Economic production of rubber plants comes from the extraction of the cytoplasm of latex vessels which are specialised cells that produce latex, following tapping\(^1\). This consists in making an incision or cut, in the bark of the tree trunk which causes the flow of latex\(^2-7\), when processed gives natural rubber. Tapping can be made full-spiral, where the entire girth...
of the tree is tapped, half-spiral or quarter-spiral. It can be oriented towards bottom of the tree (downward tapping) or towards top of the tree (upward tapping). The stress caused by the injury to the bark during tapping (which is a mechanical stimulation) is not the only factor affecting rubber yield potential of all cultivated clone groups because of their different latex-producing metabolisms. It is possible to induce a higher activation of latex production metabolism by hormonal stimulation which consists of applying a chemical substance on the tapping panel. The cultivated clones do not have the same response to yield hormonal stimulation.

Presently, a strategy of rubber production by hormonal stimulation is added systematically for tapping of latex. This practice has developed considerably after the discovery of the important stimulating power of ethylene, a growth regulator that releases ethylene in situ. The stimulating products commonly used have an active substance 2-chloroethylphosphonic acid or ethephon, which generates ethylene in latex vessels. The presence of ethylene in these tissues, enables an extension of the duration of latex flow and a high rubber yield. More recently, Silpi et al. showed that ethylene stimulation with ethephon significantly modified sugar balance between supply and demand in the bark producing latex, while increasing metabolic activation. Moreover, recent findings showed that upward tapping on virgin bark followed by nine years of downward tapping improved the yield of rubber trees by 35% compared to those tapped downward on regenerated bark.

In order to take into account the proven productivity of upward tapping and the positive effects of ethylene stimulation, a study was conducted in the experimental plantation of the research station of the Centre National de Recherche Agronomique (CNRA) of Bimbresso in south eastern Côte d'Ivoire. Different latex harvesting systems were tested including the introduction of half-spiral upward tapping as early at tapping commencement and the implementation of different strategies of ethylene stimulation in order to improve productivity of clone GT 1 at the opening of tapping. This research paper analyses the results of seven years of experiments to determine the best latex harvesting systems that is able to optimise the yield of clone GT 1 at tapping start without causing any damage in long term exploitation.

MATERIALS AND METHODS

Planting Material Clone and Experimental Design

The trial was laid out with clone GT 1, characterised by growth which was average before and weak after tapping start; an average yield and sensitivity to tapping panel dryness. This clone originating from Indonesia and belonging to the class of moderate metabolic activity is used as a reference in Côte d'Ivoire. Clone GT 1 was planted in June 1989 at a density of 510 trees per hectare (7 m × 2.8 m). The experiment started in April 1995 when tapping commenced. The experimental design is completely randomised (CRD) in which a tree is a repetition, with 33 trees per treatment (single tree plot design). The trees were selected so as to obtain a girth homogeneity (average girth of 49 cm) and a trunk regularity within each treatment. Clone GT 1 is characterised by a low sensitivity to tapping panel dryness and a relatively low breakage due to wind.

Treatments

A total of 11 treatments (A–L) were tested. Trees in treatment A (A) which were the control were not tapped. Treatments B, C, D, E and F were opened at 1.20 m above the
ground level and tapped downward. They were stimulated without gradient 0 (B), 4 (C) and 8 (D) times per year; with increasing gradient 4 then 8 times per year (E) or with decreasing gradient 13 to 4 times per year (F). Treatments G, H, J, K and L were opened at 0.7 m above ground level. Treatment G tapped downward in the first four years and then upward from the fifth year and stimulated with decreasing gradient 13 to 6 times per year while the trees of the other treatments were tapped upward as early as the first year and stimulated without gradient 0 (H), 4 (J) or 8 (K) and 13 (L) times per year (Table 1).

Measurements

Rubber Yield. The yield was determined tree by tree carried out every four weeks (28 days). A sample of 2 kg of coagulum was weighed before (fresh weight) and after drying (dry weight) to determine the transformation coefficient. This coefficient was obtained from the fresh weight, the dry rubber yield in grams per year (g.t\(^{-1}\).yr\(^{-1}\)) and in grams per tree and per tapping (g.t\(^{-1}\).t\(^{-1}\)). In order to limit the effect of varying girths of tree trunks on rubber yield, (expressed in grams per tree per tapping and per centimetre of tapping cut (g.t\(^{-1}\).t\(^{-1}\).cm\(^{-1}\))) from the estimated length of tapping panel (ELTP), depending on the girth at 1.70 m above ground\(^{11}\):

\[ \text{ELTP} = \text{Girth at the end of the experiment (cm)/(2 Cos 30°) and/or (2 Cos 45°)} \]

Yield of dry rubber was expressed in grams per tree per tapping and per centimetre of tapping cut (g.t\(^{-1}\).t\(^{-1}\).cm\(^{-1}\)) over a period of:

- seven years of treatments tapped downward only*;
- seven years of treatments tapped upward only**;
- four years downward and three years upward, in the case of treatment G.

Radial Vegetative Growth. The girth of mature rubber plants were measured at 1.70 m above ground level throughout the experimental period. The average annual girth increment determined by the following relationship:

\[ \text{Girth}_{\text{increment}} = \text{Girth}_n - \text{Girth}_{n-1} \]

with Girth\(_{\text{increment}}\): annual increase in girth; Girth\(_n\): Girth of trees in the current crop year; Girth\(_{n-1}\): Girth of trees in the previous crop year.

Latex Analysis. Physiological parameters of latex were assessed once a year between August and December. Latex samples were collected according to the method for micro diagnosis\(^8\) and extracted with trichloroacetic acid. The sucrose, inorganic phosphorus and the reduced thiols were measured in the TCA extract according to the methods described by Ashwell\(^{24}\), Taussky and Shorr\(^{25}\), and Boyne and Ellman\(^{26}\). The results are expressed in mmole per litre of latex (mM). Dry rubber content was determined after acid coagulation and known weight of latex dried in oven at 80°C and weighed again and expressed as a percentage.

Tapping Panel Dryness (TPD). The progress of tapping panel dryness was monitored through visual assessment\(^27\). In this respect, the trees tapped were rated from 0 to 6 in proportion to the progress of the “disease”. The sensitivity of tree TPD is assessed through the parameters of dry cuts (%).

Statistical Analysis. All the yield data, plant growth and the latex analysis were subjected to analysis of variance with CRD. Level of significant differences between means was estimated by the Newman-Keuls test at 5% threshold. Principal components analysis was used to determine the best latex harvesting system.
<table>
<thead>
<tr>
<th>N°</th>
<th>Latex harvesting technologies</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Control</td>
<td>Untapped trees</td>
</tr>
<tr>
<td>B</td>
<td>S/2 d4 6d/7 nil stimulation,</td>
<td>Half spiral cut tapped downward at fourth daily frequency, six days in tapping followed by at 1.20 m from the ground one day rest; without stimulation.</td>
</tr>
<tr>
<td>C</td>
<td>S/2 d4 6d/7.ET2.5% Pa1(1) 4/y*, (without gradient of stimulation)</td>
<td>Half spiral cut tapped downward at fourth daily frequency, six days in tapping followed by at 1.20 m from the ground one day rest; stimulated with ethephon of 2.5 % active ingredient with 1 g of stimulated applied on panel on 1 cm band, 4 applications per year.</td>
</tr>
<tr>
<td>D</td>
<td>S/2 d4 6d/7.ET2.5% Pa1(1) 8/y, (without gradient of stimulation)</td>
<td>Half spiral cut tapped downward at fourth daily frequency, six days in tapping followed by at 1.20 m from the ground one day rest; stimulated with ethephon of 2.5 % active ingredient with 1 g of stimulated applied on panel on 1 cm band, 8 applications per year.</td>
</tr>
<tr>
<td>E</td>
<td>Year 1 and 2: S/2 d4 6d/7.ET2.5% Pa1(1), Year 3 to 7: S/2 d4 6d/7.ET2.5% Pa1(1) 8/y (5 years) (with increasing gradient of stimulation)</td>
<td>Half spiral cut tapped downward at fourth daily frequency, six days in tapping followed by 4/y (2 years) at 1.20 m from the ground one day rest; stimulated with ethephon of 2.5 % active ingredient with 1 g of stimulated applied on panel on 1 cm band, 4 applications at first and second year (2 years); 8 applications from third to seventh year (5 years).</td>
</tr>
<tr>
<td>F</td>
<td>Year 1: S/2 d4 6d/7.ET2.5% Pa 1(1) 13/y, Year 2: S/2 d4 6d/7.ET2.5% Pa 1(1) 10/y (B0-1) Year 3: S/2 d4 6d/7.ET2.5% Pa 1(1) 8/y (B0-2) Year 4: S/2 d4 6d/7.ET2.5% Pa 1(1) 6/y (B0-1) Year 5: S/2 d4 6d/7.ET2.5% Pa 1(1) 6/y (B0-2) Year 6: S/2 d4 6d/7.ET2.5% Pa 1(1) 4/y (B0-1) Year 7: S/2 d4 6d/7.ET2.5% Pa 1(1) 4/y (B0-2) (with decreasing gradient of stimulation)</td>
<td>Half spiral cut tapped downward at fourth daily frequency, six days in tapping followed by at 1.20 m from the ground (B0-1) one day rest; stimulated with ethephon of 2.5 % active ingredient with 1 g of stimulated applied on panel on 1 cm band, 13 applications for the first year on panel B0-1; 10 applications for the second year on panel B0-1; 8 applications for year 3 on panel B0-2; 6 applications for years 4 (B0-1) and 5 (B0-2); 4 applications for year 6 (B0-1) and 7 (B0-2).</td>
</tr>
<tr>
<td>No</td>
<td>Latex harvesting technologies</td>
<td>Description</td>
</tr>
<tr>
<td>----</td>
<td>------------------------------</td>
<td>-------------</td>
</tr>
</tbody>
</table>
| G  | Year 1 : S/2 d4 6d/7.ET2.5% Pa1(1) 13/y, at 0.70 m from the ground (B0-1)  
Year 2 : S/2 d4 6d/7.ET2.5% Pa 1(1) 10/y (B0-1)  
Year 3 : S/2 d4 6d/7.ET2.5% Pa 1(1) 8/y (B0-2)  
Year 4 : S/2 d4 6d/7.ET2.5% Pa 1(1) 6/y (B0-1)  
(with decreasing gradient of stimulation)  
Year 5 to 7 : S/2U d4 6d/7.ET2.5% Pa 1(1) 8/y in annual panel change (H0-1, H0-2, H0-3) | Half-spiral cut tapped downward at fourth daily frequency, six days in tapping followed by one day rest; stimulated with ethephon of 2.5% active ingredient with 1 g of stimulated applied on panel on 1 cm band; 13 applications for the first year on panel B0-1; 10 applications for the second year on panel B0-1; 8 applications for year 3 on panel B0-2; 6 applications for years 4, then, half-spiral cut tapped upward at fourth daily frequency, six days in tapping followed by one day rest; stimulated with Ethephon of 2.5% active ingredient with 1 g of stimulated applied on panel on 1 cm band; 8 applications from year 5 to 7, annual panel change. |
| H  | S/2U d4 6d/7 nil stimulation at 0.70 m from the ground, from year 1 to 7 in annual panel change. | Half-spiral cut tapped upward at fourth daily frequency, six days in tapping followed by one day rest; without stimulation; annual panel change from year 1 to 7. |
| J  | S/2U d4 6d/7.ET2.5% Pa1(1) 4/y*, at 0.70 m from the ground, from year 1 to 7 in annual panel change. | Half-spiral cut tapped upward at fourth daily frequency, six days in tapping followed by one day rest; stimulated with ethephon of 2.5% active ingredient with 1 g of stimulated applied on panel on 1 cm band; 4 applications for year; annual panel change from year 1 to 7. |
| K  | S/2U d4 6d/7.ET2.5% Pa1(1) 8/y, at 0.70 m from the ground, from year 1 to 7 in annual panel change. | Half-spiral cut tapped upward at fourth daily frequency, six days in tapping followed by one day rest; stimulated with ethephon of 2.5% active ingredient with 1 g of stimulated applied on panel on 1 cm band; 8 applications for year; annual panel change from year 1 to 7. |
| L  | S/2U d4 6d/7 12 m/12.ET2.5% Pa1(1) 13/y, at 0.70 m from the ground, from year 1 to 7 in annual panel change. | Half-spiral cut tapped upward at fourth daily frequency, six days in tapping followed by one day rest; stimulated with Ethephon of 2.5% active ingredient with 1 g of stimulated applied on panel on 1 cm band; 13 applications for year; annual panel change from year 1 to 7. |
RESULTS

Agronomic Parameters

Rubber yield, expressed as g.t\(^{-1}\).t\(^{-1}\).cm\(^{-1}\), varied significantly depending on the treatment. Four homogeneous groups of technologies or latex harvesting systems have been identified. Group 1, represented by treatments G, D, E and C, showed yields of 1.859; 1.715; 1.719 and 1.643 g.t\(^{-1}\).t\(^{-1}\).cm\(^{-1}\) respectively. Group 2 was made up of treatments D, E, C and F (1.751; 1.719; 1.643 and 1.607 g.t\(^{-1}\).t\(^{-1}\).cm\(^{-1}\)) where the yields did not show any statistical difference. The third group (Group 3) was composed of treatments B, K, L and J and recorded yields of 1.269; 1.205; 1.149 and 1.112 g.t\(^{-1}\).t\(^{-1}\).cm\(^{-1}\) respectively. Group 4 consisted of treatment H with a yield of 0.951 g.t\(^{-1}\).t\(^{-1}\).cm\(^{-1}\). Treatment G gave the highest rubber yield equivalent to that of treatments C, D and E. Treatments of downward tapping in half-spiral and stimulated at decreasing gradient (13, 10, 8, 6 and 4/y), of yields equivalent to those of treatments C, D and E (tapped in downward half-spiral, with or without increasing gradient of stimulation, stimulated eight times per year and opened at 0.70 m above ground respectively). Rubber yield under treatment K was similar to treatments L, J and B, tapped in upward half-spiral and stimulated respectively at 13 and 4/y and open at 0.70 m above ground in downward half-spiral, not stimulated and open at 1.20 m (Table 2). Moreover, the time-course curves of yield per centimetre of tapping panel (g.t\(^{-1}\).t\(^{-1}\).cm\(^{-1}\); Figure 1) overall showed two phases. In the first phase upward tapping was practised (except the break at the third year) until the fifth year when the yield peaked. The second phase is downward tapping which starts from the fifth to the seventh year.

Table 2 showed the average annual increase in girth of five homogeneous groups. Group 1 consisted of untapped trees of treatment A (control) with an increase of 5.14 cm/year. Group 2 was represented by the trees from treatment B, which showed an increase of 3.03 cm/year. Group 3 was made up of trees of treatments C, D, E and H, with average annual increase ranging from 2.22 to 2.49 cm/year. Group 4 was formed by the trees from treatments C, D, E and F which had average annual increase in girth ranging from 2.29 to 2.10 cm/year. Group 5 consisted of treatments G, J, K and L with increase between 1.56 and 1.79 cm/year. The untapped trees had an average annual increase in girth which is higher than that of the tapped trees. The unstimulated trees showed an average annual increase higher than that of stimulated trees. Thus, the trees stimulated 4 and 8 times per year without gradient, and those stimulated with increasing gradient of 2, 8 and 10 times per year, showed similar increase identical to those of the trees stimulated at decreasing gradient (13, 10, 8, 6, then 4/y). The lower increase in girth was observed in the stimulated trees opened at 0.70 m above ground.

Physiological Parameters

Table 3 showed physiological parameters after seven years, where the dry contents of the trees in different treatments were in the same order of magnitude. Sucrose content and four homogeneous groups were identified. Group 1, consisting of treatment H showed a content of 46.27 mmol.l\(^{-1}\), statistically equivalent to that of treatment B. Group 2, identified by treatments B, C, D, E, F, J, K and L, produced latex sucrose contents, ranging from 22.63 to 35.24 mmol.l\(^{-1}\). The trees in treatments C, D, E, F, G, J, K and L, (group 3) produced sucrose contents between 28.91 and 19.67 mmol.l\(^{-1}\). Overall, the sucrose content was satisfactory for trees in all treatments. The unstimulated trees showed the highest sucrose contents. All stimulated trees had statistically similar
## TABLE 2. AGRONOMIC PARAMETERS OF CLONE GT 1 AT OPENING ACCORDING TO LATEX HARVESTING TECHNOLOGY, DURING SEVEN YEARS OF EXPERIMENTATION

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Yield (g·t⁻¹·year⁻¹)</th>
<th>Yield Girth (g·t⁻¹·t⁻¹·cm⁻¹)</th>
<th>Girth Increment (cm·year⁻¹)</th>
<th>Dry cut (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. control (without tapping)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5.14 a</td>
</tr>
<tr>
<td>B. S/2 d4 6d/7 12 m/12 at 1.20 m from the ground</td>
<td>3432 d</td>
<td>1.269 c</td>
<td>3.03 b</td>
<td>0.6</td>
</tr>
<tr>
<td>C. S/2 d4 6d/7 12 m/12 ET2.5% Pa1(1) 4/y* at 1.20 m from the ground (without gradient)</td>
<td>4212 ab</td>
<td>1.643 ab</td>
<td>2.29 cd</td>
<td>0</td>
</tr>
<tr>
<td>D. S/2 d4 6d/7 12 m/12 ET2.5% Pa1(1) 8/y at 1.20 m from the ground (without gradient)</td>
<td>4290 ab</td>
<td>1.751 ab</td>
<td>2.22 cd</td>
<td>1.2</td>
</tr>
<tr>
<td>E. S/2 d4 6d/7 12 m/12 ET2.5% Pa1(1) at 1.20 m from the ground (increasing gradient): 4/y for years 1 and 2 (2 y), 8/y from 3 to 7 (5 y)</td>
<td>4446 ab</td>
<td>1.719 ab</td>
<td>2.25 cd</td>
<td>1.5</td>
</tr>
<tr>
<td>F. S/2 d4 6d/7 12 m/12 ET2.5% Pa1(1) at 1.20 m from the ground (decreasing gradient): 13/y, for year 1(B0-1), 10/y, year 2 (B0-1), 8/y, year 3 (B0-2), 6/y, years 4 (B0-1) and 5 (B0-2), 4/y, years 6 (B0-1) and 7 (B0-2)</td>
<td>4056 bc</td>
<td>1.607 b</td>
<td>2.10 d</td>
<td>1.5</td>
</tr>
<tr>
<td>G. S/2 d4 6d/7 12 m/12 ET2.5% Pa1(1) at 0.70 m from the ground (decreasing gradient): 13/y for year 1 (B0-1), 10/y, year 2 (B0-1), 8/y, year 3 (B0-2), 6/y, year 4 (B0-2), next, S/2 one half spiral cut, tapped upward d4 6d/7 12 m/12 ET2.5% Pa1(1) 8/y, from year 5 at 7 in annual panel change.</td>
<td>4680 a</td>
<td>1.859 a</td>
<td>1.76 e</td>
<td>12.5</td>
</tr>
<tr>
<td>H. S/2U d4 6d/7 nil stimulation, at 0.70 m from the ground, from year 1 to 7 in annual panel change.</td>
<td>3042 d</td>
<td>0.951 d</td>
<td>2.49 c</td>
<td>0</td>
</tr>
<tr>
<td>J. S/2U d4 6d/7 ET2.5% Pa1(1) 4/y*, at 0.70 m from the ground, from year 1 to 7 in annual panel change.</td>
<td>3432 d</td>
<td>1.112 c</td>
<td>1.79 e</td>
<td>0</td>
</tr>
<tr>
<td>K. S/2U d4 6d/7 ET2.5% Pa1(1) 8/y, at 0.70 m from the ground, from year 1 to 7 in annual panel change.</td>
<td>3588 cd</td>
<td>1.205 c</td>
<td>1.70 e</td>
<td>0.3</td>
</tr>
<tr>
<td>L. S/2 U d4 6d/7 ET2.5% Pa1(1) 13/y, at 0.70 m from the ground, from year 1 to 7 in annual panel change.</td>
<td>3432 d</td>
<td>1.149 c</td>
<td>1.56 e</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Treatment B
Year 1: S/2 d4 6d/7 nil stimulation
(at 1.20 m from the ground, B0-1)
Year 2: S/2 d4 6d/7 nil stimulation (B0-1)
Year 3: S/2 d4 6d/7 nil stimulation (B0-2)
Year 4: S/2 d4 6d/7 nil stimulation (B0-1)
Year 5: S/2 d4 6d/7 nil stimulation (B0-2)
Year 6: S/2 d4 6d/7 nil stimulation (B0-1)
Year 7: S/2 d4 6d/7 nil stimulation (B0-2)

Treatment C
Year 1: S/2 d4 6d/7 ET2.5% Pa1(1) 4y*
(at 1.20 m from the ground, B0-1)
Year 2: S/2 d4 6d/7 ET2.5% Pa1(1) 4y* (B0-1)
Year 3: S/2 d4 6d/7 ET2.5% Pa1(1) 4y* (B0-2)
Year 4: S/2 d4 6d/7 ET2.5% Pa1(1) 4y* (B0-1)
Year 5: S/2 d4 6d/7 ET2.5% Pa1(1) 4y* (B0-2)
Year 6: S/2 d4 6d/7 ET2.5% Pa1(1) 4y* (B0-1)
Year 7: S/2 d4 6d/7 ET2.5% Pa1(1) 4y* (B0-2)
(Without gradient of stimulation)

Treatment D
Year 1: S/2 d4 6d/7 ET2.5% Pa1(1) 8/y
(at 1.20 m from the ground, B0-1)
Year 2: S/2 d4 6d/7 ET2.5% Pa1(1) 8/y (B0-1)
Year 3: S/2 d4 6d/7 ET2.5% Pa1(1) 8/y (B0-2)
Year 4: S/2 d4 6d/7 ET2.5% Pa1(1) 8/y (B0-1)
Year 5: S/2 d4 6d/7 ET2.5% Pa1(1) 8/y (B0-2)
Year 6: S/2 d4 6d/7 ET2.5% Pa1(1) 8/y (B0-1)
Year 7: S/2 d4 6d/7 ET2.5% Pa1(1) 8/y (B0-2)
(Without gradient of stimulation)

Treatment E
Year 1: S/2 d4 6d/7 ET2.5% Pa1(1) 4/y
(at 1.20 m from the ground, B0-1)
Year 2: S/2 d4 6d/7 ET2.5% Pa1(1) 4/y (B0-1)
Year 3: S/2 d4 6d/7 ET2.5% Pa1(1) 8/y (B0-2)
Year 4: S/2 d4 6d/7 ET2.5% Pa1(1) 8/y (B0-1)
Year 5: S/2 d4 6d/7 ET2.5% Pa1(1) 8/y (B0-2)
Year 6: S/2 d4 6d/7 ET2.5% Pa1(1) 8/y (B0-1)
Year 7: S/2 d4 6d/7 ET2.5% Pa1(1) 8/y (B0-2)
(with increasing gradient of stimulation)

Treatment F
Year 1: S/2 d4 6d/7 ET2.5% Pa1(1) 13/y,
(at 1.20 m from the ground, B0-1)
Year 2: S/2 d4 6d/7 ET2.5% Pa1(1) 10/y (B0-1)
Year 3: S/2 d4 6d/7 ET2.5% Pa1(1) 8/y (B0-2)
Year 4: S/2 d4 6d/7 ET2.5% Pa1(1) 6/y (B0-1)
Year 5: S/2 d4 6d/7 ET2.5% Pa1(1) 6/y (B0-2)
Year 6: S/2 d4 6d/7 ET2.5% Pa1(1) 4/y (B0-1)
Year 7: S/2 d4 6d/7 ET2.5% Pa1(1) 4/y (B0-2)
(with decreasing gradient of stimulation)

Treatment G
Year 1: S/2 d4 6d/7 ET2.5% Pa1(1) 13/y,
(at 0.70 m from the ground, B0-1)
Year 2: S/2 d4 6d/7 ET2.5% Pa1(1) 10/y (B0-1)
Year 3: S/2 d4 6d/7 ET2.5% Pa1(1) 8/y (B0-2)
Year 4: S/2 d4 6d/7 ET2.5% Pa1(1) 6/y (B0-1)
Year 5: S/2 d4 6d/7 ET2.5% Pa1(1) 6/y (B0-2)
Year 6: S/2 d4 6d/7 ET2.5% Pa1(1) 4/y (B0-1)
Year 7: S/2 d4 6d/7 ET2.5% Pa1(1) 4/y (B0-1)
(with decreasing gradient of stimulation)

Figure 1. Panel Management of clone GT 1 according to latex harvesting technology during seven years of experimentation.
Figure 1 (cont.). Panel Management of clone GT 1 according to latex harvesting technology during seven years of experimentation.
### TABLE 3. PHYSIOLOGICAL PARAMETERS OF CLONE GT 1 AT OPENING ACCORDING TO LATEX HARVESTING TECHNOLOGY, AT THE END OF SEVEN YEARS OF EXPERIMENTATION

<table>
<thead>
<tr>
<th>Treatments: Latex harvesting technologies</th>
<th>DRC (%)</th>
<th>Suc (mmol.l(^{-1}))</th>
<th>Pi (mmol.l(^{-1}))</th>
<th>RSH (mmol.l(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. S/2 d4 6d/7 nil stimulation at 1.20 m from the ground</td>
<td>55.96 a</td>
<td>35.24 ab</td>
<td>19.63 a</td>
<td>0.88 a</td>
</tr>
<tr>
<td>C. S/2 d4 6d/7.ET2.5% Pa1(1) 4/y* at 1.20 m from the ground (without gradient)</td>
<td>51.98 a</td>
<td>28.91 bc</td>
<td>17.74 a</td>
<td>0.76 ab</td>
</tr>
<tr>
<td>D. S/2 d4 6d/7.ET2.5% Pa1(1) 8/y at 1.20 m from the ground (without gradient)</td>
<td>58.14 a</td>
<td>27.44 bc</td>
<td>15.82 ab</td>
<td>0.54 cd</td>
</tr>
<tr>
<td>E. S/2 d4 6d/7.ET2.5% Pa1(1) at 1.20 m from the ground (increasing gradient): 4/y for years 1 and 2, 8/y from 3 to 7</td>
<td>52.54 a</td>
<td>27.55 bc</td>
<td>17.57 a</td>
<td>0.58 c</td>
</tr>
<tr>
<td>F. S/2 d4 6d/7.ET2.5% Pa1(1) at 1.20 m from the ground (decreasing gradient): 13/y (year 1, B0-1), 8/y (year 2, B0-1), 10/y (year 3, B0-2), 6/y (years 4, B0-1) and 6/y (year 5, B0-2), 4/y (year 6, B0-1) and 4/y (year 7, B0-2)</td>
<td>49.78 a</td>
<td>24.60 bc</td>
<td>17.00 a</td>
<td>0.55 cd</td>
</tr>
<tr>
<td>G. S/2 d4 6d/7.ET2.5% Pa1(1) at 0.70 m from the ground (decreasing gradient): 13/y (year 1, B0-1), 8/y (year 2, B0-1), 10/y (year 3, B0-2), 6/y (year 4, B0-2), next, S/2U d4 6d/7 .ET2.5% Pa1(1) 8/y, from year 5 at 7 in annual panel change.</td>
<td>55.16 a</td>
<td>19.67 c</td>
<td>12.58 abc</td>
<td>0.34 e</td>
</tr>
<tr>
<td>H. S/2U d4 6d/7 nil stimulation, at 0.70 m from the ground, from years 1 to 7 in annual panel change.</td>
<td>51.72 a</td>
<td>46.27 a</td>
<td>11.80 abc</td>
<td>0.63 bc</td>
</tr>
<tr>
<td>J. S/2U d4 6d/7 .ET2.5% Pa1(1) 4/y*, at 0.70 m from the ground, from year 1 to 7 in annual panel change.</td>
<td>57.03 a</td>
<td>25.22 bc</td>
<td>13.72 abc</td>
<td>0.48 cde</td>
</tr>
<tr>
<td>K. S/2U d4 6d/7.ET2.5% Pa1(1) 8/y, at 0.70 m from the ground, from year 1 to 7 in annual panel change.</td>
<td>52.89 a</td>
<td>27.12 bc</td>
<td>8.45 c</td>
<td>0.38 de</td>
</tr>
<tr>
<td>L. S/2U d4 6d/7.ET2.5% Pa1(1) 13/y, at 0.70 m from the ground, from year 1 at 7 in annual panel change.</td>
<td>59.18 a</td>
<td>22.63 bc</td>
<td>10.10 bc</td>
<td>0.35 de</td>
</tr>
</tbody>
</table>

Mean followed by the same letter in each column are not significantly different (Student Newman & Keuls, at 5 %)
sucrose contents while trees in treatment G had the lowest.

Three groups of inorganic phosphorus were identified. Group 1, which consisted of treatments B, C, G, E, F, H and J showed inorganic phosphorus content that varied according to treatment from 11.80 to 19.63 mmol.l\(^{-1}\). Group 2, consisting of treatments D, G, H, J and L recorded an inorganic phosphorus content ranging from 10.10 to 15.82 mmol.l\(^{-1}\). Treatments L, K, J, H and G, have an inorganic phosphorus content ranging from 10.10 to 12.58 mmol.l\(^{-1}\) (group 3). Almost all trees in all the treatments resulted in good inorganic phosphorus contents except treatment K.

Meanwhile, three groups were identified in the thiol compounds content. Group 1, represented by treatments B and C, showed thiol compounds content ranging from 0.88 to 0.76 mmol.l\(^{-1}\). Group 2, composed of trees in treatments D, E, F, H and J recorded a thiol compound content ranging from 0.48 to 0.58 mmol.l\(^{-1}\). The trees in treatments L, K, J and G, with a thiol content oscillating between 0.48 and 0.34 mmol.l\(^{-1}\) made up group 3. Opening height showed that the unstimulated trees have thiol compounds higher than those of stimulated trees. The stimulated trees tapping opened at 1.20m above ground level showed higher thiol compound contents than those opened and stimulated at 0.70 m. Similar results were obtained from unstimulated trees.

**Determinant of Latex Harvesting Technology Adapted to Clone GT 1 at Opening**

The correlation matrix between the parameters studied (Table 4), revealed that the increase in the girth of tree trunks has been positively correlated with sucrose contents \((r = 0.696)\), inorganic phosphorus \((r = 0.750)\) and thiol compounds of latex \((r = 0.922)\). Rubber yield has increased statistically in the opposite direction of the latex sucrose content \((r = -0.772)\) and was positively correlated with the dry cuts \((r = 0.651)\). Inorganic phosphorus and thiol compounds contents were positively correlated \((r = 0.792)\).

The combination of the parameters studied were shown in the Biplot dispersion plan (Figure 2). The parameters of increase in girth, sucrose contents and thiol compounds of the latex, positively correlated with axis F1 (Table 4). The rubber yield, length of diseased tapping panel and rate of dry trees were negatively correlated to the same axis which contributed by 59.01% to the total variance expressed. The inorganic phosphorus content was positively correlated with axis F2 which represented

<table>
<thead>
<tr>
<th>TABLE 4. CORRELATION MATRIX BETWEEN PARAMETERS STUDIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girth Increment</td>
</tr>
<tr>
<td>Girth Increment</td>
</tr>
<tr>
<td>Yield</td>
</tr>
<tr>
<td>Suc</td>
</tr>
<tr>
<td>Pi</td>
</tr>
<tr>
<td>RSH</td>
</tr>
<tr>
<td>TPD</td>
</tr>
<tr>
<td>DRC</td>
</tr>
</tbody>
</table>

On gras, significative values at 5 % (bilateral test)
Suc = sucrose, Pi = inorganic phosphorus, RSH = thioles, TPD = tapping panel dryness, DRC = dry rubber content
23.49% of the total variance (Table 5). These two axes characterise the different latex harvesting systems.

Treatments J, K and L located in the lower left quarter of the plan showed generally low values in each of the parameters studied. Treatment H located in the lower right quarter of the plan showed a high sucrose content, a low production, as well as small increases in girth, inorganic phosphorus content, thiol compounds, and low values of dry cuts. Located in the upper left quarter of the plan, treatment G recorded the highest yield but also the highest rate of dry cuts. The inorganic phosphorus contents and thiol compounds, as well as the increase of the trunk girth were the lowest. Treatments B (unstimulated), C, D, E and F showed low rates of length of diseased tapping panel and dry trees, a good increase in trunk girth, good contents in sucrose, inorganic phosphorus and thiol compounds. The rubber yield in treatment B was lower than that of treatments C, D, E and F.

**DISCUSSION**

**Agronomic Parameters**

The downward half-spiral harvesting system at the opening of B, C, D, E, F, G were more efficient than those in upward half-spiral as early as the first year of tapping (H, J, K, L). The downward tapping system for four years followed by upward tapping for the rest of time (G) was the most productive. These results showed that rubber production performance of upward tapping are linked to downward tapping. A minimum period of years of downward tapping is thus necessary to make upward tapping efficient. That period of time is equal to four to five years of downward tapping.
The average annual yield per centimetre of tapping cut (Figure 1) clearly showed that with the exception of the unstimulated and upward control, the yield peak is reached at the sixth year of latex harvesting. All other latex harvesting systems showed maximum yield in the fifth year. This indicates that regardless of the orientation of tapping and hormonal stimulation regime, the actual activation of the tree (moderate metabolism clone GT 1) under tapping occurs after five years.

According to Traoré unstimulated clone GT 1 had a yield level statistically equivalent to that of all other treatments which was stimulated from the fifth year of harvesting. It is concluded that the ideal minimum period is five years of downward tapping. All the rubber trees stimulated and unstimulated (control) had at the end of the fifth year a level of activation of rubber production cell metabolism significantly in the same order of magnitude.

It was found that upward tapping system was inefficient as compared to downward tapping system. It is suggested that this harvesting system be excluded in the management of clone GT 1 and probably other moderate metabolism clones.

The results of rubber yield in treatment G were excellent. However, the high rate of tapping panel dryness in this treatment is the expression of an additional metabolic activation linked to an excess of energy from the precocity of upward tapping start, especially intensification of the harvesting system by a tapping frequency and probably strong stimulation regime for the latex harvesting years concerned.

These results highlight the important role of the activation of rubber production metabolism at the origin of latex vessels as demonstrated by several authors. This is because tapping and hormonal stimulation of rubber production bring energy to the latex vessel cells. This process which is essential to the efficiency of the isoprene synthesis intensifies over time, but more with the number of tapping and probably explains the poor performance of upward tapping as early as opening, yet good as noted by Obouayeba. Indeed, due to tapping stress from trauma it induces, might activate the metabolism of latex vessels as well as hormonal stimulation by the production of ethylene. This ethylene is produced and released during stress in tissues by activating all the synthesis process of the \textit{cis}-polyisoprene or rubber molecule. Moreover, the presence of this hormone in those tissues, enables an extension of the duration of latex flow and high rubber yield. Due to the action of ethylene on glycolysis, there is production of energy needed for the transformation of the \textit{cis}-polyisoprene molecule into rubber.

TABLE 5. CORRELATION OF VARIABLES WITH AXES F1 AND F2

<table>
<thead>
<tr>
<th>Variables studies</th>
<th>F1</th>
<th>F2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girth Increment</td>
<td>0.851</td>
<td>0.432</td>
</tr>
<tr>
<td>Yield</td>
<td>-0.693</td>
<td>0.578</td>
</tr>
<tr>
<td>Suc</td>
<td>0.786</td>
<td>-0.268</td>
</tr>
<tr>
<td>Pi</td>
<td>0.581</td>
<td>0.761</td>
</tr>
<tr>
<td>RSH</td>
<td>0.898</td>
<td>0.379</td>
</tr>
<tr>
<td>TPD</td>
<td>-0.692</td>
<td>0.539</td>
</tr>
<tr>
<td>DRC</td>
<td>-0.827</td>
<td>0.200</td>
</tr>
</tbody>
</table>
Tapping in upward half-spiral being very productive, requires good activation by the exogenous energy associated with tapping and hormonal stimulation before its implementation. This justifies and promotes the practice of downward tapping for several years prior to upward tapping. Hence, tapping in downward half-spiral for four years has strongly activated the metabolism through its action and favoured a better production when it was alternated by upward half-spiral tapping. This would explain the fact that the alternation between downward half-spiral tapping and upward half-spiral tapping after four years have produced the highest rubber yield.

The average annual increase in girth of untapped trees was higher than that of tapped trees. This is due to diversion of a fraction of photosynthetic assimilates and the necessary energy, strictly assigned to the general metabolism of the tree and the primary biomass (leaves, wood and bark)\textsuperscript{11,35–40}. It thus directs the metabolism towards a regeneration of the cell material exported during tapping and corresponding to the synthesis of secondary biomass, as indicated by Jacob\textsuperscript{1}. The consequence is a reduction of radial vegetative growth that was expressed by a less significant girth of trees started to be tapped compared to untapped trees\textsuperscript{39}. Our results are similar to the observations of several authors\textsuperscript{23,39–42}. These authors explained that the onset of tapping is inevitably accompanied by a reduction in the annual rate of radial vegetative growth.

The intensification by stimulation of ethylene on the harvesting technique was also expressed by relatively less significant trunk girth, compared to the unstimulated control. Indeed, the orientation of energy and photosynthetic assimilates towards latex production occurs at the expense of the radial vegetative growth\textsuperscript{39}. It is a fact that,

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{biplot.png}
\caption{Latex harvesting technology repartition at opening of clone GT 1.}
\end{figure}

GI : Girth increment ; TPD : Tapping Panel Dryness ; Suc : Sucrose
hormonal stimulation, by its effect, increases the production of rubber by strongly directing hydrocarbon assimilates to the detriment of vegetative growth. This resulted in reduced growth in the thickness of the trunks of stimulated trees compared to unstimulated ones. Therefore, there is a reduction in the girth of stimulated trees due to increasing number of annual stimulations which is partly responsible for the increase in yield.

Physiological Parameters

The different treatments had no impact on dry rubber content which was very high. This reflects good latex regeneration during tapping due to dry rubber content which reflects biosynthetic activity of latex vessels. In this study the sucrose content was good for all trees in all treatments. Unstimulated trees showed strong sucrose contents. The trees of treatment G had the lowest sucrose content, because of the high yield of rubber present. This is the sign of a good supply of sucrose in latex vessels, not only as raw material for the biosynthesis of rubber, but also as an efficient synthesis of rubber.

This indicates that there is sucrose permanently available in latex vessels, enabling good rubber yield. The sucrose content of treatment G is the result of good rubber yield generated. Indeed, the sucrose was heavily used for rubber production as reported by Lacrotte, Gohet and Jacob et al.

The inorganic phosphorus in latex can be considered as an indicator of the intensity of energy metabolism of latex vessel cells. The trees in all treatments have good inorganic phosphorus content except those in treatment K, reflecting better availability of energy necessary to the biosynthesis of rubber. This exception is certainly due to a metabolic dysfunction caused by latex harvesting system in the sense that the trees subjected to this treatment maintained good sucrose content.

The thiol groups, in their reduced form RSH, are capable of neutralising the toxic oxygen species. These are antioxidants which protect the cellular compartmentalisation of the latex including that of lutoids, and therefore, the functioning of latex vessels. Unstimulated trees showed thiol compounds contents higher than those of stimulated trees. This is explained by the fact that the intensification of the metabolism of clones by stimulation leads to an increasingly intense stress, reflected by a weakening of protective systems and resulting in physiological fatigue.

CONCLUSION

The study undertaken for seven years on the latex harvesting systems of Hevea brasiliensis clone GT 1 with start of tapping at 1.20 m above ground (downward tapping) gives better results compared to the upward tapping at 0.70 m (which was not preceded by downward tapping for a minimum period of four years). The latex harvesting system C (S/2 d4 6d/7 12 m/12.ET2.5% Pa1 (1) 4/y at 1.20 m above ground (without gradient)) is probably the most suitable for clone GT 1 at opening. Even if downward half spiral tapping during four years from 1.20 m above ground, alternated with an upward half-spiral tapping at 0.70 m, proved more productive, with little harmful effects on the radial vegetative growth, good sucrose and inorganic phosphorus contents of the latex, but with a very high sensitivity to tapping panel dryness. Furthermore, our results indicate that the upward tapping (upward half spiral or likely quarter spiral) can be introduced at least as early as the fifth year of latex harvesting.

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par la réduction des intensités de saignée. Thesis (PhD). Université Cocody, Côte d’Ivoire.


