Performance of Different Latex Harvesting Systems to Increase the Labor Productivity of Rubber Plantations in Thailand.

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Summary

Yield gaps between rubber smallholdings and rubber agro-industries often exist. These gaps are usually important regarding land productivity (kg/ha) but even more important regarding labor productivity (kg/tapper/day). However, technical packages of GAP (good agricultural practices) are available from decades of research in breeding, physiology, agronomy, crop protection and latex harvesting technology. Regarding latex harvesting, the differences between agro-industries and smallholdings are very often even more important than for other disciplines. Reduced tapping frequencies compensated by accurate stimulation intensities or controlled upward tapping are scarcely encountered in smallholdings. Other quality standards are also often less respected, mainly regarding bark consumption, bark wounding and homogenous panel management. In Thailand, smallholders own 85% of the total rubber area. In the southern and eastern regions of the country, climate conditions with heavy rains during the rainy season, associated with rubber price fluctuation, lead farmers to use high frequency tapping systems (S/3 d1 2d/3 or S/3 d1 3d/4 mainly) in order to compensate the reduction of the number of tapping days due to rains. Labor shortage is also a new and increasing issue for farmers who hire tappers. To improve labor productivity in each farm and address the increasing labor shortage, one way might be to reduce the time spent by tappers in the field, using low frequency tapping systems (LFT). LFT systems combine reduction of tapping frequency with Ethephon stimulation. Under accurate stimulation, yield significantly improves at each tapping, leading to a higher labor productivity (g/t/t and kg/tapper/day) and this can at least partly compensate the effect of the reduction of the tapping frequency on production. The objectives of this publication are (i) to assess the efficiency of different LFT systems with Ethephon stimulation on yield, labor productivity and latex physiological parameters and (ii) to select among those systems the ones showing an improved efficiency regarding labor productivity, in order to test them on farm.

Keywords: *Hevea brasiliensis*, latex harvesting, low frequency tapping (LFT), smallholding, yield, labor productivity, latex diagnosis, latex physiological parameters.

1. Introduction

In the global rubber industry, yield gaps between rubber smallholdings and rubber agro-industries are important. These gaps are important regarding land productivity (kg/ha) and even more important regarding labor productivity (kg/tapper/day). However, technical packages of good agricultural practices are available from decades of research in breeding, physiology, agronomy, crop protection and latex harvesting technology. Regarding latex harvesting, the differences between agro-industries and smallholdings are very often even more important than for other disciplines. More specifically, reduced tapping frequencies compensated by accurate stimulation intensities or controlled upward tapping are scarcely encountered in smallholdings, where other standards of tapping quality are often not respected, regarding bark consumption, bark wounding, homogenous panel management… conversely to agro-industries.

In Thailand, 85% of the total rubber area is owned by smallholders (Chambon *et al*., 2014, Chantuma *et al*., 2015). This results in a large diversity of tapping systems at country scale. In most of cases, mainly in the southern region of Thailand, there are two major issues concerning rubber smallholders. Climate conditions with heavy rainy season and rubber price fluctuations are leading farmers to use high frequency tapping systems (HFT) in order to compensate the reduction in number of tapping days due to the rains during the wet season and to save as much as possible a daily income whatever the rubber price (Chantuma *et al*., 2011, 2015). Labor shortage is now a new issue for farmers hiring tappers as well.

To address such issues, one way might be to reduce the time spent by tappers in field using low frequency tapping systems (LFT) (Gohet *et al*., 1991, 2003, Soumahin *et al*., 2009, 2012, Kudaligama *et al*., 2010, Prasanna *et al*., 2010, Soumahin *et al*., 2010). LFT systems combine reduction of tapping frequency with Ethephon stimulation. Under proper stimulation intensity, yield is significantly improved at each tapping (Buttery and Boatman 1967, Lustinec *et al*. 1965, Pakianathan *et al*. 1976, Abraham *et al*., 1968, d'Auzac and Ribaillier, 1969, Jacob *et al*., 1989, d'Auzac *et al*., 1997, Gohet *et al*., 1991). This leads to a higher labor productivity (kg/tapper/day) that can at least partly compensate the reduction of the tapping frequency (Gohet *et al*., 1991, 2003, Lacote *et al*., 2010, Njukeng *et al*., 2007, 2011, Traoré *et al*., 2011, Sainoi *et al*., 2017 a and b, Samila *et al*., 2017).

The objectives of this paper are (i) to assess the efficiency of LFT systems with Ethephon stimulation on yield and on some biochemical parameters of latex in Thailand under different experimental conditions (in research station and on farm), then (ii) to get insight on the systems showing an improved efficiency at each tapping.

2. Material and Methods

2.1. Research station trials:

Experimental site, plant material and statistical design

The experiments were carried out at:

- **Thepa Research Station**, Prince of Songkla University, Thepa district, Songkhla province in Southern Thailand. Trees (Clone RRIM600) were planted at the density of 476 trees per ha (7m x 3 m spacing). Experiment trees were selected before tapping with a homogenous girth and were opened at 1.50 m from the ground on panel BO-1. The experiment was set up as a randomized complete block design (RCBD), with 5 treatments and 3 replications. There were 10 homogeneous selected trees per treatment in each replication (Table 1).

Table 1: Treatments of the Thepa Research Station experiment.

Treatments	Tapping system and Description	TI*
T1	S/3 d1 2d/3 *(Third spiral cut downward at daily tapping, two days in tapping followed by one day of tapping rest in three days)*	89
T2	S/2 d2 *(Half spiral cut downward at alternate daily tapping)*	100
T3	S/2 d3 ET 2.5% Pa1(1) 8/y (m) *(Half spiral cut downward at third daily tapping, stimulated with Ethephon with 2.5% active ingredient with 1 gram of stimulant applied on panel on 1 centimeter band, 8 applications per years)*	67
T4	S/3 d2 ET 2.5% Pa1(1) 4/y (m) *(Third spiral cut downward at alternate daily tapping, stimulated with Ethephon with 2.5% active ingredient with 1 gram of stimulant applied on panel on 1 centimeter band, 4 applications per years)*	67
T5	S/3 d3 ET 2.5% Pa1(1) 12/y (m) *(Third spiral cut downward at third daily tapping, stimulated with Ethephon with 2.5% active ingredient with 1 gram of stimulant applied on panel on 1 centimeter band, 12 applications per years)*	44

Note: *TI is tapping intensity according to Vijayakumar *et al*., 2009

- **Sitthiporn Kridakorn Research Station** of Kasetsart University, Amphoe Bang Saphan Noi, Prachuap Khirikhan Province, in Southern Thailand. Trees (Clone RRIT 251) were planted at the density of 500 trees/hectare (8m x 2.5 m spacing). The experiment was set up as a randomized complete block design (RCBD), with 3 treatments and 3 replications. There were 55 trees per treatment in each elementary plot (Table 2).

Table 2: Treatments of the Sitthiporn Kridakorn Research Station experiment.

Treatments	Tapping system and Description	TI*
T1	S/2 d2 *(Half spiral cut downward at alternate daily tapping), nil stimulation.* Opening BO-1 at 1.50 m from ground (Control)	100
T2	S/2 d3 ET 2.5% Pa1(1) 6/y *(Half spiral cut downward at third daily tapping, stimulated with Ethephon with2.5% active ingredient with 1 gram of stimulant applied on panel on 1 centimeter band, 6 applications per years)* Opening BO-1 at 1.30 m from ground	67
T3	S/2 d4 ET 2.5% Pa1(1) 8/y *(Half spiral cut downward at fourth daily tapping, stimulated with Ethephon with2.5% active ingredient with 1 gram of stimulant applied on panel on 1 centimeter band, 8 applications per years)* Opening BO-1 at 1.30 m from ground	50

Note: *TI is tapping intensity according to Vijayakumar *et al*., 2009

Data collection and analysis

In Thepa Research Station, latex yield was calculated from each tree by weighing the latex at each tapping. In Sitthiporn Kridakorn Research Station, latex yield was calculated from each elementary plot by weighing the latex yield at each tapping. In both experiments, total solid content was measured from a bulk sample taken in each treatment in order to convert fresh weights into grams of dry rubber.

In both research stations, latex diagnosis (LD) was performed every year on a pooled sample of 10 trees in each replication. The latex biochemical parameters (total solid content (TSC%), sucrose content (Suc, $mM.l^{-1}$), inorganic phosphorus content (Pi, $mM.l^{-1}$) and reduced thiols content (RSH, $mM.l^{-1}$)) were

evaluated according to the method developed by CIRAD and adopted in 1995 by IRRDB (Jacob *et al*., 1988, IRRDB, 1995). Bark consumption (cm) was measured on the tapped panel every year from the beginning to the end of the tapping period.

2.2. On farm trials:

Demonstrative plots and plant material

"On farm" trials were carried out at Union Rubber plantation, nearby the city of Na Yai Am in the Southeastern part of Thailand. In Union Rubber plantation rubber fields, plots are under the responsibility of families implementing share-cropping. Tapping organization is therefore very similar to that of typical Thai smallholdings. The clone chosen for the experiments is RRIM 600.

Data collection and analysis

Latex yield was calculated from each plot by weighing the latex yield at each tapping. Trees were counted twice a year. Cumulative yield was monthly calculated. Total solid content was measured from a bulk sample taken in each treatment in order to convert fresh weights into grams of dry rubber.

3. Results

3.1. Research station trials:

In Thepa Research Station in southern Thailand and after 3 years of tapping, there were significant differences among the 5 treatments (Table 3). The highest yield in gram per tree per tapping (g/t/t) was found with T3 (S/2 d3 ET 2.5% Pa1(1) 8/y (m), producing 68 % more than T1 (conventional farmers tapping system), which showed the lowest g/t/t. For the d2 tapping systems, yield (S/2) was not significantly different of T4 with a shorter cut (S/3) but with ehephon stimulation. For the d3 tapping systems, T3 (S/2) with a longer cut length but with less Ethephon stimulations than T5 (S/3), showed higher yield than T5.

T1 gave the highest cumulative yield (kg/t). This can relate to the higher number of tappings per year for this high tapping frequency. The lowest yield was found for T5, combining a short cut length and a lower tapping frequency that could not be compensated by the use of Ethephon stimulation in d3. Cumulative yield of T2, T3 and T4 were not significantly different of T1. For d2 tapping frequency, cumulative yield of T2 (S/2 nil stim) was not different of T4 with a shorter cut (d3 with Ethephon stimulation). For d3 tapping frequency, T3 (S/2 with Ethephon stimulation) gave a comparable cumulative yield to T1. Table 3 shows that the number of tappings logically depends on the tapping frequency. However, actual number of tappings was not as high as theoretically expected, as tapping was not performed on rainy days, in conformity with the farmers' practices in this area. T1 showed an average of 155 tappings per year (almost equivalent to a true d2 frequency), T2 and T4 showed an average of 113 tappings per year, (almost equivalent to a true d3 frequency). T3 and T5 also showed an average of 91 tappings per year, inferior to a true d3 frequency).

Table 3: Average g/t/t, average yield per tree/year (kg/t) and average number of tapping per year over 3 years tapping (NT = number of tappings per year). (Sainoi *et al.*, 2017).

Treatments	g/t/t	%	kg/t	%	NT
T1: S/3 d1 2d/3	46.57 [d]	100	7.2 [a]	100	155
T2: S/2 d2	62.88 [c]	135.0	7.1 [a]	99.1	113
T3: S/2 d3 ET 2.5% Pa1(1) 8/y (m)	78.32 [a]	168.2	7.1 [a]	99.4	91
T4: S/3 d2 ET 2.5% Pa1(1) 4/y (m)	61.22 [c]	131.5	6.9 [ab]	96.5	113
T5: S/3 d3 ET 2.5% Pa1(1) 12/y (m)	71.31 [b]	153.1	6.5 [b]	90.5	91

Note: Values with different letters in the same column indicate a significant difference with $P \leq 0.05$.

Table 4 shows the average of TSC, Suc, Pi and RSH measured during the 3 years of tapping. TSC was not different for the 5 treatments. There were significant differences in Suc, Pi and RSH contents between the 5 treatments. The highest Suc was found for T1 (S/3 d1 2d3) and the lowest Suc was found for T3 (S/2 d3 with stimulation). When using Ethephon stimulation, Suc was lower than that of non-stimulated treatments, whatever the length of the cut and the tapping frequency. T4 having the lowest Ethephon stimulation frequency showed intermediary Suc content. T3 (S/2 d3 with stimulation) showed the highest Pi, whereas T1 (S/3 d1 2d/3) showed the lowest. The lowest RSH was measured for T3 (S/2 d3 with stimulation). Higher g/t/t resulted in a lower Suc content, a higher Pi content and a lower RSH content. All LD parameters were therefore explaining the difference in yield (g/t/t), leading to an almost equal kg/t when reducing the tapping frequency compensated by the use of stimulation.

Table 4: Latex biochemistry (TSC; total solid content, Suc; Sucrose content, Pi; inorganic phosphorus content and RSH; reduced thiol content) of five treatments in three years of tapping (Sainoi *et al*, 2017).

Treatment	TSC (%)	SUC (mM)	Pi (mM)	RSH (mM)
T1: S/3 d1 2d/3	55.2	10.9 [a]	17.2 [b]	0.24 [a]
T2: S/2 d2	53.3	9.7 [ab]	17.3 [b]	0.22 [a]
T3: S/2 d3 ET 2.5% Pa1 (1) 8/y (m)	52.7	7.7 [b]	20.9 [a]	0.17 [b]
T4: S/3 d2 ET 2.5% Pa1 (1) 4/y (m)	54.3	9.6 [ab]	17.5 [b]	0.22 [a]
T5: S/3 d3 ET 2.5% Pa1 (1) 12/y (m)	54.2	7.8 [b]	18.6 [ab]	0.21 [a]

Note: Values with different letters in the same column indicate significant difference with $P \leq 0.05$

The bark consumption was significantly different among the 5 treatments. Over 3 tapping years, T1, with the highest tapping frequency showed the highest bark consumption (42.0 cm). The d3 tapping frequency systems showed a lower bark consumption than all other treatments (Figure 1) (Sainoi *et al.*, 2017).

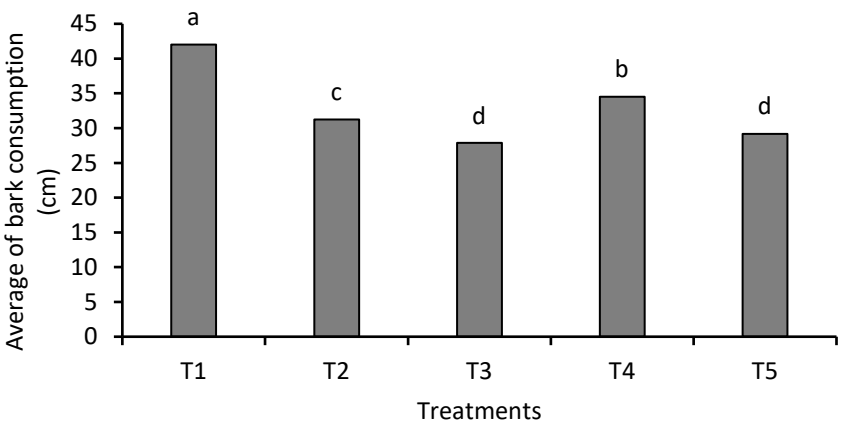


Figure 1: Average of bark consumption (cm); T1: S/3 d1 2d/3; T2: S/2 d2; T3: S/2 d3 ET 2.5% Pa1(1) 8/y (m); T4: S/3 d2 ET 2.5% Pa1(1) 4/y (m); T5: S/3 d3 ET 2.5% Pa1(1) 12/y (m) over 3 years tapping; different letters in each bar graph indicate significant difference at $p \leq 0.05$ by DMRT.

In the research station of Kasetsart University (Prachuap Khiri Khan), the cumulative yields (g/t) of d3 and d4 tapping frequencies after 8 years of tapping were respectively 108% and 91% of that of d2 (Figure 2). The yield per tapping (g/t/t) was increased significantly by 38% for S/2 d3 and by 48% for S/2 d4 (Figure 3).

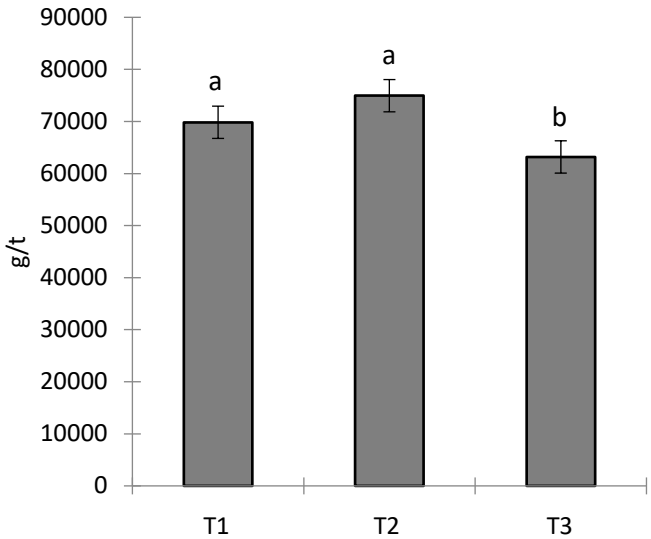


Figure 2: Latex yield (g/t) over 8 years tapping; T1: S/2 d2; T2: S/2 d3 ET 2.5% Pa1(1) 6/y; T3: S/2 d4 ET 2.5% Pa1(1) 8/y (m); different letters in each bar graph indicate significant difference at $p \leq 0.05$ by DMRT.

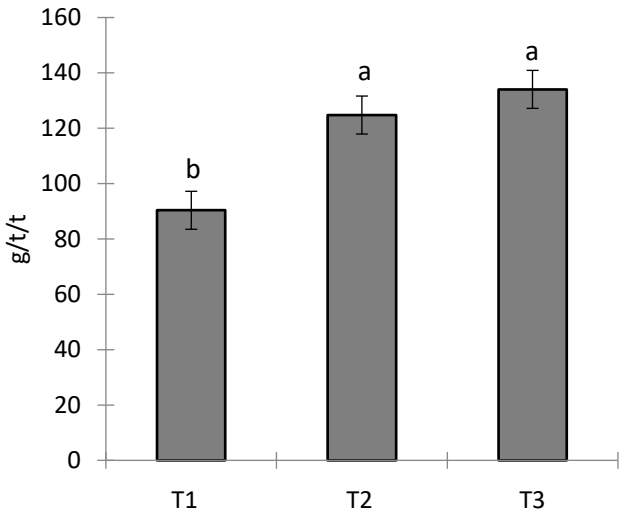


Figure 3: Latex yield (g/t/t) over 8 years tapping; T1: S/2 d2; T2: S/2 d3 ET 2.5% Pa1(1) 6/y; T3: S/2 d4 ET 2.5% Pa1(1) 8/y (m); different letters in each bar graph indicate significant difference at $p \leq 0.05$ by DMRT.

Table 5 shows the average of TSC, Suc, Pi and RSH measured during 8 years of tapping. There was no significant difference among the 3 treatments for TSC, Suc and RSH. T3. Inorganic phosphorus content (Pi) was significantly lower for T3 than for T1, logical as this treatment obtained a lower cumulative production. Latex Diagnosis (LD) profiles are quite logical regarding the observed productions. It can be hypothesized that with d4 tapping frequency, showing slightly higher Suc and TSC and a lower Pi

content, the applied Ethephon stimulation might be not enough to maintain the yield (trend to under-exploitation).

Table 5: Latex biochemistry (TSC; total solid content, Suc; Sucrose content, Pi; inorganic phosphorus content and RSH; reduced thiol content) over the 8 years of tapping.

Treatment	TSC (%)	SUC (mM)	Pi (mM)	RSH (mM)
T1: S/2 d2	45.1	6.44	21.75[a]	0.15
T2: S/2 d3 ET 2.5% Pa1 (1) 6/y (m)	45.4	7.72	20.78[ab]	0.11
T3: S/2 d4 ET 2.5% Pa1 (1) 8/y (m)	45.6	8.08	15.10[b]	0.11

Note: Values with different letters in the same column indicate significant difference with $P \leq 0.05$

The annual tapping bark consumption was significantly different among the 3 treatments (Figure 4). Over 8 tapping years, T1, d2 tapping frequency (T1) showed the highest bark consumption (17.4 cm/year). The d3 tapping frequency (T2) showed an intermediary bark consumption (14.8 cm/year) and T3 with the lowest tapping frequency (d4) had the significantly lowest annual bark consumption (11.6 cm/year).

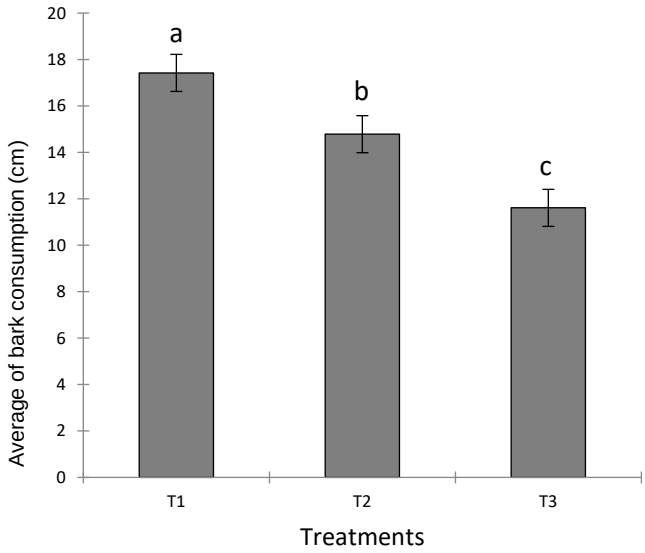


Figure 4: Average of annual bark consumption (cm) over 8 years tapping; T1: S/2 d2; T2: S/2 d3 ET 2.5% Pa1(1) 6/y; T3: S/2 d4 ET 2.5% Pa1(1) 8/y (m); different letters in each bar graph indicate significant difference at $p \leq 0.05$ by DMRT.

3.2. On farm demonstrative fields: alternative tapping systems, adaptation to labor evolution

In the southeast of Thailand, experiments have been set up in a large scale farm of 200 ha (Union Rubber Co Ltd, province of Chanthaburi). The management is there very similar to those used in rubber smallholdings. In fact, a tapping task of 500 to 600 trees is tapped each day by one tapper and is assigned to a tapper's family. The field manager cares about the yield expected from each tapping task. Demonstrative plots have been set up for years under "on farm" actual conditions, dealing with the climatic events, rainy season and dry/wintering season. Usually tapping is stopped during the defoliation-refoliation period from beginning of February to beginning of May.

Different tapping systems were introduced and evaluated in order to improve the daily work productivity without much reduction in the tree / land productivity.

During a first phase of 10 years, tapping is made downward. Then, tapping could be done on the upper panel in the upward direction (Figure 5). According to the classic tapping systems used by farmers, both

tapping in S/2 (half spiral downward) and S/3 (third of spiral downward) have been tested. A second phase was proposed to be tested, for the first time on farm, using the upward tapping system (S/4U after the first phase in S/2 downward, S/3U after the first phase in S/3 downward). The rubber clone was RRIM 600, the most planted in Thailand.

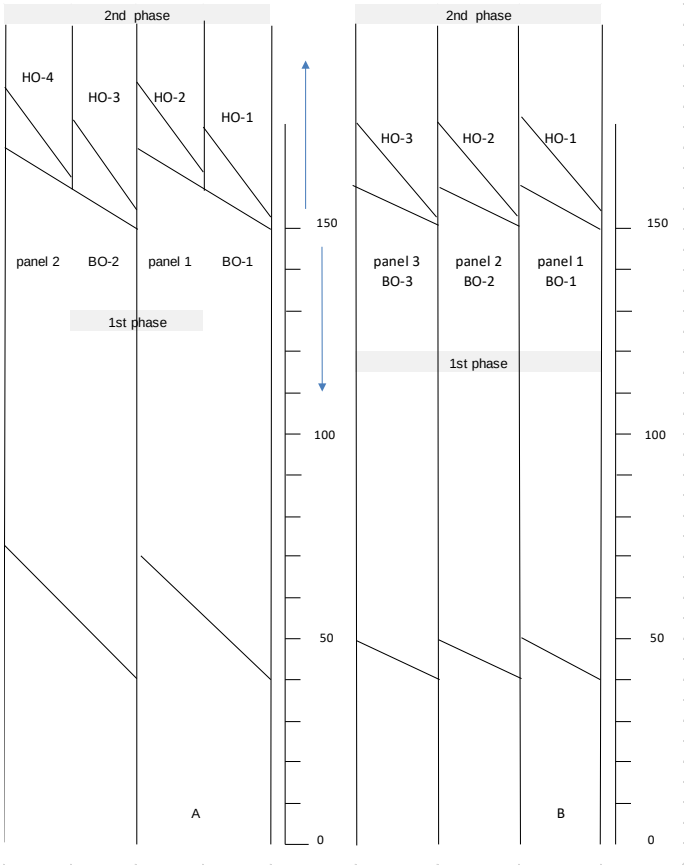


Figure 5: Tapping panel management according to the length of the tapping cut. Downward and upward tappings were tested in a sequence according to the number of tapping years. A: S/2 downward then S/4U after 10 years during the 1st phase, B: S/3 both downward then upward (S/3U) after 10 years during the 1st phase.

In a first approach it was important to talk with the management of the plantation to find a consensus on the different tapping systems to be evaluated. For the first case, to show the effectiveness of the hormonal Ethephon stimulation, the tapping in S/3 was chosen with the d2 frequency. This tapping system is recommended by the RAOT (Rubber Authority of Thailand) although not much used by planters, as most of them tend to tap as often as possible. Ethephon stimulation was tailored to the age of the tapping itself (Figure 6). With such properly adjusted Ethephon stimulation, the yield of S/3 d2 was sustainably increased by 22% for the 10 years of the 1st phase in S/3 d2 downward.

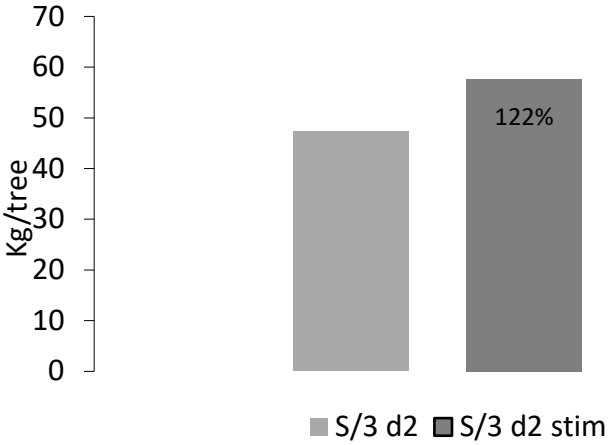


Figure 6: Yield (kg), over 10 years of tapping in S/3 d2. Demonstrative plot with 250 trees per treatment. Hormonal stimulation with 2.5% *a.i.* (Ethephon) was tailored to the age of tapping as follows: year 1; 3 stimulations, years 2-3; 4 stimulations, the year 4 and more; 6 stimulations per year.

When changing the tapping direction to the 2nd phase in upward (S/3U), the yield per tree (Kg/t the 1st and 2nd year of upward tapping, i.e. 11th and 12th years of tapping) was increased by 53% in year 11 and by 59% in year 12 compared to the control maintained in S/3 d2 downward (Figure 7).The yield at each tapping (g/t/t) was respectively increased by 31% and 47% in year 11 and in year 12. Over 2 years upward tapping, hormonal stimulation gave +56% in Kg/t and +39% in g/t/t (Figure 8). Panel changing to upward tapping and a tailored use of Ethephon stimulation are therefore favourable to increase the land productivity.

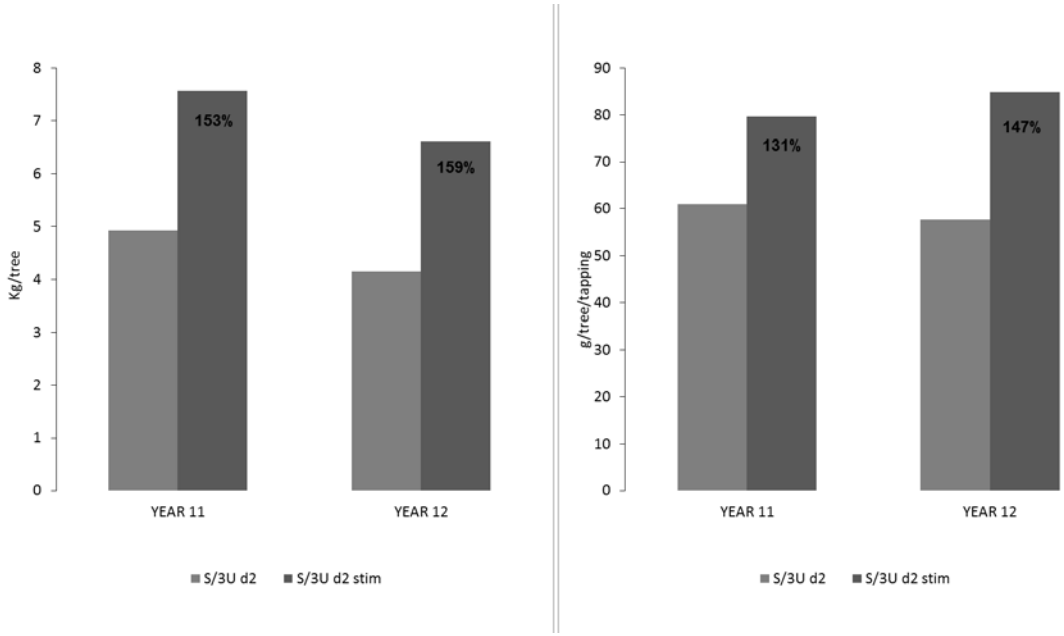


Figure 7: Annual yield, Kg/t and g/t/t, over 2 years of upward tapping in S/3U d2. Demonstrative plot with 250 trees per treatment. Hormonal stimulation with 2.5% *a.i.* (Ethephon): ET 2.5% Pa1(1) 3/y.

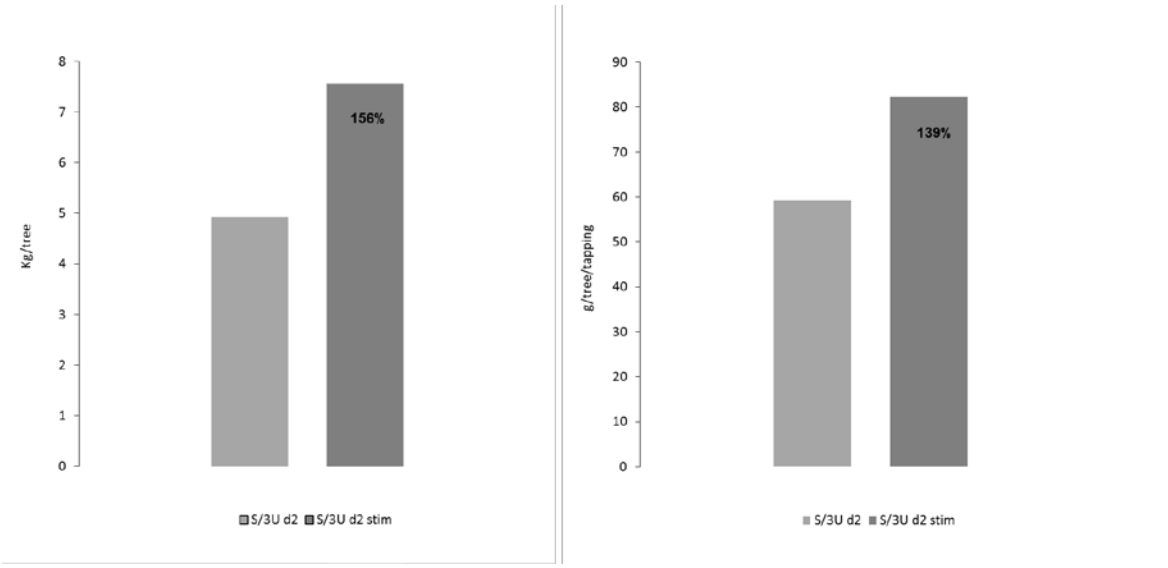


Figure 8: Cumulated yield, kg/t and average yield, g/t/t, over 2 years of upward tapping in S/3U d2. Demonstrative plot with 250 trees per treatment. Hormonal stimulation with 2.5% *a.i.* (Ethephon): ET 2.5% Pa1(1) 3/y.

In Union Rubber Co Ltd Plantation, two tapping frequencies were compared over a period of 10 years of downward tapping, clone RRIM 600: S/2 d2 nil stimulation and S/2 d3 ET 2.5% Pa 1(1) 6/y. Upward tapping was introduced in year 11 with 2 systems: S/2U d2 ET 2.5% 4/y and S/2U d3 ET 5% Pa 1(1) 8/y. During this period, and under real conditions of tapping that can occur on a farm: climatic events (loss of tapping days, no recovery tappings…), constraints of the tappers (health, family issues, social events…), yield have been recorded for each tapping day. The reduction of the tapping frequency from d2 to d3 resulted in a slight decrease of yield (kg/t) by 3% only over the period of 10 years of downward tapping on virgin bark. (Figure 9); The reduction of tapping frequency was therefore almost totally compensated by the use of stimulation. Under stimulation, although the tapping intensity was decreased by 33% from d2 to d3, the daily yield (g/t/t) increased by 30%.

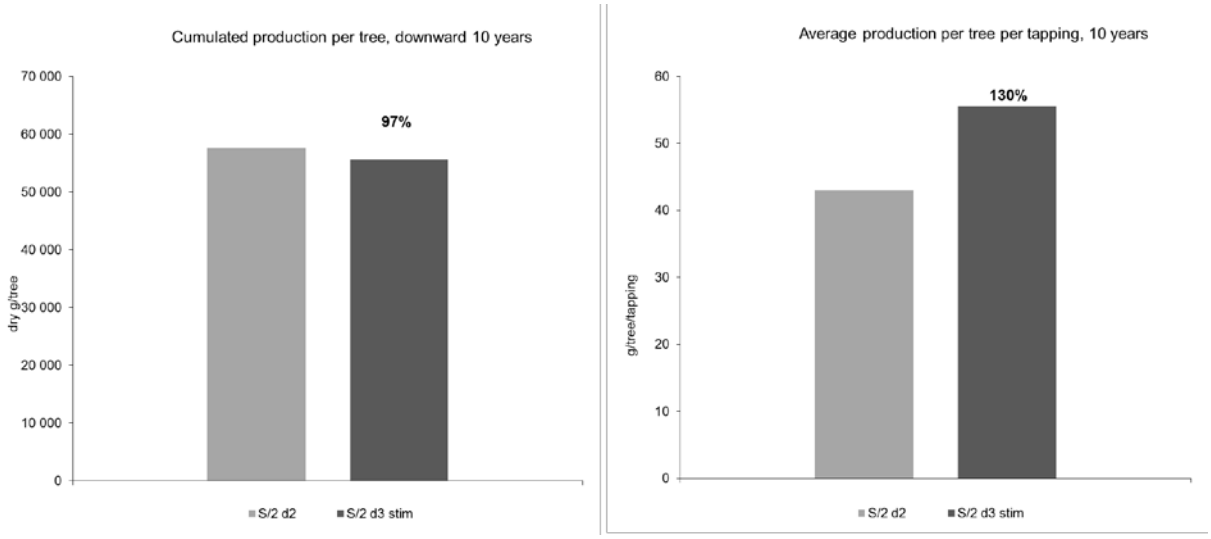


Figure 9: Cumulated yield (Kg/t) and average yield per tree per tapping (g/t/t) of clone RRIM 600: S/2 d2 nil stimulation, S/2 d3 ET 2.5% Pa 1(1) 6/y over 10 years of downward tapping on virgin bark.

When changing over the tapping panel in upward on the panel HO-1, and while a part of each plot of the trials was maintained in downward tapping on renewed bark (B1-1), the tapping on panel HO-1

produced much more than the tapping on panel B1-1 (Figure 10). Even on renewed bark tapped downward, the S/2 d3 tapping frequency still produced 10% more than the S/2 d2. The yield at each tapping (g/t/t) shows the positive effect of the reduction of tapping frequency when compensated by a proper use of stimulation.

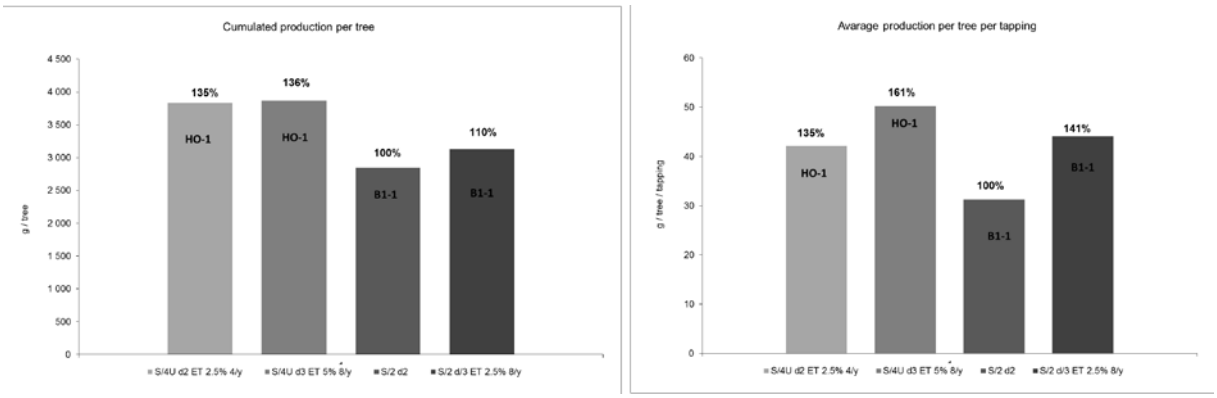


Figure 10: Cumulated yield (Kg/t) of clone RRIM 600 and average of yield per tree per tapping (g/t/t): downward tapping on renewed bark in year 11; S/2 d2 nil stimulation, S/2 d3 ET 2.5% Pa 1(1) 6/y, upward tapping on virgin bark; S/4U d2 ET 2.5% 4/y, S/4U d3 ET 5% 8/y

In Union Rubber Co Ltd Plantation, three tapping frequencies were compared over a period of 11 years of downward tapping, clone RRIM 600: S/2 d2, S/2 d3 ET 2.5% Pa 1(1) 6/y and S/2 d4 ET 2.5% Pa 1(1) 8/y. The reduction of the tapping frequency from d2 to d4 led to a slight decrease of yield (kg/t). The main difference was observed between d2 and d4 with a loss of 10% of the cumulated kg/t (Figure 11). Under stimulation, although the tapping intensity was decreased by 33% and 50% respectively from d2 to d3 and d4, the kg/t was lower only by 5% to 10%. In the same time the yield at each tapping (g/t/t) increased respectively by 37% and 69%.

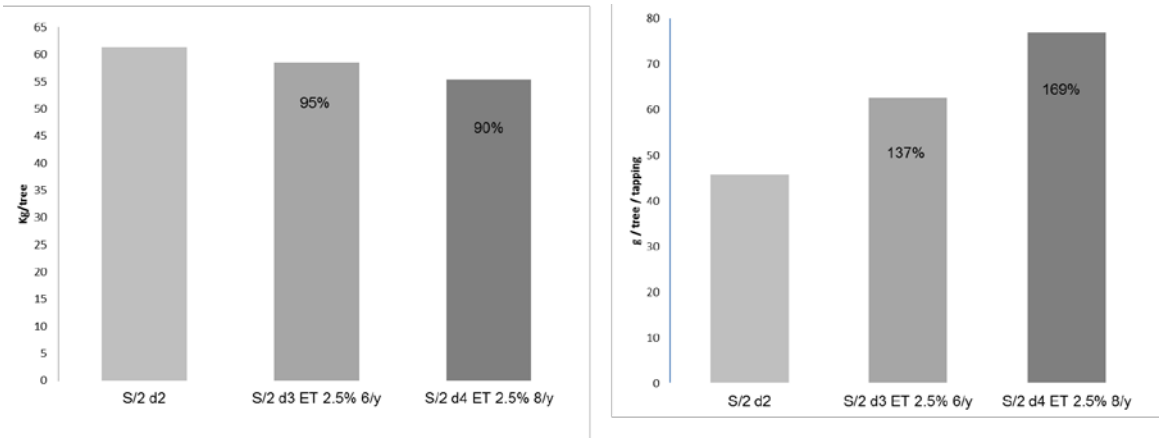
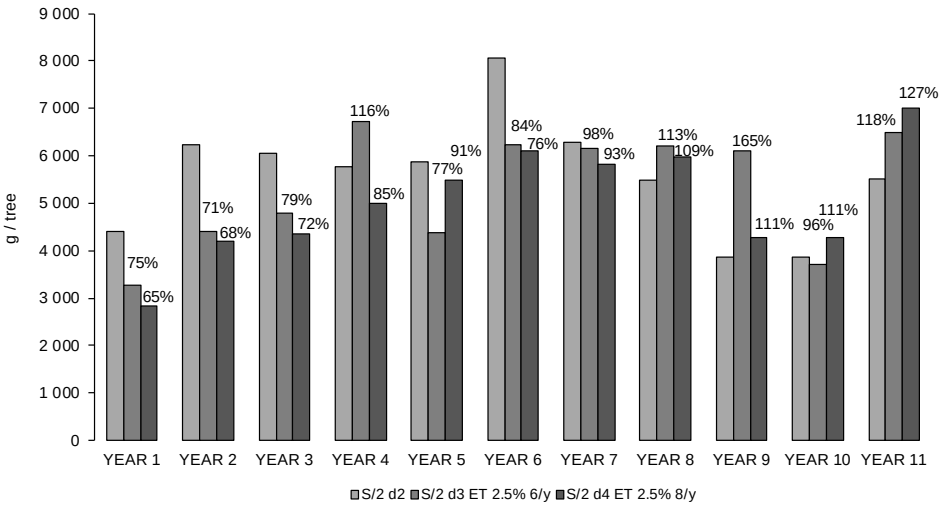


Figure 11: Cumulated yield (g/t) of clone RRIM 600 and average yield per tree per tapping (g/t/t) in S/2 d2, S/2 d3 ET 2.5% Pa1(1) 6/y and in S/2 d3 ET 2.5% Pa1(1) 8/y over 11 years of tapping.

One other interesting aspect of reduction of tapping frequency is the impact of the reduction of the bark consumption. A lower tapping frequency allows to reduce the bark consumption due to the decreased number of tappings per year, even if the daily bark consumption is slightly increased. Hence, the period of tapping on virgin bark can be increased. Also, the virgin bark is potentially producing more than the renewed bark (Lacote et al., 2010). At last, the position of the tapping cut on the panel has a great influence on the yield. The figure 10 shows the yield evolution per year (g/tree). Until the year 6 all treatments are tapped on virgin bark. The S/2 d2 and d3 systems changed over the panel from BO-1 to

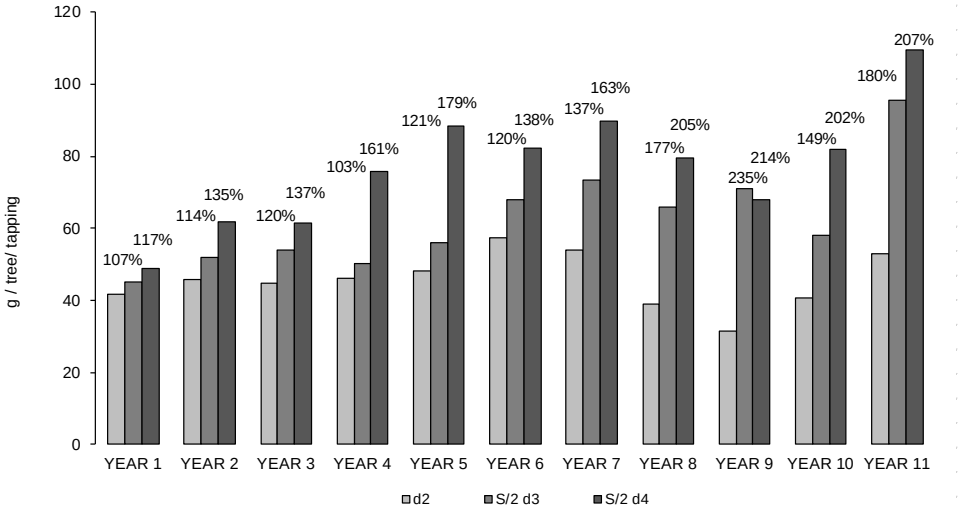
BO-2 in the year 4. The S/2 d4 system changed over the panel BO-1 to BO-2 in year 6. The S/2 d2 system moved back on the renewed bark (B1-1) in year 7. For the 2 other treatments (S/2 d3 and S/2 d4) the panel change-over on the renewed bark was done, in year 9 for the d3 frequency and in year 11 for the d4 frequency. The yield per tree (Figure 12) as the yield per tree per tapping (Figure 13) were related to the dynamics of panel bark consumption and hence to tapping panel management. As the tapping system S/2 d2 is consuming more bark in a year and descending faster on each panel than the 2 other treatments d3 and 4, the yield (g/t) is changing accordingly. Since the year 7, once S/2 d2 tapping was on the renewed bark and for the following years, the difference in yield between the d2 and the d3 and d4 systems was reduced. The d3 and d4 systems were still tapped on virgin bark and their yield per tree (kg/t) were nearly similar to the d2 system. When d3 tapping frequency and d4 tapping frequency were still tapped on virgin bark (BO-2), respectively until the year 8 and 10, their yield was higher than that of d2 tapping frequency. At last, in year 11, S/2 d2 tapping had to move to panel B1-2, *i.e.*, the second panel on renewed bark and got the lowest yield. According to this dynamic in panel management, at each tapping, the gap of yield between d2 and d3-d4 frequencies is higher: kg/t was higher from year 8 to 11 for d3 and d4 tapping frequencies than for d2 frequency. It clearly shows that yield is related to the panel management. Lower tapping frequency, lower bark consumption, longer time on virgin bark and higher g/tree/tapping. During all years the yield per tree per tapping (g/t/t) was higher for the lowest tapping frequencies d3 and d4 than d2. The difference with the d2 frequency was higher while d2 frequency was descending faster on the tapping panel and when the panel changeover was done earlier than d3 and d4 frequencies. All these parameters: tapping frequency, bark consumption and tapping frequency are related each other and make the yield per tree.



d2	BO-1	BO-1	BO-1	BO-2	BO-2	BO-2	B1-1	B1-1	B1-1	B1-1	B1-2
d3	BO-1	BO-1	BO-1	BO-2	BO-2	BO-2	BO-2	BO-2	B1-1	B1-1	B1-1
d4	BO-1	BO-1	BO-1	BO-1	BO-1	BO-2	BO-2	BO-2	BO-2	BO-2	B1-1

Figure 12: Yield (g/tree/year), over 11 years of tapping and according to the tapping panel sequence. Effect of the type of bark (virgin or renewed). Demonstrative plot with 150 trees per treatment. Hormonal stimulation per year was done according to the tapping frequency and the direction of tapping with 2.5% *a.i.* (Ethephon) and tailored to the age of tapping as follows:

- d3; years 1 to 3; 3 stimulations, years 4 and 5; 6 stimulations, years 6 to 11; 8 stimulations, the year 4 and more; 6 stimulations per year,
- d4; years 1 to 3; 4 stimulations, years 4 and 5; 8 stimulations, years 6 to 11; 10 stimulations.



d2	BO-1	BO-1	BO-1	BO-2	BO-2	BO-2	B1-1	B1-1	B1-1	B1-1	B1-2
d3	BO-1	BO-1	BO-1	BO-2	BO-2	BO-2	BO-2	BO-2	B1-1	B1-1	B1-1
d4	BO-1	BO-1	BO-1	BO-1	BO-1	BO-2	BO-2	BO-2	BO-2	BO-2	B1-1

Figure 13 Yield (g/tree/tapping), over 11 years of tapping and according to the tapping panel sequence. Effect of the type of bark (virgin or renewed). Demonstrative plot with 150 trees per treatment. Hormonal stimulation per year was done according to the tapping frequency and the direction of tapping with 2.5% *a.i.* (Ethephon) and tailored to the age of tapping as follows:

- d3; years 1 to 3; 3 stimulations, years 4 and 5; 6 stimulations, years 6 to 11; 8 stimulations, the year 4 and more; 6 stimulations per year,
- d4; years 1 to 3; 4 stimulations, years 4 and 5; 8 stimulations, years 6 to 11; 10 stimulations.

In year 12, tapping panels have been changed to upward tapping HO-1 for all tapping systems (Figure 14). For this first year of upward tapping, it was possible to sustain the same yield (kg/t) when reducing the tapping frequency to d3 and d4 in comparison to the d2 frequency. The yield at each tapping (g/t/t) was increased (+49% to +72%) respectively in d3 and in d4 tapping frequencies. This shows that it is possible, on farm, to use lower tapping frequency and to use upward tapping to increase the yield at each tapping and therefore to maximize the labor productivity (kg/tapper/day).

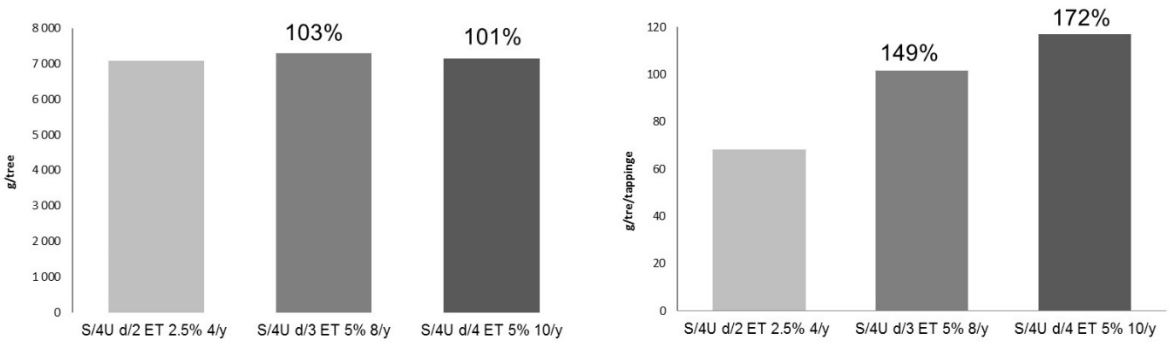


Figure 14: Cumulated yield (g/t) of clone RRIM 600 and average yield per tree per tapping (g/t/t) in year 12 of tapping and according to the tapping panel sequence; panel HO-1.

4. Discussion and conclusion

In our experiments, the yield per tree and per tapping (g/t/t) of low frequency tapping systems (LFT) (S/2 d3 and S/3 d3) with stimulation was always shown significantly higher than that of the traditional tapping system (S/3 2d/3), commonly used in southern Thailand. LFT systems combining reduction of tapping frequency with a tailored and proper Ethephon stimulation increase the duration of latex flow after tapping. Stimulation delays latex coagulation (improved water importation to the latex and lutoid stabilization) and activates the latex cell metabolism. This, combined with a longer regeneration time between two consecutive tappings, leads to export more latex at each tapping (Jacob *et al*., 1989; Gohet *et al*., 1991, d'Auzac *et al*., 1997, Vijayakumar *et al*., 2003, Soumahin *et al*., 2009, Traoré *et al*., 2011, Sainoi *et al*., 2017a and b). This increase in g/t/t can compensate the reduction of the number of tappings per year. In Thepa Research Station, Prince of Songkla University, cumulative yield was nearly the same over 3 years of tapping for all treatments. Only the treatment using S/3 d3 with stimulation showed a lower yield compared with S/3 2d/3, although it gave higher yield per tapping. The reduction of both the tapping cut length and of the tapping frequency, even using intensified stimulation, induced a lower cumulative yield. On the other hand, S/2 d3 with stimulation showed no significant difference with the traditional tapping system (S/3 2d/3) or other tapping systems (S/2 d2 and S/3 d2 with stimulation). This indicated that the reduction of tapping frequency with properly adjusted stimulation could compensate almost totally the cumulative yield per tree, with a higher yield per tapping, even under the prolonged rainy season of Southern Thailand. These results are also supported by Gohet *et a*l. (1991), Njukeng and Gobina (2007) and Rodrigo *et al*. (2011). Low tapping frequency systems (LFT) must be used with stimulation to increase the yield at each tapping, in order to compensate the decrease of the annual number of tappings. (Jacob *et al*., 1989; d'Auzac *et al*., 1997, Obouayeba *et al*., 2011, Diarrassouba *et al*., 2012).
The latex parameters consist of total solid content (TSC), inorganic phosphorus content (Pi), reduced thiol content (RSH) and Sucrose content (Suc). TSC did not show significant difference among the treatments, so there was no effect of tapping cut length and tapping frequency on the TSC. Pi content was found higher in the LFT systems d3 with Ethephon stimulation, mainly with the longest cut S/2. This reflects a good metabolic activity of the yield (Jacob *et al*., 1988; 1989; Gohet *et al*., 2003; Lacote *et al*., 2010), giving one of the highest yields. The increased metabolic activity with Ethephon stimulation leads to high Pi content and depleted the Suc content involved in the latex regeneration to sustain a high yield. The d3 tapping frequency systems with stimulation always showed a lower RSH content in latex than the d2 tapping frequency systems. However, the longer cut length (S/2) with d3 frequency induced lower RSH content than other treatments. The colloidal stability of the latex was more preserved in the short cut length than the long cut length (Obouayeba *et al*., 2011). The effect of stimulation is well known on the use of RSH as scavengers to protect the stability of the membranes of the vacuo-lysosomal system in the latex cells (Jacob *et al*., 1989; d'Auzac *et al*., 1997). A decrease of Suc content was clearly found in the LFT systems d3 with stimulation. It is related to the increase of yield per tapping and per tree, and the cumulative yield was balanced with all treatments. A lower Suc content indicates a higher Suc consumption due to a more activated metabolism of the latex cells under Ethephon stimulation in d3 tapping frequency: higher the volume of latex exported at each tapping, higher the need to regenerate the latex cell content by using more Suc (Jacob *et al*., 1989; Lacote *et al*., 2004) leading to a depletion of sucrose in latex (Gohet *et al*., 1996, 2003; Obouayeba *et al*., 2009; Rodrigo *et al*., 2011). Our results confirm that the sugar loading capacity of the latex cells is one of the main factors that enables a significant increase in latex yield after Ethephon stimulation (Gohet *et al*., 1996, 2001, 2003).

In the research station of Kasetsart University (Prachuap Khiri Khan), for the clone RRIT251, the cumulative yields of d3 and d4 tapping frequencies after 8 years of tapping were respectively 108% and 91% of that of d2. The yield per tapping (g/t/t) was increased significantly by 38% for S/2 d3 and by 48% for S/2 d4. The loss in cumulative yield in S/2 d4 might be related to the metabolic activity of the laticiferous tissues. The latex Diagnosis has shown that TSC, Suc, Pi and RSH measured during 8 years of tapping were not different among the 3 treatments. Inorganic phosphorus content (Pi) was significantly lower for the d4 frequency than for d2. Latex Diagnosis (LD) profiles are quite logical

regarding the observed productions (Jacob *et al*., 1988; 1989; Gohet *et al*., 2003; Lacote *et al*., 2010). It can be hypothesized that with d4 tapping frequency, showing slightly higher Suc and TSC and a lower Pi content, the Ethephon stimulation might be not enough to maintain the yield (trend to under-exploitation).

LFT systems showed a marked decrease of bark consumption comparing with the traditional tapping system in Thailand S/3 2d/3 and other tapping systems (S/2 d2). Less bark consumption increases economic life span of rubber trees. (Nugawela *et al*., 2000; Rodrigo 2007). Besides, the commencement of tapping in renewed bark could be delayed, increasing the additional time for bark regeneration (Rodrigo *et al*., 2011).

The results have shown how it was possible to enhance the yield per tree and tapping. It is possible to use LFT (low frequency tapping systems) when using hormonal stimulation, with the condition that this hormonal Ethephon stimulation must be tailored to rubber tree clone, tapping frequency, direction of tapping and tree age. Accordingly, this leads to a higher labor productivity (kg per tapper and per day) that can compensate the reduction of the tapping frequency (Gohet *et al*., 1991, Lacote *et al*., 2010; Njukeng *et al*., 2011; Traore *et al*., 2011, Zar Ni Zaw *et al*., 2017). In Southern Thailand, LFT systems with stimulation were difficult to recommend as it is difficult to change the habits of both owners and hired tappers. In Thailand, farmers usually select a latex harvesting system that defines a theoretical frequency of tapping, like tapping 2 days out of 3 (d1/2d/3) or every two days (d/2). In reality, on farms, the actual number of tapping days (and therefore the actual tapping frequency) depends on the rain, as tapping is not performed on rainy days. Therefore, farmers tap their rubber trees with relatively lower intensity and without a regular pattern (Chambon *et al.*, 2014). Although the repartition of tapping days is uneven, such systems are considered well adapted to the smallholder's conditions, with an acceptable productivity (Chambon *et al*., 2014). In Northeastern and North Thailand, it seems that planters are adopting a lower tapping frequency as d/2. On one hand they face less risk of tapping losses due to a shorter rainy season than in the southern area, on the other hand, they face a longer dry season and defoliation-refoliation period (almost 5 months). In that case, and opposite to the southern area, the adaptation to climate constraints maybe more profitable in term of land and labor productivity, using lower tapping frequency as d/3, compensated by the use of Ethephon stimulation. At the farm level, the risk is then trees exhaustion by using too intensive Ethephon stimulation of the laticiferous tissues (d'Auzac *et al*., 1997), particularly as the farmers and tappers lack experience. However, it seems that farmers really worry about the stimulated tapping systems as they experienced a misuse of Ethephon stimulation in the past (70's).

The on farm trials have confirmed results obtained under controlled conditions in research stations. The reduction of the tapping frequency can be compensated by a tailored use of Ethephon stimulation. Results clearly show that the daily yield is greatly increased when using lower tapping frequencies. According to these results, during more than 11 years of tapping, the panel management and the location of the tapping cut on the panel in downward tapping has a significant effect of the yield. Tapping on virgin bark when using d3 and d4 frequencies is more favorable to yield than d2 frequency on the renewed bark. Moreover, when changing the tapping panel upward, the positive effect of the lower tapping frequencies is higher than in downward tapping. It clearly shows that a good panel management, combined with a tailored stimulation and a reduced tapping frequency can be efficient on farm. These results are encouraging to support a transfer of such technology (TOT) to smallholders in Thailand and neighboring countries to increase the daily income of the farmers. That is the point to focus on, with the guidance of the extension officers involved in rubber development and innovations transfer.

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