HEVEA BRASILIENSIS: RESULTS FROM THE CAMBODIAN LARGE SCALE CLONE TRIALS IN 2011

Phen Phearun[1], Kong Mengchheang[1], and A. Clément-Demange [2]

1. Cambodian Rubber Research Institute (CRRI)
9, Penn Nuth Blvd., P.O. Box: 1337, Phnom Penh, Cambodia

2. CIRAD, UMR AGAP 1334 – TA- A108/03 – Av Agropolis
34398 Montpellier Cedex 5 - France

ABSTRACT

In order to update the clonal recommendations in Cambodia, a set of 14 Large Scale Clonal Trials (LSCT) was analysed globally for 36 clones, based on linear adjustments of the data from each trial. Although this method was statistically not very powerful, it made possible to compare all the clones between each other, whatever the trials in which they were set. Among the 36 clones, the adjusted mean girth at opening varied from 41 cm (RRIC102) to 52 cm (PB235), with a medium group of 20 clones (including GT1) varying from 46 cm to 48 cm. The cumulated yield over the first 7 years of tapping (Cum1-7) varied from 5279 kg/ha (K2) to 14935 kg/ha (IRCA130).

The ranking of the clones by decreasing girth at opening was as following : PB235, PB330, IRCA130, IRCA209, PB280, IRCA111, KV4, IRCA230, TJIR1, PR261, IRCA209, PB310, PB254, GT1, AVROS208, PB255, PB260, RRIC121, IRCA18, RRIM600, RRIC101, RRIM712, PB314, PB217, KHA9, PR306, BPM24, PR303, PR255, K2, IRCA41, PR300, PR107, PB324, PB86, and RRIC102.

The ranking of the clones by decreasing cumulated yield over 7 years of tapping (Cum1-7) was as following : IRCA130, PB235, KV4, RRIC101, IRCA109, PB314, RRIM712, PB280, PB260, IRCA230, RRIM600, PB330, PB310, PR303, IRCA111, RRIC121, PB255, IRCA41, PB254, PB217, PR300, PR255, BPM24, IRCA18, PR306, IRCA209, PB324, GT1, PB86, KHA9, PR261, PR107, RRIC102, AVROS308, TJIR1, and K2.

The relationships between girth at opening and yields were examined, and a method was carried out for making cumulated yields independent from girth at opening (Cum1-7reg). However this correction had important effects only for the two extreme clones PB235 (highest vigour) and RRIC102 (lowest vigour). There was a good correlation between the initial yield of the first four years (Cum1-4) and the later yield from year 5 to year 7 (Cum5-7) with R^2 = 0.40. Girth at opening partly explained the initial yield (R^2 = 0.37), but its correlation with the later yield was non significant (R^2 = 0.09).

Initial yield was generally higher than later yield for high-yielding clones, and the opposite was found for low-yielding clones. By decreasing order of Cum1-7, the clones with initial yield higher than later yield were IRCA130, PB235, RRIC101, PB314, PB280, PB260, IRCA230, IRCA111, PB255, IRCA18, and IRCA209 (group A, quick-starters). The clones with initial yield equivalent to later yield were KV4, IRCA109, RRIM712, RRIM600, PB330, PB310, IRCA41, PB254, PB217, PR300, PR255, BPM24, GT1, PB86, and PR261 (group B). The clones with later yield higher than initial yield were PR303, RRIC121, PR306, PB324, KHA9, PR107, RRIC102, AVROS308, TJIR1, and K2 (group C). These results were submitted to a critical discussion for application to clonal recommendations.

Keywords : Hevea brasiliensis, Cambodia, rubber, clones, Large Scale Clonal Trials, growth, yield.
Contact : phearun_phen@yahoo.com

INTRODUCTION

Rubber development in Cambodia was restarted in the 1980s'. In 1995, it was made of industrial estates in the Kampong Cham region, with the three clones GT1, PR107, and PB86 covering most of a total area of 46 000 ha, and RRIM600 being initiated. Since then, a smallholding programme was developed, first with the clone GT1. With the fast development of the last ten years, there is now more than 180 000 ha under rubber in Cambodia. For the next ten years, an objective of 300 000 ha is planned over the traditional region and other less favorable provinces as well. This was anticipated by the introduction of new clones and the development of clonal experimentation so that genetic progress can contribute to the improvement of the performances of rubber cropping in Cambodia. For preparing clonal diversification in smallholdings, a network of tests was set in varied locations with the clones GT1, RRIM600, PB260, and IRCA18. One first Large Scale Clonal Trial (LSCT) was set in 1986, and a total number of 20 LSCT were set since 1995, at the experimental center of CRRI and in industrial estates, for assessing the performances of about 50 different clones. Each year, these trials generate new information for updating clonal recommendations in Cambodia. Here are presented the main results from the 14 LSCTs for which a number of 7 years of tappings or more are still available.

MATERIAL AND METHODS

Ecological conditions

The 14 trials presented here were planted in 1986 (1 trial) and then from 1995 to 1999 (table 1). They are located at CRRI and in the estates of Chup and Krek (latitude 12 °N, longitude 105 °E), in the Kampong Cham province. The mean annual rainfall of the last 10 years was of 1398 mm, varying from 986 mm to 1678 mm, with two seasonal maxima in May-June and September-October. Although the dry season may count up to 5 months with monthly rainfall lower than 50 mm, the deep red soils of this region ensure a good water storage and availability to the rubber trees. Minimal temperatures, almost always higher than 15 °C, cannot be considered as a limiting factor. Until recently, no wind damage was observed, but this may be attributed to the ages of rubber plantations which were predominantly out of the critical period of rubber susceptibility to wind damage (assumed to be between 8- and 15-year old). In July 2009, after complete renewal of the old plantations in Cambodia, a storm was responsible for some damages, notably on the clone PB235. This can be considered as a signal that susceptibility to wind damage should be included in the set of criteria to be taken into account for clonal recommendations in Cambodia. Susceptibility to Tapping Panel Dryness (TPD, including the simple tapping cut dryness and/or brown bast) varies among the clones. The two main fungus diseases are pink disease (*Corticium salmonicolor*) and *Oïdium heveae*. Although some small symptoms of *Corynespora cassiicola* were observed in budwood gardens, it can be noticed that no real attack was observed in Cambodian plantations so far.

Plant material

The 36 clones studied in these trials (table 1) are issued from Indonesia (GT1, TJIR1, AVROS308, PR107, PR255, PR261, PR300, PR303, PR306, BPM24), from Sri-Lanka (RRIC101, RRIC102, RRIC121), from Malaysia (RRIM600, RRIM712, PB86, PB217, PB235, PB254, PB255, PB260, PB280, PB310, PB314, PB324, PB330), from Côte d'Ivoire (IRCA18, IRCA41, IRCA109, IRCA111, IRCA130, IRCA209, IRCA230), from Vietnam (KV4, also called VM515), and from Cambodia (KHA9, K2).

Table 1 Characteristics of the 14 Large Scale Clonal Trials. Year of planting, year of opening, and names of the clones.

Trials	Planting	Opening	Clones
CH0	1986	1993	GT1, KV4, PB86, PB235, PB255, PB310, PB324, PR107, RRIC102, RRIC121, RRIM600
KR1	1995	2005	GT1, IRCA18, PB217, PB260, PB280, PB254
KR2	1995	2005	GT1, IRCA111, IRCA130, IRCA230, IRCA41, PR107
KR4	1995	2005	GT1, PB314, PB330, RRIC101, RRIM712
KR5	1996	2005	GT1, K2, PB255, PR261, RRIM600
CH1	1996	2002	GT1, PB86, PB217, PB235, PB260, PB280, PB314, PB330
CH2	1996	2002	GT1, IRCA111, IRCA130, IRCA230, IRCA41, IRCA18, RRIC101
CH3	1996	2002	GT1, PB310, PR107, PR255, PR300, PR303, PR306
CH4	1996	2002	GT1, AVROS308, BPM24, KHA9, KV4, RRIM600, RRIM712, TJIR1
IR1	1996	2002	GT1, IRCA111, IRCA130, IRCA18, PB235, PB260, PB280, PB330
IR2	1996	2002	GT1, PR107, PR255, PR300, PR303, PR306, RRIC101, RRIM600
IR3	1997	2004	GT1, IRCA109, IRCA209, IRCA230, IRCA41, PB217, PB254, PB314
IR4	1997	2004	GT1, BPM24, IRCA209, K2, PR261, RRIM712
IR5	1999	2005	GT1, IRCA41, KV4, PB310, PB324, RRIC121

Design of the experiments, selection traits and statistical methods

Each LSCT had from 6 to 12 different clones, including GT1 as one common control. The design was a Random Complete Block Design (RCBD), with four complete blocks. Each clonal plot was made of at least 75 budded trees. The planting design was of 6 x 3 meters (555 trees per ha). The girths of the trunks were measured every year, at 1-m high before opening, and at 1.70-m high after opening. Opening was carried out on the same year for all the clones in each trial, but only for the trees with a girth higher than 50 cm at 1-m high. The other trees were opened 6 or 12 months later when reaching the tappable size. The tapping system was ½ S d/3 7d/7 ET 2.5 %, Pa 1(1) 6/y with continuous tapping on panel A for 6-year long.

To measure latex yields, daily fresh latex in each plot was measured. Cup lumps were collected and weighed the day after. Cumulated yields were calculated every month. Dry Rubber Content (DRC) of the latex was determined gravimetrically in each block by use of a densitometer at each tapping. DRC of the cup lumps was measured for a bulk in each treatment. Dry rubber yield in kg/ha was calculated for each plot and each year of tapping; this type of yield is considered as the best yield indicator for the comparison of clones in LSCT. As a matter of fact, yield per tree (gram/tree/year, or gram/tree/tapping) can easily be calculated but it is negatively correlated with the density of living trees, which makes direct comparisons among the clones more difficult. Based on annual census of the trials, the density of tapped trees per ha was determined each year in each plot, in order to appreciate the future yield potentials of the clones in the trials.

For girth at opening and annual yields in kg/ha/year, a global analysis was carried out among the 14 trials, based on linear adjustments of the data from each trial. Each trial was considered as one incomplete block in one global experiment. This was made possible by the presence of clones common to 2, 3 or 4 different trials, and of the clone GT1 used as control in each trial. The adjusted mean results for each clone were estimated by use of the Lsmeans procedure of SAS statistical software (least square method). As a result, the standard errors of the adjusted means (such as presented for girth at opening in table 2) depended on the number of trials for each clone, and this standard error was logically the lowest for GT1 (included in all the trials). Due to the large differences among the trials, the power of the "global experiment" (or the ability to detect statistically significant differences among the clones) was rather limited. However this method allowed us to generate tables for direct comparisons among all the 36 clones for girth at opening and for each annual yield in kg/ha/year from year 1 (Y1) to year 7 (Y7). From these adjusted yield data, cumulated yields in kg/ha were calculated from Y1 to Y7 (total cumulated yield Cum1-7), from Y1 to Y4 (initial yield Cum1-4), and from Y5 to Y7 (later yield Cum5-7). The relationship between girth at opening and the yields was examined. A general regression equation was found, predicting yield from girth at opening, and the differences between the real yield of each clone and the yield predicted by the equation were used for estimating corrected yields Cum1-7reg. These corrected yields had the property of being independent from the differences in girth at opening among the clones.

For a global comparison of the 36 clones, weighted indexes were calculated based on a set of coefficients and on the scoring of each clone for the following characteristics: Yield Cum1-7 (coefficient 8), group A, B, or C (coefficient 1), level of knowledge of each clone (coefficient 1), girth at opening (coefficient 3), girth increment during tapping (coefficient 3), susceptibility to TPD (coefficient 2) and to wind damage (coefficient 2). Scoring was from 5 (good level) to 1 (bad level).

$$\text{Weighted index} = \sum (\text{coefficient x score})$$

The coefficients were designed for a theoretical maximum index (for all scores = 5) equal to 100.

RESULTS

Growth

Table 2 shows the adjusted mean girth at opening in decreasing order for the 36 clones. Among them, the adjusted mean girths at opening varied from 41.37 cm (RRIC102) to 52.38 cm (PB235), with a medium group of 20 clones (including GT1) varying from 46 to 48 cm. The standard errors of the mean girths varied from 0.37 cm (GT1 present in the 14 trials) to 1.67 cm (TJIR1, AVROS308, KHA9 which were present in only one trial), depending on the number of trials for each clone (from 1 to 4, apart from GT1).

With a Type-I error $\alpha = 0.05$, only PB235 was significantly higher than GT1, and only PB86 and RRIC102 were significantly lower than GT1. If we admit a Type-I error $\alpha = 0.30$, the clones in group 1 (PB235, PB330, IRCA130, IRCA209, PB280, and IRCA111) can be considered as higher than GT1, and the clones in group 3 (BPM24, PR303, PR255, K2, IRCA41, PR300, PR107, PB324, PB86, and RRIC102) can be considered as lower than GT1. In the medium group 2, 19 clones cannot be considered as significantly different from GT1 (with $\alpha = 0.30$).

The ranking of the clones by decreasing girth at opening was as following : PB235, PB330, IRCA130, IRCA209, PB280, IRCA111, KV4, IRCA230, TJIR1, PR261, IRCA209, PB310, PB254, GT1, AVROS208, PB255, PB260, RRIC121, IRCA18, RRIM600, RRIC101, RRIM712, PB314, PB217, KHA9, PR306, BPM24, PR303, PR255, K2, IRCA41, PR300, PR107, PB324, PB86, and RRIC102.

Table 2 Adjusted means of the girth at time of opening (cm). Standard errors. P-values of the comparison of each clone with GT1 for girth.

Group	Clones	Adjusted mean girth	Standard error	p-value / GT1
1	PB235	52.38	0.92	<.0001
	PB330	49.06	0.96	0.0616
	IRCA130	48.84	0.81	0.0566
	IRCA209	48.61	1.16	0.2215
	PB280	48.52	0.96	0.1721
	IRCA111	48.42	0.95	0.1998
2	KV4	48.00	0.96	0.3840
	IRCA230	47.75	0.81	0.4702
	TJIR1	47.39	1.67	0.8642
	PR261	47.35	1.22	0.8480
	IRCA109	47.31	1.14	0.8635
	PB310	47.21	0.96	0.9127
	PB254	47.15	1.16	0.9654
	GT1	47.10	0.37	1.0000
	AVROS308	47.09	1.67	0.9969
	PB255	47.09	1.17	0.9919
	PB260	46.96	0.83	0.8768
	RRIC121	46.95	1.17	0.9061
	IRCA18	46.88	0.82	0.8075
	RRIM600	46.83	0.65	0.7194
	RRIC101	46.81	1.15	0.8096
	RRIM712	46.80	0.83	0.7383
	PB314	46.68	0.96	0.6807
	PB217	46.60	0.73	0.5409
	KHA9	46.59	1.67	0.7677
	PR306	46.03	1.22	0.4056
3	BPM24	45.74	1.20	0.2821
	PR303	45.68	1.22	0.2706
	PR255	45.58	1.22	0.2386
	K2	45.55	1.22	0.2267
	IRCA41	45.49	0.72	0.0514
	PR300	45.38	1.22	0.1830
	PR107	45.34	0.83	0.0574
	PB324	45.25	1.17	0.1384
	PB86	44.39	1.13	0.0265
	RRIC102	41.37	1.60	0.0009

Latex yield

Table 3 shows the adjusted mean yields per clone for each year of tapping (from year Y1 to Y10). The cumulated yield over the first 7 years of tapping (Cum1-7) varied from 5279 kg/ha (K2) to 14935 kg/ha (IRCA130). The ranking of the clones by decreasing cumulated yield over 7 years of tapping (Cum1-7) was as following : IRCA130, PB235, KV4, RRIC101, IRCA109, PB314, RRIM712, PB280, PB260, IRCA230, RRIM600, PB330, PB310, PR303, IRCA111, RRIC121, PB255, IRCA41, PB254, PB217, PR300, PR255, BPM24, IRCA18, PR306, IRCA209, PB324, GT1, PB86, KHA9, PR261, PR107, RRIC102, AVROS308, TJIR1, and K2.

The average yield among all the clones was increased from 857 kg/ha/year in the first year of tapping to 2036 kg/ha/year in the ninth year of tapping. The highest yield (2706 kg/ha) was achieved by the clone KV4 in Y9. The coefficient of variation of the yield in Y1 was high (43 %), then it decreased down to 12 % in Y10.

Table 3 Adjusted means of the yield for the first 10 years of tapping (kg/ha/year). Cumulated yield of the first 7 years (Cum7). Yield after correction of the effect of the girth (Cum7-reg).

Clones	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Cum7	Cum7-reg
IRCA130	1807	2376	2553	2141	1955	1944	2159	1316	1685		14935	13723
PB235	1720	1770	2186	2318	1827	1909	1981	1366	1847	1645	13711	10358
KV4	1238	1508	2022	2287	2115	2251	2182	2451	2706	2113	13602	12897
RRIC101	1702	1758	1580	1839	1721	1933	1910	1591	2088		12443	12461
IRCA109	827	1387	1881	1790	1791	2004	2089				11769	11484
PB314	1241	1836	1784	1824	1555	1628	1876	1417			11745	11842
RRIM712	955	1421	1688	1831	1635	2065	2016				11611	11635
PB280	1243	1642	1824	1793	1712	1761	1617	1643	2310		11592	10574
PB260	1125	1474	1717	1910	1575	1731	1887	1471	1849		11420	11345
IRCA230	1050	1519	1703	1899	1703	1788	1699	1269			11362	10809
RRIM600	773	1113	1522	1950	1806	2023	2090	1938	2340	1745	11278	11282
PB330	991	1272	1486	1893	1786	1899	1924	1453	1893		11251	9906
PB310	979	1135	1555	1959	1667	2102	1841	1982	2477	2389	11237	11009
PR303	594	1118	1477	1813	1843	1958	2067	1832	2264		10871	11570
IRCA111	1233	1416	1656	1642	1570	1595	1627	1381	1945		10738	9781
RRIC121	706	974	1372	1517	1868	1934	2309	2041	2374	1972	10681	10609
PB255	758	1474	1880	1966	1630	1356	1604	1654	1734	1601	10669	10517
IRCA41	662	1184	1571	1830	1741	1796	1823	1553			10607	11423
PB254	798	1124	1495	1728	1474	1856	2076				10551	10359
PB217	674	1266	1546	1736	1560	1811	1855	1608			10447	10592
PR300	670	1370	1478	1665	1556	1810	1767	1503	1966		10317	11198
PR255	576	1309	1626	1711	1627	1677	1730	1335	1853		10257	11017
BPM24	690	1435	1563	1688	1480	1744	1586				10186	10849
IRCA18	832	1437	1677	1765	1489	1390	1596	1321	1531		10185	10159
PR306	515	1071	1336	1791	1726	1900	1745	1649	2061		10083	10570
IRCA209	1038	1444	1562	1502	1221	1479	1835				10081	9010
PB324	688	915	1105	1482	1553	1950	1895	1795	2459	1944	9589	10547
GT1	736	1022	1267	1515	1441	1621	1726	1537	1892	1774	9329	9169
PB86	437	939	1264	1524	1405	1474	1652	1535	1927	2005	8695	10178
KHA9	400	685	958	1575	1426	1873	1714				8631	8778
PR261	599	913	1187	1433	1471	1526	1022				8151	7843
PR107	438	837	1075	1317	1296	1579	1572	1293	1601	1857	8114	9022
RRIC102	579	841	828	1191	1376	1396	1768	1511	1997	2074	7980	11287
AVROS308	880	676	633	1404	1154	1556	1643				7947	7791
TJIR1	396	550	512	1441	1168	1661	1628				7356	7019
K2	313	402	698	900	1022	1314	630				5279	6061
Mean	857	1239	1480	1710	1582	1758	1782	1594	2036	1920	10408	10408
Std	371	396	422	284	234	230	307	277	308	229	1875	1562
CV %	43	32	29	17	15	13	17	17	15	12	18	15

Table 4 shows the coefficients of correlation between yield traits. All the yield traits were correlated between each other, although with a decrease along time : Y1 was strongly correlated with Y2 (r = 0.84) but less correlated with Y6 (r = 0.34) or Y7 (r = 0.42).

Table 4 Coefficients of correlation between the adjusted mean girth at opening and the adjusted mean yields from year Y1 to Y7 (36 clones, df = 34. For α = 0.05, significance threshold rs = 0.32).

Variables	Girth at opening	Y1	Y2	Y3	Y4	Y5	Y6	Y7
Girth at opening	**1**	0.66	0.48	0.53	0.58	0.34	0.30	0.21
Y1	0.66	**1**	0.84	0.73	0.67	0.52	0.34	0.42
Y2	0.48	0.84	**1**	0.93	0.76	0.62	0.30	0.46
Y3	0.53	0.73	0.93	**1**	0.84	0.76	0.40	0.50
Y4	0.58	0.67	0.76	0.84	**1**	0.82	0.63	0.63
Y5	0.34	0.52	0.62	0.76	0.82	**1**	0.74	0.68
Y6	0.30	0.34	0.30	0.40	0.63	0.74	**1**	0.70
Y7	0.21	0.42	0.46	0.50	0.63	0.68	0.70	**1**

Relationship between the girth at opening and the cumulated yield

Among the 36 clones, the relationship between the girth at opening and each annual yield from Y1 to Y7 was examined (table 4). From Y1 to Y7, the coefficient of correlation decreased from r = 0.66 to r = 0.21, thus indicating a decreasing dependency of yield on the girth at opening with time. Figure 1 shows the linear correlation between the girth at opening and the cumulated yield Cum1-7 (R^2 = 0.31). However, after discarding on the one hand PB235, IRCA130, KV4 (vigorous and high-yielding), and on the other hand K2 and RRIC102 (poor in vigour and low-yielding), the correlation was no more significant (R^2 = 0.07). Whatsoever, an estimation of the cumulated yield independent from girth at opening was carried out (Cum1-7reg).

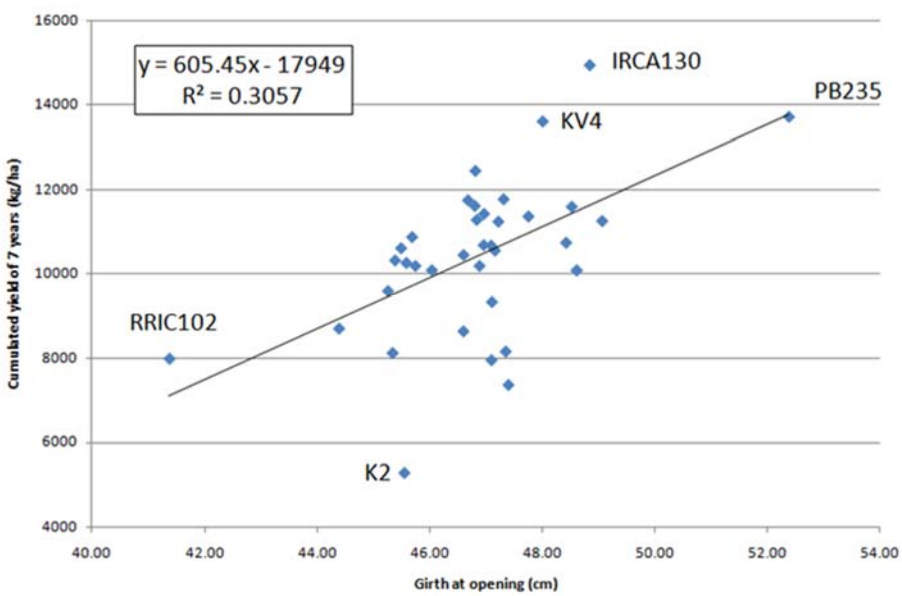

Figure 1 Relationship between the adjusted mean girth at opening (cm) and the cumulated yield Cum1-7 (kg/ha) for the 36 clones.

Figure 2 shows a high correlation between Cum1-7 and Cum1-7reg ($R^2 = 0.69$), thus indicating little effect of the correction on the ranking of the clones. In fact this correction had important effects only for the two extreme clones PB235 (highest vigour) and RRIC102 (lowest vigour). If we discard these two clones, we observe an increase of the coefficient of determination ($R^2 = 0.86$).

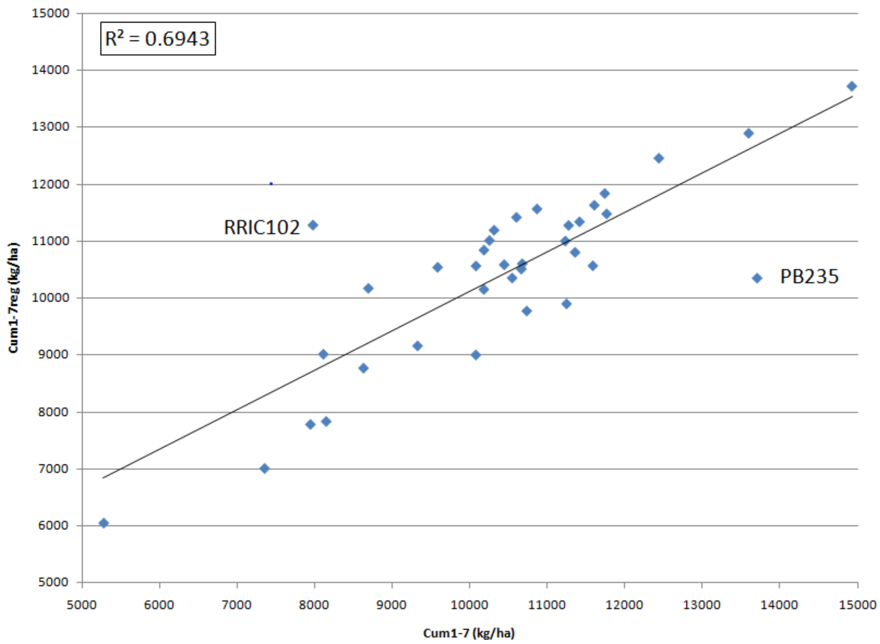

Figure 2 Correlation between the cumulated yield Cum1-7 and the cumulated yield Cum1-7reg corrected from the variations of girth at opening among the clones.

Initial yield and later yield

There was a good correlation between the initial yield of the first four years (Cum1-4) and the later yield from year 5 to year 7 (Cum5-7), with $R^2 = 0.40$. The girth at opening partly explained the initial yield ($R^2 = 0.37$), but its correlation with the later yield was non significant ($R^2 = 0.09$).

Figure 3 shows a comparison of the initial yield Cum1-4 with the later yield Cum5-7. From left to right, the clones are shown in decreasing order of the cumulated yield Cum1-7.

Initial yield was generally higher than later yield for high-yielding clones, and the opposite was found for low-yielding clones. By decreasing order of Cum1-7, the clones with initial yield higher than later yield were IRCA130, PB235, RRIC101, PB314, PB280, PB260, IRCA230, IRCA111, PB255, IRCA18, and IRCA209 (group A, quick-starters). The clones with initial yield equivalent to later yield were KV4, IRCA109, RRIM712, RRIM600, PB330, PB310, IRCA41, PB254, PB217, PR300, PR255, BPM24, GT1, PB86, and PR261 (group B). The clones with later yield higher than initial yield were PR303, RRIC121, PR306, PB324, KHA9, PR107, RRIC102, AVROS308, TJIR1, and K2 (group C). For clonal recommendations, attention was focused on the clones IRCA130, PB235, RRIC101, PB314, PB280, PB260 and IRCA230 (group A), on IRCA109, RRIM712, RRIM600, PB330, IRCA41, PB217 and GT1 (Group B), and on PR303, RRIC121, PR107, and RRIC102 (group C).

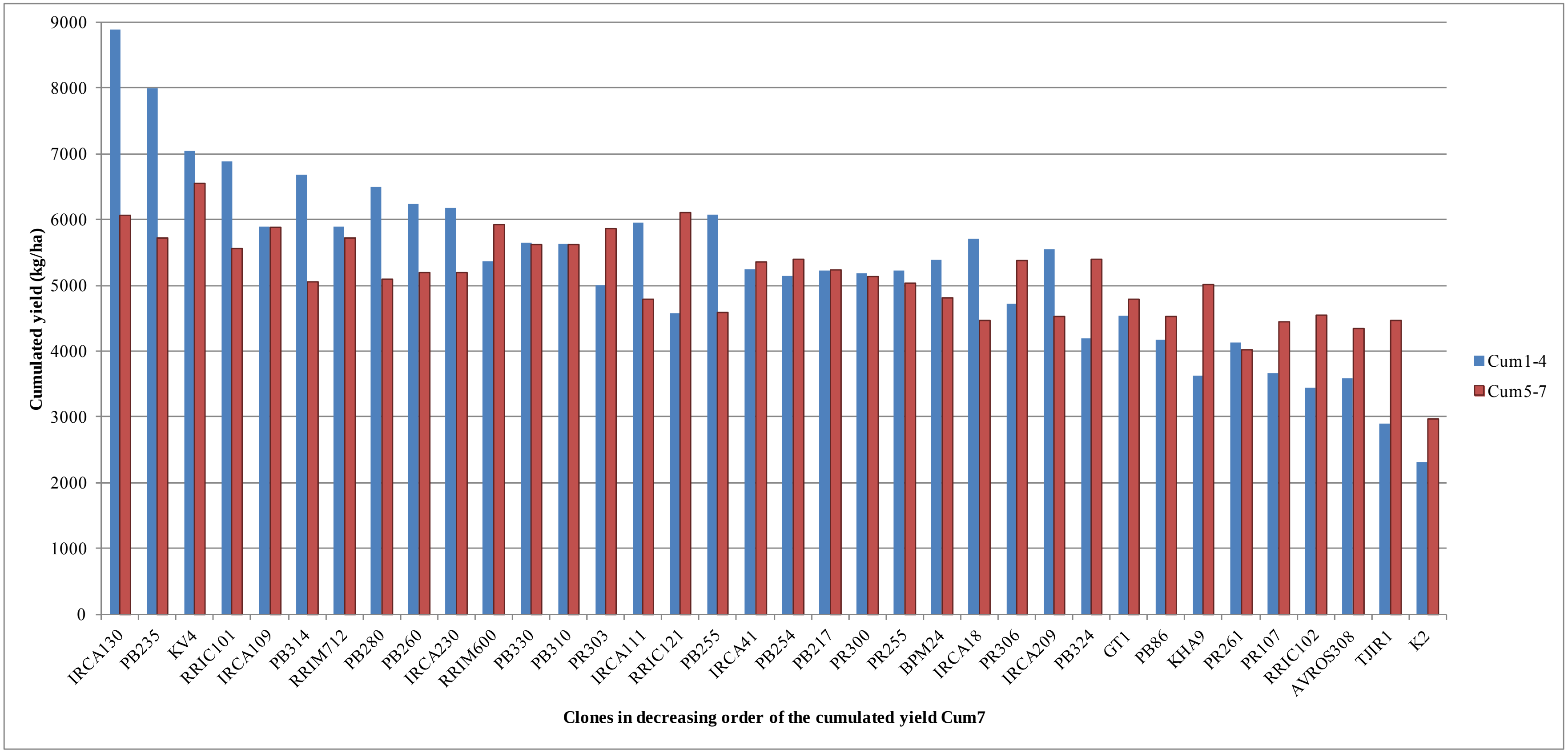

Figure 3 Comparison of the cumulated yield from year 1 to year 4 (Cum1-4) and from year 5 to year 7 (Cum5-7). From left to right, the clones are in decreasing order of the cumulated production Cum1-7.

Characterization of the clones

The 36 clones are hereafter presented by group (A, B, C), in decreasing order of their cumulated yield, with their number of trials of observation. For each clone, the yield Cum1-7 is presented in index of GT1 (for GT1 = index 100, Cum1-7 = 9329 kg/ha).

Group A

IRCA130 (3 trials, index 160) appeared vigorous and the highest yieIding clone, with a very high initial yield (group A). It was tall but strongly bented in some cases. Its girth increment during tapping was medium or good. It was highly susceptible to TPD. In Y8 and Y9, it showed an important decrease in yield. In Côte d'Ivoire it was found highly susceptible to wind damage.

PB235 (2 trials, index 147) was the most vigorous clone. Its very high yield was over-estimated by the influence of a high girth at opening. Its usually tall and straight aspect is very attractive. Its high susceptibility to TPD, wind damage, and Oïdium is well known.

RRIC101 (2 trials, index 133) had a medium vigour and a high yield. It showed a dense canopy and a very low girth increment during tapping. In Côte d'Ivoire, it was found susceptible to TPD and wind damage.

PB314 (3 trials, index 126) had a medium vigour, a high yield, a nice aspect although some trees broken by wind were observed. This clone is known as susceptible to wind damage. After 7 years of tapping, girth increment was high but the density of tapped trees was relatively low.

PB280 (3 trials, index 124) is vigorous and high yielding. It showed a very good girth increment during tapping. The trees showed their usual scratchy bark and slightly twisted trunks (due to the weight of branching). In trial IR1, PB280 was not affected by TPD but suffered from wind damage in 2009; susceptibility to Oïdium seemed low; in 2009 and 2010, its yield was increased. As a result, although classified in group A, PB280 may be able to maintain or increase its yield over time.

PB260 (3 trials, index 122) had a medium vigour and a high yield. It showed its usual tall and straight aspect, but with a low girth increment during tapping, a high susceptibility to TPD. Susceptibility to Oïdium seemed low. This clone is also known for its high susceptibility to wind damage and unfavorable environments.

IRCA230 (2 trials, index 122) had a medium vigour and a high yield. It showed a twisted trunk and a low girth increment during tapping.

IRCA111 (3 trials, index 115) had a good vigour and a good yield. It showed a straight trunk but rather heavy branching, a medium girth increment during tapping, but it was rather susceptible to TPD.

PB255 (2 trials, index 114) had a medium vigour and a good yield.

IRCA18 (3 trials, index 109) had a medium vigour, a medium yield, but a low girth increment during tapping and some susceptibility to TPD and Corticium. In IR1, after 10 years of tapping, it showed the lowest density of tapped trees, and its yield decreased with time.

IRCA209 (2 trials, index 108) had a good vigour, a good girth increment during tapping, and a medium yield. Trees were tall with heavy branching. This clone suffered from wind damage during the storm of July 2009, and its density of tapped trees after 7 years of tapping was relatively low.

Group B

KV4 (or VM515, 3 trials, index 146) was vigorous and very high yielding. Probably due to its high yield, its girth increment during tapping was very low. It had abundant branching and was strongly bented. It was highly susceptible to TPD.

IRCA109 (1 trial, index 126) had a medium vigour, a high yield, a nice aspect, and showed an increasing yield trend, but its girth increment during tapping was low.

RRIM712 (4 trials, index 124) had a medium girth at opening, a high yield, a low girth increment during tapping. After several years of tapping, it appeared as a small tree with a thin trunk.

RRIM600 (4 trials, index 121) had a medium girth at opening, a medium girth increment during tapping, a nice aspect, and a high yield with an increasing trend. It showed a low susceptibility to TPD. It seemed susceptible to Corticium in 2007.

PB330 (3 trials, index 121) had a high vigour, a very good girth increment during tapping, and a high yield. It had a medium susceptibility to TPD and a low susceptibility to Oïdium. The trees were tall and straight. In other environments, it was found very susceptible to wind damage.

PB310 (2 trials, index 120) had a medium girth at opening, a medium girth increment during tapping, and a high yield. It was found susceptible to wind damage. The trees were tall.

IRCA41 (3 trials, index 114) had a low girth at opening, a low girth increment during tapping, a good yield. It had thin and twisted trunks. In IR5 in 2010, it seemed susceptible to Oïdium.

PB254 (2 trials, index 113) had a medium girth at opening, a good girth increment during tapping, and a good yield. In IR3, it was bented by wind.

PB217 (3 trials, index 112) had a medium girth at opening, a medium girth increment during tapping, and a good yield. The trees had a medium aspect. In IR3, this clone lost many trees after planting and during growth before tapping. As a result, the density of tapped trees after 7 years of tapping was very low, thus limiting the yield capacity.

PR300 (2 trials, index 111) had a low girth at opening and a low girth increment during tapping, some susceptibility to TPD, but a rather good yield.

PR255 (2 trials, index 110) had a low girth at opening, but a good girth increment during tapping and a rather good yield.

BPM24 (2 trials, index 109) had a low girth at opening, a medium girth increment during tapping, and a medium yield.

GT1 (all the 14 trials, index 100) was medium-low for vigour and yield, with a low girth increment during tapping. The trees had slightly twisted trunks. The clone showed a high incidence of Oïdium in some plots in 2011.

PB86 (2 trials, index 93) had a low girth at opening, a medium girth increment during tapping, and a medium-low yield.

PR261 (2 trials, index 87) had a medium growth but a low yield. The trees had abundant branching at low level.

Group C

PR303 (2 trials, index 117) had a low girth at opening but a high girth increment during tapping, and a high yield with an increasing trend.

RRIC121 (2 trials, index 114) had a medium girth at opening, but a very high girth increment during tapping, a good yield with an increasing trend. The trees were tall with twisted trunks.

PR306 (2 trials, index 108) had a medium-low girth at opening, a medium girth increment during tapping, and a medium yield.

PB324 (2 trials, index 103) had a low girth at opening, a good girth increment during tapping, and a medium-low yield.

KHA9 (1 trial, index 93) had a medium girth at opening and a medium-low yield.

PR107 (4 trials, index 87) had a low girth at opening, a good girth increment during tapping, and a low yield. The trees were straight and had a very nice aspect. In the past, this clone showed a high capacity to maintain a stable tapped stand and to increase its yield with time.

RRIC102 (1 trial, index 86) has the lowest girth at opening, which partly explained its low yield.

AVROS308 (1 trial, index 85) had a medium vigour but a low yield.

TJIR1 (1 trial, index 79) had a medium vigour but a very low yield.

K2 (2 trials, index 57) had a low girth at opening, a good girth increment during tapping but a very low yield.

Estimation of a weighted index for the comparison of the clones

Table 5 shows the details of scoring of the clones for their main characteristics (Yield, Group, Level of knowledge, Girth at opening, Girth increment, susceptibility to TPD and Wind damage. The index calculated for the 36 clones varied from 80 to 38.

Table 5 Scoring of the 36 clones, and calculation of weighted indexes with a specific choice of coefficients.

	Coefficients	8	1	1	3	3	2	2	
Clones	Index-Cum1-7	Yield	Group	Knowledge	Girth	Increment	TPD	Wind	Index
PB280	124	4	1	4	4	5	5	3	80
IRCA130	160	5	1	4	5	4	1	1	76
PB330	121	4	3	4	4	5	3	1	74
RRIM712	124	4	3	5	3	2	4	5	73
PB235	147	5	1	3	4	4	1	1	72
RRIM600	121	4	3	5	3	3	4	3	72
RRIC121	114	3	5	3	3	5	3	4	70
RRIC101	133	5	1	3	3	2	2	2	67
PB217	112	3	3	4	3	3	5	4	67
KV4	146	5	3	4	3	2	1	1	66
PB314	126	4	1	4	3	4	3	1	66
IRCA109	126	4	3	1	3	2	4	3	65
PB254	113	3	3	3	3	4	4	3	65
PB310	120	4	3	3	3	3	2	2	64
IRCA230	122	4	1	3	3	2	3	3	63
PR303	117	3	5	3	2	4	3	3	62
PR255	110	3	3	3	2	4	3	3	60
IRCA111	115	3	1	4	4	3	2	2	58
IRCA41	114	3	3	4	2	2	4	3	57
PB260	122	4	1	4	3	2	1	1	56
PB255	114	3	1	3	3	3	2	3	56
PR107	87	1	5	5	2	4	5	5	56
PR300	111	3	3	3	2	2	3	3	54
PR306	108	2	5	3	3	3	3	3	54
KHA9	93	2	5	1	3	3	3	3	52
PB324	103	2	5	3	2	3	3	3	51
GT1	100	2	3	5	3	2	3	3	51
IRCA209	108	2	1	3	4	3	3	2	51
PB86	93	2	3	3	2	3	3	3	49
BPM24	109	2	3	3	2	3	2	3	47
IRCA18	109	2	1	4	3	2	2	3	46
K2	57	1	5	3	2	4	3	3	46
AVROS308	85	1	5	1	3	3	3	3	44
PR261	87	1	3	3	3	3	3	3	44
TJIR1	79	1	5	1	3	3	2	3	42
RRIC102	86	1	5	1	1	3	3	3	38

DISCUSSION

Dynamics of growth and yield

In commercial plantations, rubber trees are opened at a standard girth of the trunk (45 or 50 cm at 1-m high). Therefore the most vigorous clones are opened earlier than the less vigorous clones. By contrast, in these Large Scale Clonal Trials, all the clones of one trial are opened in the same year, and a higher density of trees is opened for more vigorous clones. In both cases, the vigorous clones have an initial advantage in terms of cumulated yield per hectare.

Then the evolution of rubber yield partly depends on the interaction between growth and yield. Higher the initial yield, lower the girth increment during tapping, and lower the later yield. As a result, there is a general trend towards reduction of the yield differences between the clones with time, as shown by the decrease in the coefficient of variation among the clones from Y1 to Y7. In fact, Cum1-7reg is highly correlated with the later yield Cum5-7 ($R^2 = 0.62$). But the later yield Cum5-7 had a low dependency on the girth at opening of the clones.

Synthesis for recommendations

Table 5 takes into account the main characteristics of the 36 clones in order to calculate one weighted mean per clone, used as a selection index. These characteristics, scored from 5 (good) to 1 (weak) are : yield, girth at opening (growth), girth increment during tapping, susceptibility to TPD and wind damage, importance of later yield as compared to initial yield (group C = 5, group B = 3, group A = 1) which is assumed to be related with the ability to increase yield along time, and the amount of knowledge about the clones (nb-trials). The coefficients, which determine the relative importances of the different characteristics, are designed so that the theoretical maximum index is 100. These coefficients presented here can be modified depending on the ecological sites and the objectives of the planters.

The weighted index makes possible a ranking of the 36 clones. A simple application of this index would lead to choose a certain number of clones in the top of the ranking. But it must be noticed that this ranking system is based on a first principle of compensation: for one clone, one good characteristic can compensate for another bad characteristic. A second principle that can be applied to clonal recommendations is to exclude some clones which appear too bad or too hazardous for some important characteristics. A third principle is to consider that knowledge about the clones is never perfect, and that a diversification of clones is necessary for providing a good stability to rubber plantations.

Despite of its interest, this study is still limited to about 7 years after opening. Some clones with high indexes such as IRCA130, PB330, PB235, or KV4 may appear as very hazardous in terms of susceptibility to TPD and wind damage. By contrast, some clones such as PB217 and PR107 did not have enough time to exhibit their yield potential under intensive tapping and in the long run. Even the clone GT1, with a rather low index, may not be totally excluded from recommendations, if we take into account its wide adaptation to many ecological conditions.

As a conclusion, this presentation provides elements for the rubber planter to make their own choices, based on their specific objectives and on the ecological conditions of their planting areas. It must be underlined that the present results were issued from the Kampong Cham region of Cambodia. As far as there is uncertainty on the possibility to extend these results to other areas, a higher level of clonal diversification is necessary in those new areas.

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