THE "DOUBLE CUT ALTERNATIVE" (DCA) TAPPING SYSTEM: AN INNOVATIVE TAPPING SYSTEM DESIGNED FOR THAI RUBBER SMALLHOLDINGS USING HIGH TAPPING FREQUENCY.

RESULTS AFTER TEN YEARS OF TAPPING

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ABSTRACT

In Thailand, the continuous decrease in the size of rubber plantations has led to the general adoption of intensive tapping systems which may lead to over harvesting, high rates of tapping panel dryness (TPD), short life-cycles of the plantations, and low labour productivity. In Thailand, farmers usually use a half-spiral downward tapping system (S/2) or a one third-spiral (S/3) with a tapping frequency of once two days (d2) or more. To increase productivity, it is difficult to reduce tapping frequencies, even with ethylene stimulation, as this would result in days without work for tappers. The purpose of this study was to characterize the behaviour of the Hevea rubber yield under the double cut alternative tapping system (DCA). The aim was to ensure the long-term sustainability of latex yield by increasing the time required for latex regeneration between two tappings through splitting this high tapping intensity (100% or above) into two different tapping cuts tapped alternately (S/2 d4 7d7 (t,t). Over a period of 10 years, compared to a single cut tapping system (S/2 d2) of equivalent intensity, DCA increased cumulative rubber production by 9%. Ability of the trees to produce more latex under DCA was related to the sucrose and inorganic phosphorus contents of the latex cells in each tapping panel. DCA produced metabolic activity more favourable to yield during the first 10 years of tapping. But DCA also resulted in higher TPD rates, a sign of a metabolic dysfunction of the productive bark. DCA is a new tapping system. Further research is required to optimize the use of the DCA strategy. Such research, particularly those related to study of multiple-cut systems, should lead to new advances in our knowledge of the physiology of the rubber tree, mainly at the trunk scale.

INTRODUCTION

Thailand represents 23% of the total area under *Hevea brasiliensis* in the world, and 32% of total natural rubber production, with 3.1 million tons produced in 2009. Rubber producers are mainly smallholders who represent more than 85% of the total rubber area in the country. In Thailand, farmers harvest latex using a multi-annual tapping system comprising a half-spiral (S/2) or a one third-spiral (S/3) cut downward tapped at a frequency of two days (d2). In the last decade, the continuous decrease in the size of Thai rubber plantations has led to the general adoption of more intensive frequencies than d2, i.e. daily tapping (d1) for two days out of three (2d/3) or three days out of four (3d/4), with only one day of tapping rest. These very intensive tapping systems may result in overexploitation, high rates of tapping panel dryness (the dryness of the cut), short life-cycles of the plantations, and rather low labour productivity. The main physiological and practical causes of this low output per tapper are known. The insufficient time for latex regeneration between consecutive tappings because of too high tapping frequencies reduces output per tree per tapping (Jacob et al., 1988, 1995a; d'Auzac et al., 1997; Obouayeba et al., 2009a). A high rate of tapping panel dryness also occurs with such intensive tapping systems (Anekachai, 1989). The general use of a one third-spiral (S/3) often leads to a huge "bark island", with associated low yield potential of the third panel (BO-3) of the trunk (Anekachai, 1989), and early opening of small trees aggravates the situation (Anekachai, 1989). Different strategies have already been experimented to improve rubber productivity. One of the main strategies combines reduced tapping frequency with ethylene stimulation. This strategy has been successfully used in rubber plantations worldwide with tapping systems like S/2 d3 or S/2 d4 (Abraham et al., 1971;Paardekooper et al., 1975; Eschbach and Banchi, 1985; Gohet, 1996; Gohet et al., 1996, 1997; Lacote et al., 2010; Rodrigo et al., 2009; Thanh et al., 1996; Vijayakumar et al., 2001, 2003). In Thailand, it is difficult to reduce tapping frequencies in the smallholding context, as this would result in days without work for farmers and/or tappers. This is mainly due to the uneconomic size of the farms (less than 2 ha on average): one farm is usually made up of only one tapping task. We propose another strategy: the double cut alternative (DCA) tapping system. The aim is to increase the time available for latex regeneration by splitting the tapping into two different tapping cuts, tapped alternately, avoiding competition between the two cuts as far as possible by leaving sufficient distance between their respective latex regeneration areas. The new tapping strategy may provide an alternative to currently used intensive tapping system.Its design was based on results of former experimental studies on alternate tapping in Thailand (Anekachai, 1989). The physiological justification for DCA is based on optimization of the time available for latex regeneration, as complete regeneration generally requires 3–5 days depending on the latex metabolism of the clone concerned (d'Auzac et al., 1997, Gohet and Chantuma, 2003).

As a consequence, output per tapping of S/2 d2, the reference tapping system, is actually limited by the short regeneration period between consecutive tappings (Jacob et al., 1989, 1995a). Splitting of S/2 d2 into two different cuts tapped alternately once in every 4 days (S/2 d/4 (t,t)) instead of once in every 2 days, although maintaining a d/2 frequency of tapping of tree, would therefore theoretically result in improved latex regeneration and increased output per tree and per tapping. It may be possible to optimize exploitation of each d/4 cut by using appropriate ethylene stimulation on each cut with the DCA system, as it has already been shown that d/4 tapping frequency can be optimized in this way (Eschbach and Banchi, 1985; Eschbach et al., 1986; Gohet et al.,1996, 1997; Lacrotte et al., 1985; Lacote et al., 2010).

The purpose of this study was to analyze the results and evaluate future prospects of the DCA system to improve the productivity of Thai rubber plantations. The results will help managers choose tapping systems according to the policy of each plantation and at the same time to optimize latex productivity.

MATERIALS AND METHODS

Location of the trials

The trials were conducted between 2000 and 2010 at the Chachoengsao Rubber Research Station in east Thailand (13◦36_N, 101◦27_E, altitude 27Mmsl). The climate is subtropical, characterized by temperature amplitudes of 25–35 ◦C, high humidity (80–90%) and mean annual rainfall of up to 1200mm.

Plant material

Clone RRIM 600, the most widely planted clone in Thailand, was used for the experiment.

Experimental design

During the 10-year experimental period, trees were compared under three tapping systems. The experimental plot used for each treatment was 0.0438 ha. Trees were spaced at 7m×2.5m (571 trees.ha^{-1}). The experimental design was a "randomized complete block" comprising three treatments (A–C) and four replications per treatment with 25 trees per treatment and total randomization of all the plots in a given block. The rubber trees were 8 year old at the beginning of the trial. Trees of equal size were selected. The first opening was made in May 2000. The incision in the bark (a single tapping cut) was located 1.50m from the ground, at a standard trunk girth of 50cm measured 1m from the ground. Every two days, the trees were tapped with a half spiral downward cut (treatment A: S/2 d2 7d/7) or with a third spiral downward cut (treatment B: S/3 d2 7d/7). With treatment C, the double cut alternate system (DCA: 2×S/2 d4), a cut was made simultaneously on panel BO-1, 0.75mfrom the ground and on panel BO-2, 1.50m from the ground (Table 1). All treatments were continued for 9 months (9 month/year), as refoliation and the dry season, associated with very high temperatures, prevent economic tapping in February, March and April in the Chachoengsao area.

Table 1 Tapping sequences of d2 7d/7 tapping frequency and its DCA equivalent 2×d4 7d/7 (t,t).

Days	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**
d2 7d/7	T		T		T		T		T		T		T	
DCA: 2xd4 7d/7 (t,t)	T_{low}		T_{high}		T_{low}		T_{high}		T_{low}		T_{high}		T_{low}	

T_{low} indicates tapping on the lower panel BO-1, T_{high} indicates tapping on the upper panel BO-2.

Ethephon stimulant was applied four times per year (4/year). Trees wee stimulated by applying 0.7 gram of a mixture of water containing ethephon (2.5% active ingredient) on the single cut tapping system S/3 d2 and on each cut in the DCA system. Stimulant was applied to 1 cm of the regenerating bark just above the tapping cut (Pa 0.7 (1) according to Vijayakumar et al. (2009)). The stimulant was evenly distributed from May to December. Treatments are listed in Table 2.

Table 2 Experimental treatments

Treatments	**Opening**
A. S/2 d2 7d/7 9m/12 *nil stim*	B0-1, 1.50m
B. S/3 d2 7d/7 9m/12 ET 2.5% Pa 0.7 (1) 4/Y	B0-1, 1.50m
C. DCA 2 x S/2 d4 7d/7 (t,t) 9m/12 ET 2.5% Pa 0.7 (1) 2 x 4/Y	B0-1, 0.75m, B0-2, 1.50m

The panel management schedule for the 10 first years of tapping is shown in Figure 1.

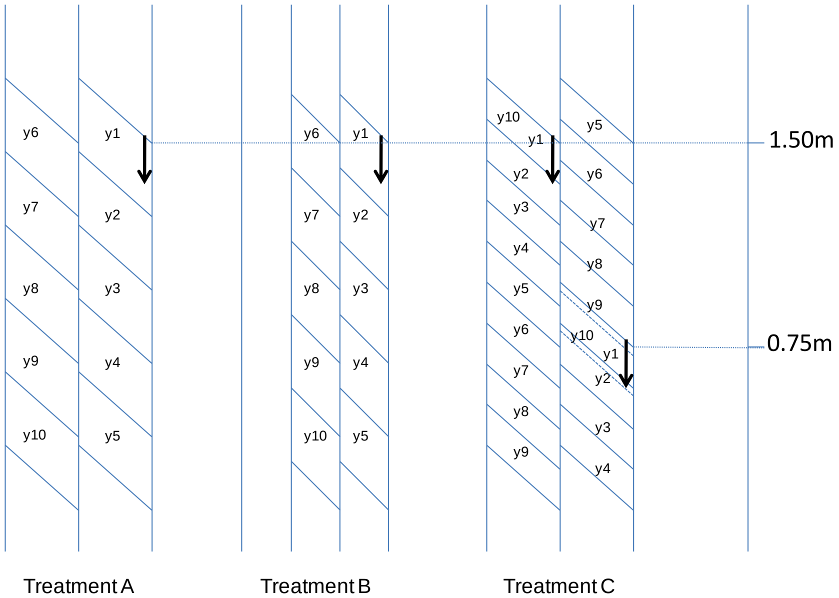

Figure 1. Compared tapping panel management.

Measurements and data processing

The latex yield per tree was measured by weighing the cumulative coagulated rubber from each tree every four weeks. Total solid content was measured from a bulk sample taken in each treatment in order to convert fresh weights into grams of dry rubber per tree. Latex yield was expressed in grams per tree (g/tree). The girth and radial growth the trees were measured every year 1.70cm above the ground.

The main latex biochemical parameters, i.e. sucrose (Suc) content and inorganic phosphorus (Pi) content, were measured in a bulk sample from 10 trees taken from each replication, each year in October, when latex metabolic activity is the highest, using methods developed by CIRAD (Jacob et al., 1989, 1995b) adapted in 1995 by IRRDB (1995). Sucrose and inorganic phosphorus contents were expressed in millimoles per litre of latex (mmol.l^{-1}). Sucrose content was measured using Ashwell's anthrone method (1957). Inorganic phosphorus content was measured using the Taussky and Shorr method (1953).

A one-way ANOVA was performed to compare the treatments. All differences were tested for statistical significance using the Student–Newman–Keuls test with an alpha threshold of 0.05. Statistical analyses of latex yield and biochemical parameters were performed using XLSTAT Version 2009.6.02 statistical software (Addinsoft 1995–2009). Tapping panel dryness was estimated by counting the trees with bark dryness in each replication of each treatment. TPD is expressed as the percentage of dry trees in each treatment.

RESULTS

Production

DCA displayed a significantly higher cumulated yield than the two recommended systems (S/2 d/2 and S/3 d2 ET2.5% 4/year) during the first nine years of tapping (Table 3). Over the 10-year period, DCA produced 9% more than S2 d2 and 27% more than S/3 d2 with ethylene stimulation. Dry rubber yield of S/2 d2 and S/3 d2 treatments showed the same trend depending on the tapping year (Figure 2). Yield increased during the first four tapping years on panel BO-1, and then decreased in year 5. After changing panel, yield increased on panel BO-2 in years 6, 7 and 8. Yield decreased in years 9 and 10.

DCA resulted in a significantly higher yield in years 1, 2 and 3 and in years 6 and 7 when compared to the two other tapping systems i.e. S/2 d2 with no stimulation and S/3 d2 with ethylene stimulation (Table 4). DCA yields obtained in years 4, 5, 8, 9 and 10 were not significantly different from those obtained with the two other treatments. With a downward tapping system used on the two panels, DCA treatment resulted in different fluctuations in yield (Figure 2). Yield increased during the first three tapping years. In year 4, yields decreased with the continuing downward tapping system on panel BO-1 and in year 5 with the continuing downward tapping system on panel BO-2. In years 6 and 7, yields increased again after changing panel. Then in years 8–10, yields decreased with the continuing downward tapping system.

Treatment S/3 d2 resulted in a significantly lower yield than S/2 d2 in years 3–8 (Table 4).

Table 3 Average cumulated dry rubber yield (g/tree) over the 10-year tapping period.

Treatment	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
A	2373 b	5961 b	10362 b	14936 b	18702 a	22165 b	28191 b	34617 a	39465 ab	44900
B	2255 b	5393 b	8951 c	12831 c	16050 b	19229 b	23444 c	28723 b	33394 b	38511
C	3066 a	7330 a	13154 a	17766 a	21251 a	26091 a	33255 a	39438 a	44485 a	48947
P>F	***0.002***	***0.002***	***0.003***	***0.001***	***0.005***	***0.002***	***0.001***	***0.005***	***0.015***	0.065

Different letters in the same column indicate a significant difference between tapping systems at $P < 0.05$.

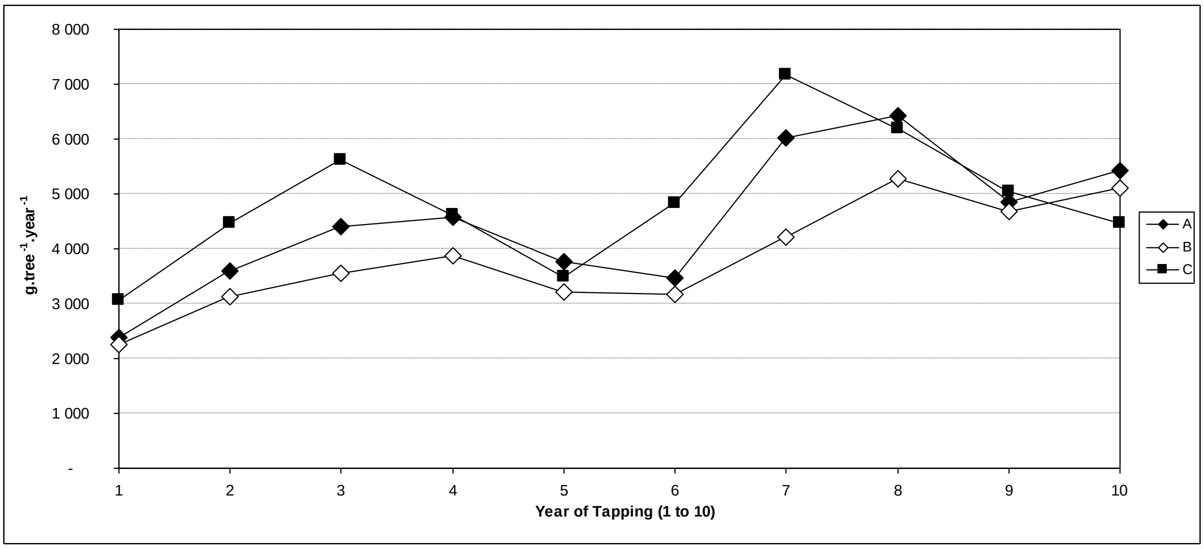

Figure 2. Annual yield (g/tree) per treatment during the 10-year tapping period. (A) S/2 d2; (B) S/3 d/2 ET2.5% Pa0.7(1) 4/y; (C) DCA S/2 d4 ET 5% Pa0.7(1) 4/Y(t,t).

Table 4 Average dry rubber yield per year (g/tree/year) during the 10-year tapping period.

Treatment	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
A	2373 b	3589 b	4401 b	4574	3766	3463 b	6026 a	6427	4847	5436
B	2255 b	3138 b	3558 c	3880	3219	3179 b	4215 b	5279	4671	5117
C	3066 a	4464 a	5624 a	4612	3485	4840 a	7164 a	6184	5047	4462
P>F	***0.002***	***0.001***	***0.001***	0.200	0.349	***0.003***	***0.008***	0.319	0.879	0.618

Different letters in the same column indicate a significant difference between tapping systems at P < 0.05.

Biochemical parameters of the latex cells

Table 5 shows the annual sucrose (Suc) measurements with the three treatments after opening. For DCA, data obtained on each cut are presented separately as they came from different latex regeneration areas (DCA-CA on panel BO-1 and DCA-CB on panel BO-2). In year 1, with DCA, the higher the tapping cut, the higher the sucrose content. Treatment S/3 d2 (with ethylene stimulation) resulted in the lowest sucrose content. In year 4, DCA-CA, reaching the lowest position on the panel BO-1, displayed lower Suc content than DCA-CB at a higher position on panel BO-2. Conventional tapping, i.e. S/2 d2 (without ethylene stimulation) and S/3 d2 (with ethylene stimulation) displayed the lowest Suc content on panel BO-1. In year 5 at the lowest position on panel BO-1 with the single cut tapping systems, treatment S/2 d2 displayed higher Suc content than treatment S/3 d2. With DCA-CA, changing to panel BO-1, in year 5, did not lead to a high Suc content. In year 5, on panel BO-2, DCA-CB displayed the highest Suc content. In year 7, DCA-CA displayed the highest Suc content on panel BO-1. In year 8, DCA-CB displayed the lowest Suc content on panel BO-2. In year 9, there were no significant differences among the treatments with the lowering of all cuts on the tapping panels. In year 10, on regenerated bark on panel BO-2, DCA-CB, did not result in significantly higher Suc content. Average data after 10 years of tapping displayed a higher SUC content with DCA, (both DCA-CA and DCA–CB) than with the two single cut tapping systems S/2 d2 (without ethylene stimulation) and S/3 d2 (with ethylene stimulation).

Table 5 Average latex sucrose content SuC (mmol l−1) during the 10-year tapping period as a function of the tapping system and the average for the 10-year tapping period (Avg10y). The different latex regeneration areas of DCA, CA on panel BO-1 and CB on panel BO-2 are separated.

Treatment	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Avg 10 y
A	9.95 bc	7.73	7.95 b	5.44 b	10.44 a	7.20	11.35 ab	9.23 a	7.16	6.40	**8.28 a**
B	8.12 c	6.20	8.16 ab	5.21 b	6.22 b	4.02	7.65 b	9.57 a	7.13	6.73	6.90 b
CA	11.90 b	7.25	10.20 a	6.07 b	6.95 b	5.28	14.40 a	8.51 a	7.35	6.37	**8.43 a**
CB	16.27 a	5.36	6.43 b	8.85 a	11.09 a	6.13	9.04 b	3.55 b	8.87	8.29	**8.39 a**
P>F	**0.001**	0.057	**0.022**	**0.010**	**0.018**	0.133	**0.027**	**0.006**	0.175	0.135	**0.001**

Different letters in the same column indicate a significant difference between tapping systems at P < 0.05.

DCA displayed the highest Pi content both on panel BO-1 (CA) and BO-2 (CB) in the first year of tapping (Table 6). In year 4, DCACB displayed the lowest Pi content. In year 5, on the lowest BO-1 panel, there was a tendency to a low Pi content with treatments S/2 d2 (without ethylene stimulation) and S/3 d2 (with ethylene stimulation). In years 7 and 8, DCA tended to increase Pi content both on panels BO-1 and BO-2. Average data after 10 years of tapping revealed a higher Pi content with DCA, mainly with DCA-CA.

Table 6 Average latex inorganic phosphorus content Pi (mmol l−1) during the 10-year tapping period as a function of the tapping system and the average for the 10-year tapping period (Avg10y). The different latex regeneration areas of DCA, CA on panel BO-1 and CB on panel BO-2 are separated.

Treatment	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Avg 10 y
A	19.39 b	17.42	19.95	18.14 a	18.97	15.93 c	23.15 bc	21.52	26.44	18.52	19.94 bc
B	15.63 c	17.32	16.9	15.44 ab	17.73	22.35 b	20.63 c	16.95	22.26	14.36	17.96 c
CA	24.04 a	18.83	20.85	20.87 a	27.73	23.26 b	33.84 a	21.78	28.87	20.34	**24.04 a**
CB	21.45 ab	18.41	22.86	11.38 b	21.94	35.74 a	30.03 ab	29.82	29.10	16.86	**23.76 ab**
P>F	**0.002**	0.816	0.052	**0.020**	0.065	**0.0001**	**0.019**	0.071	0.059	0.078	**0.019**

Different letters in the same column indicate a significant difference between tapping systems at P < 0.05.

Tapping panel dryness

The percentage of TPD trees was quite high after 10 years of tapping. S/3 d2 with ethylene stimulation resulted in the highest number of TPDtrees, 24.6% (Fig. 3). S/3 d2 with ethylene stimulation resulted in a sharp increase in TPD on panel BO-2 from year 6 to year 10. DCA resulted in an increase in TPD from year 5 to year 10 after changing the cut position on panel BO-1 and with simultaneous tapping of panel BO-2 near the regenerated bark on panel BO-1. Then TPD increased with the downward tapping on panel BO-1, reaching the regenerated bark, and at a low position on panel BO-2 until year 10. TPD reached a maximum in year 9 and then decreased in year 10 after on changing panel BO-2.

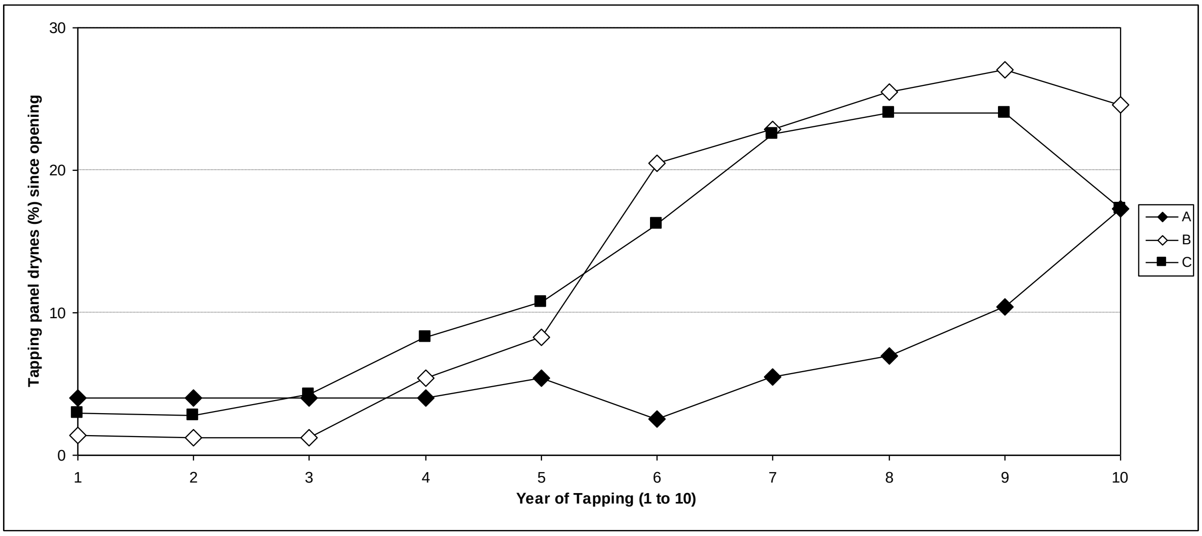

Figure 3. Annual tapping panel dryness per treatment (% of trees affected) during the 10-year tapping period. (A) S/2 d2; (B) S/3 d/2 ET2.5% Pa0.7(1) 4/y; (C) DCA S/2 d4 ET2.5% Pa0.7(1) 4/Y(t,t).

Girth increment

Girth increment did not change over the 10 years of tapping (Table 7). DCA resulted in a significantly lower girth increment than the two other treatments only in year 10, the last year of the trial. The cumulated girth increment calculated as the average increment after 10 years of tapping was near the significance level (P < 0.065) with a trend for DCA: the higher the cumulated yield, the lower the girth increment.

Table 7 Average of the yearly girth increment and of the total girth increment over the 10-year tapping period as a function of the tapping system.

Treatment	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Avg 10 y
A	2.63	2.55	2.25	1.74	1.60	0.64	1.81	1.95	1.74	1.63 a	18.20
B	2.30	2.64	2.38	1.75	1.46	0.81	2.05	2.06	1.53	1.30 a	17.73
C	1.74	1.90	1.99	1.71	1.42	0.66	1.49	1.00	1.92	0.62 b	15.33
P>F	0.189	0.473	0.310	0.968	0.837	0.194	0.118	0.133	0.350	**0.009**	0.065

Different letters in the same column indicate a significant difference between tapping systems at $P < 0.05$.

Bark consumption

Compared to both d/2 single cut treatments, DCA led to increased vertical bark consumption of +26%. This was due to the fact that tapping was performed in d/4 on each cut with increased bark hardening between two tappings (Table 8). Bark consumption in both panels CA (BO-1) and CB (BO-2) was more than half the bark consumption of the single cut tapping systems. DCA consumed all the two panels. In year 10, cutting was performed on regenerated bark, on 3 cm of panel BO-1 and on 11cm of panel BO-2 (Fig. 1). In contrast, 45–46cm of virgin bark remained on panel BO-2 with the single cut tapping systems.

Table 8 Average annual bark consumption (cm) and total bark consumption over the 10-year tapping period as a function of the tapping system. The different latex regeneration areas of DCA, CA on panel BO-1 and CB on panel BO-2 are separated. Total 1 is total bark consumption (cm) over the 10-year tapping period for each tapping cut. Total 2 is the total bark consumption (cm) over the 10-year tapping period at the tree scale (CA + CB). The height of each tapping cut is in italics for each year.

Treatment	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total 1	Total 2	% A
A	23.6	29.6	22.0	20.3	20.6	16.9	12.5	16.4	20.6	22.3	204.8	**204.8 b**	
1.50m	*126.4*	*96.8*	*74.8*	*54.5*	*33.9*	*133.1*	*120.6*	*104.2*	*83.6*	*61.3*			
B	23.0	29.7	20.3	20.7	22.0	16.8	14.6	17.2	21.1	22.4	207.8	**207.8 b**	**101 %**
1.50m	*127.0*	*97.3*	*77.0*	*56.3*	*34.3*	*133.2*	*118.6*	*101.4*	*80.3*	*57.9*			
CA	15.7	15.3	13.8	13.0	11.7	10.4	8.5	10.2	13.5	14.2	126.1	**257.4 a**	**126 %**
0.75m	*59.3*	*44.1*	*30.3*	*17.3*	*138.3*	*128.0*	*119.5*	*109.3*	*95.8*	*81.7*			
CB	16.3	17.7	13.5	14.1	13.1	13.0	9.6	10.2	12.6	11.4	131.3		
1.50m	*133.8*	*116.1*	*102.6*	*88.5*	*75.4*	*62.4*	*52.9*	*42.7*	*30.1*	*138.6*			

Different letters in the same column indicate a significant difference between tapping systems at $P < 0.05$ at the tree scale, for both cuts (Total 2).

DISCUSSION

The purpose of this study was to compare the effect of the DCA system with the two other tapping systems currently used in Thailand. Tapping frequencies used by smallholders can be as high as daily (d1 7d/7). Latex regeneration between two consecutive tappings is the main limiting factor to yield per tapping (Serres et al., 1988, Jacob et al., 1989., d'Auzac et al., 1997). As a result, yield in Thailand is high when expressed in kg/ha but low when expressed in kg/tapper/day. With DCA, by splitting this high tapping intensity (100% or above) into two different tapping cuts tapped alternately, the time for latex regeneration is doubled at each cut, which theoretically results in improved latex regeneration and subsequently in increased output per tree and per tapping (Serres et al., 1988; Jacob et al., 1989; Obouayeba et al., 2009a). Results of previous studies on the spatial extent of the latex regeneration area (Lacrotte, 1991) confirmed by further studies (Lacote et al., 2004; Silpi et al., 2006), led us to open the first tapping cut on panel BO-1 0.75m from the ground and the second cut on panel BO-2 at 1.50m from the ground in the DCA system. Previous studies also showed that DCA increases the latex regeneration area (Chantuma et al., 2007). Results after 10 years of tapping confirmed these hypotheses. For the first nine years of tapping, cumulative rubber production increased by 13% compared to the equivalent intensity single cut tapping system (S/2 d/2). But in year 10, the lower yield produced by DCA reduced the gain in total yield to 9%. Compared to the single cut tapping systems, DCA did not result in any significant reduction in tree growth. However, tree girth showed tendency to be lower under DCA than with the single tapping systems. With the single cut tapping systems, the regular increase in production from year 1 to year 4 reflects the progressive activation of latex metabolism. The decrease in production in years 5 and 6 reflects the effect of the limitation of the latex regeneration area and of the decreased sugar supply due to the low position of the tapping cut on the BO-1 panel. Production increased again in years 7 and 8. Hence, sucrose transport within the latex cells needs to be secured (Eschbach et al., 1986). The decrease in yield in year 9 and year 10 was also due to the limitation of the latex regeneration area at a low position on panel BO-2, while the supply of sucrose was reduced. This pattern is classical in the case of no change in panel management (Lacote et al., 2004; Obouayeba et al., 2009b). Pi content indicates when cellular activity is able to produce a high latex yield (Jacob et al., 1989). And, in year 10, TPD increased as the drainage area was reduced an as Pi was reduced, as a sign of a physiological fatigue. In order to compensate for the effect of very high tapping frequencies on bark consumption, which limits the lifespan of the plantation, many Thai farmers use S/3 tapping cut instead of S/2 tapping cut. Applied to d2 frequency, this reduction in length of tapping cut from S/2 to S/3 is compensated by ethylene stimulation. In our experimental, there was no full compensation of yield, cumulative production being significantly decreased (by 15%). Girth was also not better than in the control S/2 d2. Latex physiology revealed degraded profiles, with the lowest Suc and Pi values among the three treatments analyzed. Indeed, TPD increased while yield was always below than the control S/2 d2. This indicates a metabolic limitation as the tapping cut was submitted to high demand of latex by using ethylene stimulation (Chrestin et al., 1985; Jacob et al., 1989; Obouayeba et al., 2009b).

With the DCA tapping system, the increase in yield during the first three tapping years reflected activation of latex metabolism in both BO-1 and BO-2 panels by the two tapping cuts. The position of the cut on panel BO-1 and BO-2 had a significant influence on Suc and Pi contents over the 10-year tapping period. The decrease in yield in years 4 and 5 was due to the effect of the limitation of the latex regeneration area and the reduced sugar supply due to the low position of the cut on panel BO-1 in year 4. On panel BO-2, the tapping cut created a kind of bark island at a position near the height of the opening on panel BO-1. When the yield reached its maximum in year 7, the higher Suc content reflected a better sugar supply to the latex cells, while high Pi content reflected high cellular activity. In year 8, the bark-island symptom on panel BO-1,which led to a decrease in Suc content in years 9 and 10, also led to a decrease in yield. In years 9 and 10, there was no difference in Suc and Pi contents between DCA and the single cut tapping systems. Yield also did not significantly differ. The annual gain of yield using DCA was thus almost lost. With DCA, the decrease in yield mainly occurred in year 10 when the trees were tapped on regenerated bark.

During the 10 years of tapping, DCA resulted in metabolic activity that was more favourable to yield with higher average Suc and Pi contents than the single cut tapping systems. Yield for the whole 10-year period was the highest with DCA. This higher metabolic activity was mainly observed when TPD reached maximum in year 7. But when the panel

BO-1 was tapped in year 8 and 9 and then in year 10 on the regenerated bark, and when tapping was performed downward on panel BO-2 in year 8 and 9, TPD increased while yield decreased. This indicates a dysfunction within the latex cells when the two drainage areas were reduced by tapping (Lacote et al., 2004; Obouayeba et al., 2009b). Further physiological studies on conditions of metabolic synergy or competition between the two tapping cuts of the DCA system are therefore required to explain the observed pattern of fluctuations in yield. This will require separating the yield from each DCA tapping cut.

Conditions for the success of DCA tapping strategy also depend on the respective positions of the two tapping cuts. The two cuts should be located on opposite panels separated as far as possible from one another to limit possible competition between them for carbohydrates, water, and mineral nutrients (Lustinec and Resing, 1965; Buttery and Boatman, 1966; Tupy, 1973; Pakianatan et al., 1976; Silpi et al., 2007). Former small-scale (one tree plot design) studies showed that ethylene stimulation maybe not required to ensure the efficiency of the DCA tapping system on clone RRIM600 (Gohet and Chantuma, 2003). DCA without ethylene stimulation should now be tested to check whether the decrease of yield in year 8 (“bark island symptom”) and the appearance of TPD can be alleviated or not. It is also necessary to check if this TPD syndrome is a consequence of DCA itself or, as was the case in our study, the consequence of interaction between stimulation and DCA.

CONCLUSION

In a context of high intensity tapping like that used by smallholders in Thailand, it is difficult to reduce tapping frequencies, as these would result in days without work for tappers. The aim of DCA is to ensure long-term sustainability of Thai rubber farms, by splitting this high tapping intensity (100% or above) into two different tapping cuts which are tapped alternately. Our results are important since DCA increased cumulative rubber production by 9% compared to the equivalent intensity single cut tapping system (S/2 d2) for the first 10 years of tapping on virgin bark. The position of the cuts on each panel had a significant influence on the biochemical parameters that reflect the yield obtained over the 10-year tapping period. For example, when the yield reached maximum in year 7, the higher Suc content reflected a better sugar supply to the latex cells, while the high Pi content reflected high cellular activity. DCA resulted in metabolic activity that was more favourable to yield during the first 10 years of tapping, but DCA also resulted in higher TPD, which is a sign of ametabolic dysfunction of the productive bark. As DCA is a new tapping system, the evolution of the TPD trees in stands in which DCA is used must therefore be monitored. Further research is required to optimise the use of this double cut strategy. Further experiments, on farms, have been initiated to study the behaviour of DCA with or without stimulation. Such research will produce new insights into the use of DCA. The results will be used to help managers to optimize latex productivity.

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