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Impact of Reduced Tapping Frequency on Agronomic, Physiological and Biochemical Aspects of Clone PB 260 of Hevea brasiliensis *in the Centre West of Cote D'Ivoire*

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Rubber cultivation faces the problem of scarcity of skilled tapping labour despite a significant reduction in the tapping intensity owing to latex harvesting technologies. Thus, it is essential to optimise latex harvesting technologies by a greater reduction in the need for tapping labour. To achieve this, a study was conducted on clone PB 260 of Hevea brasiliensis*, in Gagnoa, in the centre west of Côte d'Ivoire. Low tapping frequencies (d4, d5 and d6) which are low consumers of tapping labour were compared to the standard (d3) system, which is a high consumer of tapping labour. The results showed that low frequency tapping leads to yield losses per tree by four to 31% compared with standard tapping. These low yield losses however, are compensated by the additional areas that these technologies are able to exploit. Furthermore, low frequency tapping improves yield per tree and per tapping as well as the output of the tapper by 23 to 36% compared with standard tapping. In addition to that, low frequency tapping systems have no significant negative impact on vegetative growth, physiological profile and sensitivity to tapping panel dryness. Therefore, these technologies can be adopted to remedy the shortage of tapping labour in rubber cultivation.*

Keywords: *Hevea brasiliensis*; latex harvesting technologies; low tapping frequency; rubber yield; radial vegetative growth; physiological profile; tapping panel dryness; Côte d'Ivoire

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The improvement in productivity of a rubber tree is determined by latex harvesting technologies which are the tapping systems and hormonal stimulation for rubber yield. Tapping enables rubber yield, which in turn may be limited by the metabolism of the latex vessel system of the tapped clone. For a better evaluation of tapping systems on different clones, hormonal stimulation is added to enable significant increase of up to double or triple, in rubber yield[1–5].

In the absence of hormonal stimulation, harvesting of rubber latex was practised through a full spiral tapping every two days[6] (d2). This tapping system requires significant tapping labour, which significantly reduces the profit margin of the farmer as tapping labour is the highest expense in latex harvesting. In addition to that, the labour is unstable (moving from one plantation to another), scarce, expensive and minimally skilled. In the perspective of an efficient management of tapping labour and rubber yield, many studies have been able to reduce progressively the tapping intensity owing to the contribution of hormonal stimulation, while maintaining a good level of yield. Tapping frequency switched, therefore, from tapping every two days (d2) to tapping every three days (d3) and from tapping in full spiral (S) to tapping in half (S/2) and quarter spiral[6,7] (S/4).

However, despite this significant reduction in the tapping intensity owing to latex harvesting technologies, rubber cultivation remains highly dependent on consumers of tapping labour[8]. This is therefore a serious barrier for rubber yield[5]. Indeed, many hectares of rubber tree plantations in Côte d'Ivoire and worldwide are untapped due to lack of tappers[8].

To cope with that, it is essential to optimise latex harvesting techniques by a greater reduction in the needs for tapping labour in order to improve the productivity of rubber cultivation. For that purpose, several low intensity tapping systems of latex harvesting have been tested in the context of a research project APROMAC-FIRCA-CNRA in Côte d'Ivoire. These techniques are able to increase the income of tappers and farmers insofar as exploited areas increase. The results of three years of experiments on rubber yield parameters are presented in this paper.

MATERIALS AND METHODS

Study Site

The experiment was carried out in Gagnoa, in the centre west of Côte d'Ivoire (6º09'N latitude, 5º52'W longitude). This region is characterised by a sub-equatorial climate with an average annual rainfall exceeding 1600 mm and a bimodal regime (two rainy seasons, from April to July and from October to November and two dry seasons from December to February or March and from August to September). The soils are ferralitic derived from tertiary sand[9].

Plant Material

The experiment focused on clone PB 260 of *Hevea brasiliensis* planted in 1998. This clone originates from Malaysia. PB 260 is a clone with active metabolic activity with high susceptibility to tapping panel dryness[10]. The trees, tapped since 2004, were exploited in downward half spiral, tapped twice a week (d3) until May 2007. The experiment began in June 2007 and was completed in May 2010.

Methods

Experimental System and Treatments. The statistical system used was in Fisher blocks with seven treatments consisting 10 trees per treatment and three repetitions. The trees were planted with a density of 555 trees per hectare (6 × 3 m). All trees showing any anomaly (breakage due to wind, tapping panel dryness, *Fomes lignosus* attacks, *etc*.) were removed from production data since the beginning of the experiment.

Low tapping frequency treatments (d4, d5 and d6) were compared to traditional tapping in d3. The details concerning these treatments were recorded in *Table 1*[11].

Measurements

Yield. The yield was estimated by weighing fresh coagulated rubber of each experimental unit every four weeks. For each treatment, a two kg sample of fresh coagulated rubber was used to calculate the transformation coefficient, which is used to determine the weight of dry rubber in gram per tree (g/t), the weight in gram per tree per tapping (g/t/t), the productivity of the tapper in kilogram per tapper per day (kg/t/d) and the productivity per tapper and per year according to the area tapped (kg/t/y).

Girth Increment. Radial growth was measured at the beginning of the experiment and thereafter, once per year. Tree girth was measured at 1.70 m above the ground. Girth increment was expressed in cm/year.

Physiological Profile. The more important physiological parameters were assessed once a year in December, taking into account dry rubber and sucrose, inorganic phosphorus and thiol contents. Thus, latex samples were taken according to the method of latex microdiagnosis[12]. To determine the dry rate (%), a latex sample was weighed before and after drying in an oven at 80ºC for 24 hours. The sucrose, the inorganic phosphorus and the reduced thiol groupings were measured on the clear serum called TCA-serum (trichloroacetic acid) that is obtained after latex acid coagulation, respectively by the Ashwell[13] anthrone method, the Tausky and Shorr[14] molybdate ammonium method and the Boyne and Ellman[15] acid dinitro-dithio-dibenzoic (DTNB) method. The results were stated in mmole per litre of latex (mM).

Visual Estimation of Tapping Panel Dryness. The tapping panel dryness quick measurement method by visual estimation[16]

TABLE 1. TREATMENTS OR LATEX HARVESTING TECHNOLOGIES USED

No.	Treatments	TI (%)	NT	TE (%)
1	S/2 d3 6d/7 12m/12 ET2.5% Pa(1) 4/y (C)	100	104	0
2	S/2 d4 6d/7 12m/12 ET2.5% Pa(1) 6/y	75	78	25
3	S/2 d5 6d/7 12m/12 ET2.5% Pa(1) 6/y	62,5	62	37,5
4	S/2 d6 6d/7 12m/12 ET2.5% Pa(1) 6/y	50	52	50
5	S/2 d4 6d/7 12m/12 ET5% Pa(1) 6/y	75	78	25
6	S/2 d5 6d/7 12m/12 ET5% Pa(1) 6/y	62,5	62	37,5
7	S/2 d6 6d/7 12m/12 ET5% Pa(1) 6/y	50	52	50

NB :
TI (%) : Tapping intensity
NT : Number of tappings
TE(%) : Tappers Economy
C : Control

facilitates a report on the progress of the tapping panel dryness panel disease. In that respect, trees tapped were rated from 0 to 6 in proportion to the progress of the disease (*Table 2*). The sensitivity of trees to tapping panel dryness is assessed through the parameters which are: dry cuts (%) and dry trees (%).

Statistical Analysis. An analysis of variance of the data including rubber yield, vegetative radial growth, latex microdiagnosis and tapping panel dryness was carried out with XLSTAT statistical software and the Student-Newman-Keuls test, at 5 percent.

RESULTS

Rubber Yield

Average Annual Yield in g/t. The trees tapped in half spiral every four days (treatments 2 and 5) provided rubber yield in g/t statistically identical to that of the control (treatment 1) tapped in downward half spiral every three days. Treatments 1, 2 and 5 yields were significantly higher than those of the other patterns (*Table 3*). The losses in rubber yield, compared with the control (d3), caused by the reduction of tapping intensity from d4, d5 and d6 were respectively 7, 26 and 31% at the concentration of 2.5% ethephon. At the concentration of 5% ethephon, they were respectively 4, 20 and 28 percent.

Productivity of Tapping in g/t/t. All the treatments provided rubber yields in g/t/t statistically higher than that of the control (treatment 1, *Table 3*). The low tapping frequency treatments facilitate rubber yields statistically identical to each other. Compared with the control, the tappings in d4, d5 and d6 lead to average rubber yield gain in g/t/t of 24, 23 and 36% respectively, at the concentration of 2.5% ethephon and 27, 33 and 42 % at the concentration of 5% ethephon (*Table 3*).

Daily Productivity of the Tapper in kg/t/d. The average output of the tapper (kg/t/d) increased with the reduction in the tapping frequency and the increase in the concentration in active matter (ethephon) of the stimulation (*Table 3*). All the treatments provided yield per tapper significantly higher than that of the control by 24 to 42 percent.

Average Annual Output of the Tapper According to Areas Tapped (kg/t/a/y). The average annual yields of rubber per tapper and per area tapped of low frequency systems (d4, d5 and d6) are superior to that of standard tapping in d3 (*Table 4*). The rubber yield gain caused by low frequency tapping vary by 22 to 44% compared with standard tapping, which

TABLE 2. RATING OF THE TREES DURING THE SURVEY OF TAPPING PANEL DRYNESS

Dry cut	Score	Meaning
0%	0	Healthy trees
1 - 20%	1	Trees affected by dry cut at a very low level
21 - 40%	2	Trees affected by dry cut at a low level
41 - 60%	3	Trees affected by dry cut at a medium level
61 - 80%	4	Trees affected by dry cut at a high enough level
81 - 99%	5	Trees affected by dry cut at a high level
100%	6	Dry trees

TABLE 3. ANNUAL MEAN RUBBER (g/t, g/t/t) AND DAILY PRODUCTIVITY OF TAPPER (kg/t/d) OF THE CLONE PB 260 OF *HEVEA BRASILIENSIS* UNDER LOW FREQUENCIES TAPPING DURING THREE YEARS IN THE CENTRE WEST OF CÔTE D'IVOIRE

No.	Treatments	TI (%)	g/t	GYg/t(%)	g/t/t	GYg/t/t(%)	kg/t/d	GYkg/t/d(%)
1	S/2 d3 6d/7 12m/12 ET2.5% Pa(1) 4/y (T)	100	9 453a	-	91c	-	36c	-
2	S/2 d4 6d/7 12m/12 ET2.5% Pa(1) 6/y	75	8 798a	-7	113b	24	45b	24
3	S/2 d5 6d/7 12m/12 ET2.5% Pa(1) 6/y	62.5	6 945b	-26	112b	23	45b	23
4	S/2 d6 6d/7 12m/12 ET2.5% Pa(1) 6/y	50	6 450b	-31	124ab	36	50ab	36
5	S/2 d4 6d/7 12m/12 ET5% Pa(1) 6/y	75	9 050a	-4	116ab	27	46ab	27
6	S/2 d5 6d/7 12m/12 ET5% Pa(1) 6/y	62.5	7 493b	-20	121ab	33	48ab	33
7	S/2 d6 6d/7 12m/12 ET5% Pa(1) 6/y	50	6 785b	-28	130a	42	52a	42

Mean followed by same letter in each column are not significantly different (Test of Newman-Keuls at 5 %)
GY : Gain in rubber yield
IT : Intensité de saignée
g/a : Gramme par arbre
g/a/s : Gramme par arbre par saignée
kg/sgr/j : Kilogramme par saigneur par jour

corresponds to two to five tonnes of rubber per year and per tapper.

Radial Vegetative Growth of Rubber Trees. The average annual increases in girth of tree trunk at the end of the different treatments carried out were statistically identical (*Table 5*). However, those increases were variant by 3.6 to 4.6 cm/year.

Physiological Profile of Rubber Trees

Average Dry Rubber Contents of the Latex. The average dry rubber contents of the latex were very high for all the latex harvesting technologies including that of the control (*Table 6*) at the beginning and at the end of the experiment. They were statistically equivalent. However, the contents

TABLE 4. ESTIMATED ANNUAL YIELD ACCORDING TO THE TAPPED AREAS AND TAPPING FREQUENCIES

Treatments	Yield (g/t)	Estimated Yield (kg/ha/year)*	No of ha tapped per tapper**	Estimated total yield (kg/year)
S/2 d3 6d/7 12m/12 ET2.5% Pa(1) 4/y (T)	9 453a	3 781a	3	11 344
S/2 d4 6d/7 12m/12 ET2.5% Pa(1) 6/y	8 798a	3 519a	4	14 077
S/2 d5 6d/7 12m/12 ET2.5% Pa(1) 6/y	6 945b	2 778b	5	13 890
S/2 d6 6d/7 12m/12 ET2.5% Pa(1) 6/y	6 450b	2 580b	6	15 480
S/2 d4 6d/7 12m/12 ET5% Pa(1) 6/y	9 050a	3 620a	4	14 480
S/2 d5 6d/7 12m/12 ET5% Pa(1) 6/y	7 493b	2 997b	5	14 986
S/2 d6 6d/7 12m/12 ET5% Pa(1) 6/y	6 785b	2 714b	6	16 284

Mean followed by same letter in each column are not significantly different (Test of Newman-Keuls at 5 %)
*1 ha = 400 trees
** Number of ha tapped per tapper : d3 : 3 ha ; d4 : 4 ha ; d5 : 5 ha ; d6 : 6ha

TABLE 5. ANNUAL AVERAGE GIRTH INCREMENT (cm/year) OF THE CLONE PB 260 OF *HEVEA BRASILIENSIS* UNDER LOW FREQUENCIES TAPPING DURING THREE YEARS IN THE CENTRE WEST OF CÔTE D'IVOIRE

No.	Treatments	Girth increment (cm/year)
1	S/2 d3 6d/7 12m/12 ET2.5% Pa(1) 4/y (C)	3.6 a
2	S/2 d4 6d/7 12m/12 ET2.5% Pa(1) 6/y	4.0 a
3	S/2 d5 6d/7 12m/12 ET2.5% Pa(1) 6/y	4.2 a
4	S/2 d6 6d/7 12m/12 ET2.5% Pa(1) 6/y	4.6 a
5	S/2 d4 6d/7 12m/12 ET5% Pa(1) 6/y	4.2 a
6	S/2 d5 6d/7 12m/12 ET5% Pa(1) 6/y	4.4 a
7	S/2 d6 6d/7 12m/12 ET5% Pa(1) 6/y	4.5 a

Mean followed by same letter in each column are not significantly different (Test of Newman-Keuls at 5 %)

showed a slight reduction at the end of the experiment regardless of the treatment.

Average Sucrose Contents of the Latex. All the treatments showed average sucrose contents of the latex at the beginning of the experiment. At the end of the experiment, there was an increase in the average sucrose content for all the treatments (*Table 6*). However, the contents of treatments 2 and 5 (tapped every four days) remained average.

Average Inorganic Phosphorus Contents of the Latex. The average Pi contents of the latex were low for all the treatments and statistically identical to each other at the beginning and at the end of the experiment. These contents however, experienced an increase at the end of the experiment following the reduction of the tapping frequency and the intensification of hormonal stimulation (*Table 6*).

Average Thiol Compound Contents of the Latex. At the beginning of the experiment, the thiol compound contents of the latex were very low for all the treatments and were statistically identical to each other. At the end of the experiment, there was a very significant increase in those contents regardless of the treatment (*Table 6*).

Sensitivity to Rubber Tree Tapping Panel Dryness

The rates of dry cut were low and statistically equivalent for all the treatments (*Table 7*). Concerning the rate of dry trees, no treatment showed dry trees (*Table 7*).

Yield of Rubber Trees

Compared to the standard tapping in d3, the low frequency tapping systems (d4, d5 and d6) caused average annual production losses per tree by 7 to 31% and by 4 to 28% respectively at the concentrations of 2.5 and 5% ethephon. The lowest annual rubber yields were recorded with the tapping in d6 whatever the concentration in active matter of the stimulating pulp. These results are in accordance with those of Hong[17], Nasir and Ghani[18], Said *et al.*[19] and Soumahin *et al.*[3] who showed that the tapping frequency should be sufficient for the yield to progress

TABLE 6. PHYSIOLOGICAL STATUS OF THE CLONE PB 260 OF *HEVEA BRASILIENSIS* UNDER LOW FREQUENCIES TAPPING DURING THREE YEARS IN THE CENTRE WEST OF CÔTE D'IVOIRE

Treatments 6d/7 12m/12 Pa1(1)	Physiological parameters							
	DRC(%)		Suc (mM)		Pi (mM)		Thiol (mM)	
	Start	End	Start	End	Start	End	Start	End
1. S/2 d3 ET2.5% Pa(1) 4/y (C)	53.3	49.2	7.7	11.4	9.9	10.3	0.20	0.74
2. S/2 d4 ET2.5% Pa(1) 6/y	54.8	53.7	6.7	7.6	8.8	9.7	0.10	0.89
3. S/2 d5 ET2.5% Pa(1) 6/y	55.1	51.0	6.3	9.9	8.5	11.0	0.10	0.76
4. S/2 d6 ET2.5% Pa(1) 6/y	69.5	52.1	6.9	10.3	9.1	10.6	0.20	0.79
5. S/2 d4 ET5% Pa(1) 6/y	55.3	49.3	7.4	7.9	9.5	10.9	0.20	0.55
6. S/2 d5 ET5% Pa(1) 6/y	56.8	50.4	7.6	10.1	8.1	12.1	0.10	0.54
7. S/2 d6 ET5% Pa(1) 6/y	54.3	52.9	7.3	9.8	8.7	9.6	0.10	0.65

TABLE 7. DRY CUT (%) AND DRY TREES (%) OF THE CLONE PB 260 OF *HEVEA BRASILIENSIS* UNDER LOW FREQUENCIES TAPPING DURING THREE YEARS IN THE CENTRE WEST OF CÔTE D'IVOIRE

No.	Treatments	Dry cut (%)	Dry trees (%)
1	S/2 d3 6d/7 12m/12 ET2.5% Pa(1) 4/y (C)	0.0 a	0
2	S/2 d4 6d/7 12m/12 ET2.5% Pa(1) 6/y	6.5 a	0
3	S/2 d5 6d/7 12m/12 ET2.5% Pa(1) 6/y	1.5 a	0
4	S/2 d6 6d/7 12m/12 ET2.5% Pa(1) 6/y	4.0 a	0
5	S/2 d4 6d/7 12m/12 ET5% Pa(1) 6/y	1.2 a	0
6	S/2 d5 6d/7 12m/12 ET5% Pa(1) 6/y	6.0 a	0
7	S/2 d6 6d/7 12m/12 ET5% Pa(1) 6/y	5.5 a	0

Mean followed by same letter in each column are not significantly different (Test of Newman-Keuls at 5 %)

towards the potential of trees. Indeed, below a certain tapping frequency, the extension of the period between two consecutive tappings has a negative impact on the flow duration of the latex and therefore on the yield[3,5,20]. Moreover, increase in the concentration of stimulation enabled to reduce rubber yield losses caused by low tapping frequencies. Indeed, hormonal stimulation of the yield enables a significant increase in rubber yield[3,6,21].

The yield per tree and per tapping was clearly improved by the reduction of tapping frequency. Indeed, extension of the period between two consecutive tappings enables a better regeneration of the content of latex vessels leading to an improvement of the yield per tree and per tapping[5,22,23].

Low tapping frequencies enabled to enhance the output of the tapper compared with standard tapping. This is due to the fact that low frequency tapping systems improve the yield per tree and per tapping and therefore the productivity of the tapper. These results are in accordance with those of Soumahin[5].

The rubber yields per tapper and area exploited were more significant with the low frequency tapping systems than the standard tapping. The yield losses caused by the low frequency tapping systems (4 to 31%) are therefore compensated by additional areas that are exploited[5]. Indeed, the standard tapping in d3 exploits three ha per tapper while the tappings in d4, d5 and d6 enable respectively four, five and six ha per tapper. In that respect, low tapping frequencies increase the areas tapped, the output of the tapper and therefore the income of the tapper and the farmer in the context of shortage of tapping labour[5,8,24,25].

Radial Vegetative Growth of Rubber Trees

The trees tapped at a low frequency showed increases statistically identical to those of the control (tapping in d3). The reduction of tapping frequency and intensification of hormonal stimulation has therefore no significant impact on the vegetative growth of clone PB 260[5,21].

Physiological Profile of Rubber Trees

Average dry rubber contents of the latex were very high for all the latex harvesting technologies at the beginning and end of the experiment. These contents reflect the high metabolic activity of regeneration which characterises clone PB 260. The different dry rubber contents were, generally, subject to decrease when we intensified hormonal stimulation[5,26] (by 2.5 to 5% ET). This fall of dry rubber content is due to the fact that hormonal stimulation induces an increase of water transfers within latex vessels[27]. This process leads to dilution of the latex in the long run which is the cause of lesser dry contents.

High sucrose contents at the end of the experiment indicate a good supply of latex vessels in relation to the productivity of rubber trees[26,27]. Indeed this content reflects the activation of latex-production metabolism since sucrose is the raw material of isoprene biosynthesis[2].

The inorganic phosphorus contents, in general, low at the beginning of the experiment, increased with the reduction of tapping frequency and intensification of hormonal stimulation. This increase can be attributable to the intensification of hormonal stimulation which causes the activation of regeneration metabolism of latex vessel cells.

Indeed, the concentration of inorganic phosphorus reflects the intensity of latex-production metabolism[26].

The very low level of thiol group contents of the latex at the beginning of experiment is the expression of an early depletion of the biological protection of latex vessels and latex stability[28]. This suggests an intensive exploitation of trees before the implementation of the experiment. At the end of the experiment, the high increase in thiol contents seems to reflect a regeneration of the latter through the degradation of the intra latex vessel sugar[29]. Indeed, the degradation of the latter provides the energy and the reducing power required for the regeneration of thiols.

Overall, the low frequency tapping systems have no negative impact on the physiological profile of trees of clone PB 260[5].

Sensitivity to Tapping Panel Dryness of Rubber Trees

The rates of dry cut and dry trees were generally low. The standard tapping in d3 recorded no rate of diseased cut length. However, the reduction in the tapping frequency with an increase of the stimulation system (from 4/y to 6/y and 2.5 to 5% ET) had a negative impact on the rate of dry cut. This result is confirmed by that of many authors who showed that the rate of tapping panel dryness increases with the frequency of stimulation[16,30–32]. The low frequency tapping systems have therefore no negative impact on the sensitivity to tapping panel dryness[4,5].

CONCLUSION

At the end of this study, the problem of scarcity of tapping labour in rubber cultivation can be solved by the adoption of low frequency tapping systems compensated by an intensification of hormonal stimulation.

Compared to standard tapping in d3, low frequency tapping systems (d4, d5 and d6) on clone PB 260 of *Hevea brasiliensis* have caused rubber yield losses per tree respectively by 7, 26 and 31% for a stimulation at 2.5% ethephon and by 4, 20 and 28% for a stimulation at 5% ethephon. These yield losses are low and significantly compensated by additional areas that these systems are able to exploit. The yield gains per tapper and per exploited area vary by 22 to 44% for low frequency tapping systems compared to standard tapping; which corresponds to yield gains of two to five tonnes per tapper and per year. Moreover, the low frequency tapping systems caused an increase in yield per tree and per tapping as well as the output of the tapper by 23 to 42 percent. In that respect, the low frequency tapping systems improved the income of the tapper and the farmer. The low frequency tapping systems (d4, d5 and d6) have no significant negative impact on vegetative growth, physiological profile and sensitivity to tapping panel dryness.

In the context of scarcity of tappers and considering the low yield losses per tree that they cause and the yield gains that they bring about per area exploited, these systems can thus be used to make up for the shortage of tappers and thus enable to cover the untapped areas. Unlike standard tapping in d3 where a tapper can tap only three ha, the low frequency tapping systems enables one tapper to tap four, five and six ha respectively in d4, d5 and d6.

Furthermore, depending on the importance of the shortage in tappers, we could adopt: S/2 d4 6d/7 12m/12 ET2.5% Pa1(1) 6/y : during low shortage (≤ 25 %); S/2 d5 6d/7 12m/12 ET2.5% Pa1(1) 6/y : during average shortage (25-37,5 %); S/2 d6 6d/7 12m/12 ET2.5% Pa1(1) 6/y : during high shortage (37.5-50 %).

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