d*y*/d*x* in the trials indicated that the different clones exhibited different yield patterns along time. The higher mean year of maximum d*y*/d*x* noted for trial CT8 can be attributed to the particular climatic conditions in that non traditional zone for rubber cultivation, with low temperatures that determine slow growth and slow yield increase after tapping (Vijayakumar et al. 2000). Another reason could be that the clones might be slow starters. Higher mean d*y*/d*x* may not be of significance because, selecting clones that perform better in later years

Table 5 Success rate achieved in selecting the three top yielding clones at different completed years of tapping by equal weighting (SR2) of selections (Weighting = 1)

Rankers selected	Total score for probability calculation	Completed year of tapping at selection							
		3	4	5	6	7	8	9	10
		No. of times a ranker is selected out of 8 trials							
1	–	5	5	7	8	8	8	8	8
2	–	2	3	4	6	6	6	6	6
3	–	5	6	4	6	7	7	7	7
		Probability of selecting clones individually							
1	8	62.5	62.5	87.5	100.0	100.0	100.0	100.0	100.0
2	8	25.0	37.5	50.0	75.0	75.0	75.0	75.0	75.0
3	8	62.5	75.0	50.0	75.0	87.5	87.5	87.5	87.5
		Probability of selecting clones in combination							
1 + 2	16	43.8	50.0	68.8	87.5	87.5	87.5	87.5	87.5
1 + 2 + 3	24	50.0	58.3	62.5	83.3	87.5	87.5	87.5	87.5

of tapping is a discarded objective in *Hevea* breeding. The correlation approach indicated that 6–7 years of yield recording were sufficient for a good prediction of the yield potential of the clones. Decision approach was different from the other two in that it focussed not only on the yield evaluation of all the clones but also on the selection of three top-rankers. This approach provided more clarity. Two methods of working out success rates gave very similar results. Success rates obtained for individual selections were identical in both SR1 and SR2, but for combination of clones the values were slightly lower in SR2 indicating not much sensitivity of the weighting system used. The results from the two success rates indicated that at least six years of yield recording is necessary for getting the maximum increase in success rate.

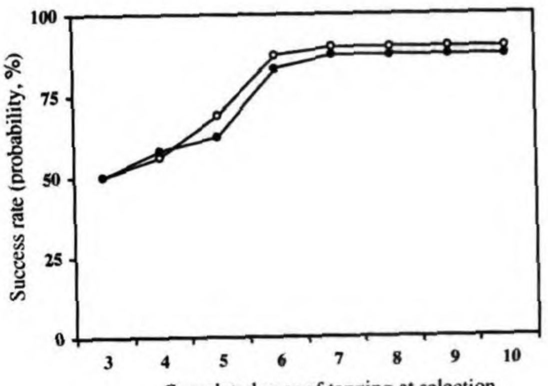

Fig. 2 Probability of selection of the three top yielding clones at different completed years of tapping following two success rates, SR1 (○) and SR2 (•)

From all the three approaches, it can be concluded that six years of yield recording would be required for optimising selection of top yielding clones from large-scale clone trials. However, additional two or more years of yield recording would be necessary for selecting high yielding and slow starter clones. In order to bring out more pipeline clones to limelight, it is necessary to shrink the breeding cycle so that more potential clones can be carried forward to onfarm trials. Therefore, 6 years of yield recording appears to be a reasonable trade-off and worth risk-taking. It should be noted here that secondary characters like, susceptibility to wind, diseases and tapping panel dryness are also of high importance. Six years of observations may not be sufficient to score the clones for these traits. The observations on these should be based on long duration data either from block plantings or from onfarm trials. Often it is possible that more than three clones will have similar yield data with negligible difference. In such situations discerning judgment is needed before rejecting the lower ranked clones.

In the current practice, potential selections from the nursery level screening are pushed through two levels of field experimentation namely small-scale and large-scale clone trials for better efficiency in selection. Though efficiency of selection can be improved by many methods, every programme will have to decide empirically whether the gain is worth the cost in space and labour. In the small-scale trials though the genotypic differences are confounded with competitive effects, selection practiced could be as much for competitive ability as for the desired performance in pure stand. On the other hand the larger plots can be more accurate to a degree depending on soil heterogeneity but are expensive and they compromise the degree of replication and hence the control of error (Simmonds 1979). Thus, only one stage of field experimentation appears to be a more prudent practice both from the point of view of selecting potential clones which are worth passing forward to onfarm trials and to shorten the total breeding cycle of *Hevea brasiliensis*.

As breeding cycle of *Hevea* is long and many different stages of trials will be running at a given time, land is also a limiting constraint for field experimentation. Therefore, it is necessary to shorten the selection duration and organize the different selection stages for adapting to this constraint. To this end, clonal nurseries appear to provide the best way out as they offer the opportunity of screening a large number of clones with wide genetic variability at high density on a small area. Selections from clonal nurseries can then either be planted in small-scale or on large-scale trials. In small-scale trials, yield recording is not advisable for more than 3 to 4 years due to the risk of development of competition effects. Thus only one stage of experimentation in large-scale trials with medium sized plots and six years of yield recording appears to be a better alternative. Feasibility of such a scheme would require a thorough research on juvenile-mature correlations.

Acknowledgements We express our sincere thanks to Dr. N. M. Mathew, Director of Research of the Rubber Research Institute of India for the encouragement to this study and to Dr. K. U. K. Nampoothiri, former Director of the Central Plantation Crops Research Institute, Kasaragod who as an expert of the annual review process of the crop improvement programs of the Rubber Research Institute of India, brought up the matter and motivated us to take up this study. Thanks are also due to Mr. K. K. Vinod, Scientist-C, for his suggestions and help in revising the manuscript for incorporating the referees' suggestions.

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