Original Research Article

Quantitative Assessment of the Agro-physiological Advantages of Upward Tapping in relation to the Downward Tapping of the GT 1 and PB 260 Rubber Clones [*Hevea brasiliensis, Muell. arg.* (Euphorbiaceae)] *in Southwest Côte d'Ivoire*

ABSTRACT

The downward tapping on virgin bark of the lower panel (BO) is immediately followed by the upward tapping on virgin bark of the upper panel (HO), consecutively. To determine the agro-physiological advantages of one tapping over another, a study of the downward and upward tapping of the GT 1 and PB 260 clones of Hevea brasiliensis was carried out in southwestern Côte d'Ivoire. For this purpose, the rubber trees were tapped in a downward half-spiral (S/2) at the opening for nine consecutive years, followed by upward quarter-spiral tapping (S/4U) for four consecutive years. The agronomic parameters (rubber production and vegetative growth), tapping panel dryness and the latex micro-diagnosis, were evaluated. For GT 1 clone, the transition from the downward tapping panels to the upward tapping panels resulted rubber productivity gain of 35%. Meanwhile for PB 260, rubber productivity gain was 37%. Regardless of the clone and tapping direction, the higher the rubber productivity of a respective tapping panel, the lower the isodiametric growth of the tree trunk was recorded. Latex harvesting systems, and clone's combination, did not influence the tapping panel dryness or the physiological profile of the trees. Finally, it should be concluded that upward tapping is more productive than downward tapping, but the quantification of the gains in this rubber production depends on the clone.

Keywords: rubber production; isodiametric increase; physiological parameters; physiological profile; Côte d'Ivoire

INTRODUCTION

Hevea brasiliensis, is a perennial plant grown for its latex which is an important source of natural rubber [1]. It is a tree native to the Amazon rainforest, with great economic interest on a global scale. It is the main source of commercially exploited natural rubber [2, 3]. It is indispensable in countless industrial applications: joints, surgical gloves, rubber, shoes, with elasticity and impermeability properties that make it a material that is irreplaceable in certain uses [4]. Rubber tree cultivation also has a very favourable ecological impact, thanks to its high capacity to fix carbon. It has been reported that rubber plantations in China have a higher carbon sequestration potential (272,000 t/ha/30 years) than primary (234,305 t/ha/30 years) and secondary (150,203 t/ha/30 years old) forests [5]. The growing demand for this raw material has led to the initiation of numerous studies aimed at increasing latex production [6].

The production necessarily involves tapping to harvest the latex following tapping notch sectioning the laticiferous in the bark of the tree. It consists of opening and then reviving the same notch at each tapping, removing with a knife or a gouge tapping, a thin sliver of bark (chip) 1 to 2 mm thick. The sectioning of the laticiferous coats allows the latex to be expelled outwards by the turgor pressure exerted *in situ* [7]. This operation is repeated throughout the year following a tapping system require tapping frequency of every three (d3), four (d4), five (d5) or six (d6) days respectively [8-10]. Trees can be taped down (downward tapping) or up (inverted or upward tapping) [8, 11]. As part of normal, modern and efficient management of a rubber plantation, these two latex harvesting systems are applied separately and complementarily, so that the conventional downward tapping operation of the low tapping panel (BO) is immediately supported and/or alternated with the upward or inverted tapping (HO) [9, 10, 12, 13].

Many works including those of Dian *et al*. [14] showed without quantifying a rubber productivity superiority of the upward tapping over the downward tapping. In addition, a recent study [15] indicated that upward tapping, at the end of the downward tapping, resulted in a statistically lower rubber productivity than the downward tapping. On the other hand, early upward tapping preceded by four years of downward tapping is more productive than downward tapping. From this result, we are justified in determining the nature and extent of the influence of downward tapping toward upward tapping of *Hevea brasiliensis* GT 1 and PB 260 clones.

EXPERIMENTAL

Plant Material

The experiment was conducted on two clones, PB 260 and GT1, belonging to different classes of metabolic activity.

The clone PB 260 (Prang Besar 260) of *Hevea brasiliensis* is native to Malaysia (Prang Besar). It was planted for the first time in Côte d’Ivoire in 1983. It comes from a cross between PB 5/51 and PB 49. PB 260 is a clone with a very active metabolism which is characterized by an easy flow of latex and a good rise in production. In the absence of hormonal stimulation, rubber production and inorganic phosphorus levels are high, while sucrose levels are very low.

It is characterized by a good vigour, higher than that of the clone IRCA 18 but, lower than that of the clones PB 235, RRIC 100 and AVROS 2037.

The GT 1 clone, originating from Indonesia, belongs to the moderate metabolic activity class and is used as a reference in Côte d'Ivoire. It is characterized by average radial vegetative growth before tapping and low tapping, average production and sensitivity to tapping panel dryness and relatively low wind breakage [16, 17].

Experimental Design and Choice of Trees

The experimental setup is Fisher blocks of two treatments (Table 1). Treatment 1 is applied on blank panel tapped down, while treatment 2 is applied on blank panel bleed inverted. Whatever the direction of the tapping, the experiment was repeated four times. Each elementary parcel contains about 21 trees selected on the basis of circumference, health status and membership of the different classes of metabolic activity. This selection was made after the removal of border trees, broken trees, those with tapping panel dryness and those attacked by root rot caused by *Fomes lignosus* and their neighbours. These selected trees were tapped after 50 % of tree trunks reached a circumference of 50 cm at 1 m from the ground. Experiments began as soon as the trees were opened at a height of 1.20 m.

During the 13 years of the experiment, these different latex harvesting technologies were applied according to the current control scheme of the panel in Côte d'Ivoire (Figure 1).

Table 1. Treatments Applied to Trees Subjected to Downward Tapping

N°	Treatments	Description
1	**S/2 d4 6d/7 ET2.5% Pa1(1) 8/y**	Downward half-spiral tapping every four days, six working days out of seven, stimulated with Ethephon of 2.5 % active ingredient with 1 g of stimulant applied on panel on a 1 cm band, 8 stimulations are performed each year, Sunday being a day of tapping rest.
2	**S/4U d4 6d/7 ET5% Pa1(1) 8/y**	Upward quarter spiral tapping every four days, six working days out of seven, stimulated with Ethephon of 5 % active ingredient with 1 g of stimulant applied on panel on a 1 cm band, 8 stimulations are performed each year, Sunday being a day of tapping rest.

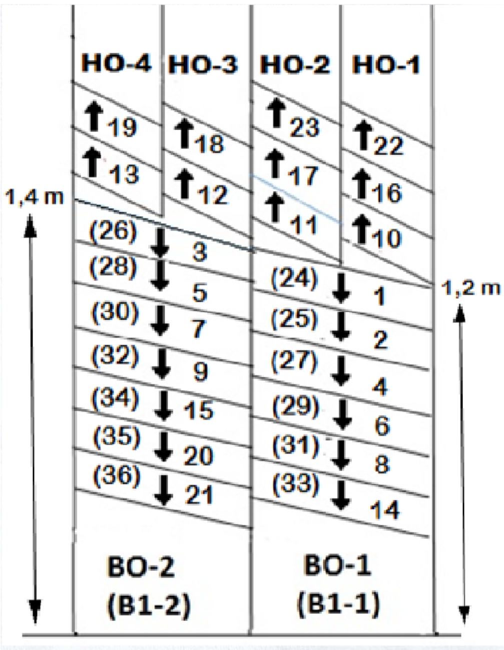

Figure 1. Recommendation for driving the Rubber Tree Tapping Panel logging In Côte d'Ivoire, for a Tapping Frequency d4 6d/7 12m/12 adapted from [12, 18]

The shaded area is the bark consumed during 36 years of rubber tree exploitation
The numbers in it represent the years of exploitation. When it is in parentheses, the exploitation is practiced on regenerated bark, this one having already been exploited a first time
The lowest point of the tapping notch is 1.20 m from the ground when the tree is tapped
The down arrows indicate a downward half-spiral tapping (S/2)
The upward arrows indicate upward quarter spiral tapping (S/4U)
In the figure, the parentheses express an exploitation on the regenerated parts of the tree.
Downward tapping (half-spiral):
BO-1: Tapping panel exploited in years 1, 2, 4, 6, 8 and 14 (virgin bark)
BO-2: Tapping panel exploited in years 3, 5, 7, 9, 15, 20 and 21 (virgin bark)
B1-1: Tapping panel exploited in years 24, 25, 27, 29, 31 and 33 (regenerated bark)
B1-2: Tapping panel exploited in years 26, 28, 30, 32, 34, 35 and 36 (regenerated bark)
Receding or upward tapping (quarter spiral):
HO-1: Tapping panel exploited in years 10, 16 and 22 (virgin bark)
HO-2: Tapping panel operated in years 11, 17 and 23 (virgin bark)
HO-3: Tapping panel exploited in years 12 and 18 (virgin bark)
HO-4: Tapping panel exploited in years 13 and 19 (virgin bark)

Tapping of the Rubber Tree

The latex from the tapping, using a knife or gouge, was collected into a plastic cup. The downward tapping was performed in half spiral and the upward tapping in quarter spiral. The tapping was done every three days, six days a week. Sunday being the day of rest for tapping. They were done 12 months out of 12.

Hormonal Stimulation of Rubber Production of Rubber Tree

It was made on the tapping panel, on a 1 cm wide band, at the rate of 1 g of stimulating product per tree. The stimulating product used is obtained by mixing Ethrel and palm oil [4,9]. Ethrel contains 2.5 to 5 % of active ingredient which is chloro-2-ethyl phosphonic acid or Ethephon. The concentration of the stimulating product is 2.5 % in downward tapping and 5 % in upward tapping.

Rubber Production

Rubber production ($kg.ha^{-1}.year^{-1}$) was recorded for treatments carried out every four weeks. A sample of 2 kg of coagulum was weighed before (fresh weight) and after drying (dry weight) to determine the transformation coefficient (C.T). This coefficient was obtained from the fresh weight, the dry rubber production in kilograms per ha per year ($kg.ha^{-1}.year^{-1}$).

Radial Vegetative Growth

The girth of mature rubber plant was measured at 1.70 m above the ground level throughout the experimental period. Indeed, the hollows of the tapping surfaces cannot reach this level of 1.7 m during the 13 years of the experiment due to the consumption of bark from trees. This avoids any influence of the bleeding surface on the circumference measurements. The average annual girth increment determined by the following equation:

$$\mathbf{Girth_{increment} = Girth_{n} - Girth_{n-1}}$$

With $\mathbf{Girth_{increment}}$ **:** annual increase in girth; $\mathbf{Girth_{n}}$**:** Girth of trees in the current crop year; $\mathbf{Girth_{n-1}}$**:** Girth of trees of the previous crop year

Physiological Parameters of Latex

Physiological parameters of latex were assessed once a year between August and December due to the fact that during this period the leaves reach their physiological maturity [19]. Latex samples were collected according to the method of micro-diagnosis and extracted with trichloroacetic acid (TCA). The sucrose (Suc), inorganic phosphorus (Pi) and the reduced thiols were measured in the TCA extract according to the methods described by Ashwell [20], Taussky and Shorr [21] and Boyne & Ellman [22]. The results are expressed in mmole per litre of the latex ($mmol.l^{-1}$). Dry rubber content (DRC, %) was determined after acid coagulation and known weight of latex dried in oven at 80°C for 24 hours and expressed as a percentage.

Tapping Panel Dryness

The progress of tapping panel dryness was monitored through visual assessment method described by Van De Sype [23].

Gain for Upward Tapping

Gains in rubber production, isodiametric tree trunk growth and tapping panel dryness for upward tapping were determined according to the following formula:

$$Gain\ (\%) = 100 * (B - A) / A$$

A = mean value expressed by the downward tapping; B = mean value expressed by the upward tapping.

Statistical Analysis

All the production data, plant growth and the latex analysis were subjected to analysis of variance with Completely Randomized Design (CRD). Statistical analyses were carried out using STATISTICA version 7.1 software. An analysis of variance (ANOVA) with one classification criterion was carried out on all the treatments applied to the rubber trees. When this analysis shows a difference between the means, the Newman-Keuls test was performed in order to determine the significant differences between the treatments at the 5 % threshold.

RESULTS

Effect of Tapping Direction on the Rubber Production of GT 1 and PB 260 Rubber Tree Clones

The analysis of Tables 2 shows that, irrespective of the clone, the average annual production of rubber, expressed in and kg.ha^{-1}.year^{-1}, presented by the downward tapping panels (BO) was lower than that displayed by upward tapping panels (HO). Thus, in GT 1, a moderately metabolized clone, from the downward tapping panels to upward tapping panels, rubber production was increased by 35 %. For PB 260, a clone with active or fast metabolism, the passage of the downward tapping panels to upward tapping panels resulted in a gain of 37 %.

Table 2. Average Annual Rubber Production of GT 1 and PB 260 Clones on Downward and Upward Tapping Panels

Tapping Panels	Rubber Production (kg.ha^{-1})	
	Clone GT 1	Clone PB 260
Downward	2134 ± 188 b	2861 ± 379 b
Upward	2873 ± 205 a	3914 ± 366 a
Upward Gain (%)	35	37

In each column, the assigned average values of the same letter are not significantly different (Newman-Keuls test at 5%); g.t^{-1}: gram per tree; kg.ha^{-1}: kilogram per hectare.

Effect of Tapping Direction on the Radial Vegetative Growth of GT 1 and PB 260 Rubber Tree Clones

The results of the trunk isodiametric growth of the GT 1 and PB 260 clones, expressed in cm.year^{-1}, relative to the different tapping panels, are given in Tables 3. These results showed that the isodiametric increase of the trunk presented by the downward tapping panels [(GT 1: 4.15 ± 0.4 cm.year^{-1}); (PB 260: 3.6 ± 0.4 cm.year^{-1})] was statistically higher than that displayed by upward tapping [(GT 1: 3.1 ± 0.3 cm.year^{-1}); (PB 260: 2.7 ± 0.2 cm.year^{-1})].

In GT 1, the passage of the downward tapping panels to upward tapping panels recorded a 25.3% decrease in isodiametric growth of tree trunks. At the level of the PB 260, the passage of the downward tapping panels to upward tapping panels resulted in a 25.0 % loss of the isodiametric growth of the tree trunks.

Table 3. Average Annual Tree Trunk Growth of GT 1 and PB 260 Clones, on Downward and Upward Tapping Panels

Tapping Panels	Isodiametric Increase (cm.year^{-1})	
	Clone GT 1	Clone PB 260
Downward	4.2 ± 0.4 a	3.6 ± 0.4 a
Upward	3.1 ± 0.3 b	2.7 ± 0.2 b
Upward Gain (%)	-25.3	-25.0

In each column, the assigned average values of the same letter are not significantly different (Newman-Keuls test at 5 %); cm.year^{-1}: centimeter per year

Effect of Tapping Direction on Tapping Panel Dryness Syndrome of GT 1 and PB 260 Rubber Tree Clones

The analysis of the results in Tables 4 indicates that, regardless of the clone, the tapping panel dryness generated by the trees, relative to the respective downward and upward tapping panels, have not significantly varied. In GT 1, the passage of the downward tapping panels to upward tapping panels resulted in a 24.1 % reduction in tapping panel dryness. For the PB 260 clone, the passage of the downward tapping panels to upward tapping panels resulted in a 34.6 % decrease.

Table 4. Average Annual Tapping Panel Dryness Rates of GT 1 and PB 260 Clones, on Downward and Upward Tapping Panels

Tapping Panels	Tapping Panel Dryness Rates (%)	
	Clone GT 1	Clone PB 260
Downward	2.9 ± 0.3 a	3.9 ± 0.8 a
Upward	2.2 ± 0.4 a	2.6 ± 0.6 a
Upward Gain (%)	-24.1	-34.6

In each column, the average values assigned to the same letter are not significantly different (Kruskal Wallis test at 5%)

Effect of Tapping Direction on the Latex Physiological Parameters of GT 1 and PB 260 Rubber Tree Clones

The analysis of Table 5 shows that the solids content (dry rubber content), greater than 43 % (reference value), independently of the clone and the direction of tapping (downward tapping and upward tapping), was very high. Regardless of the clone, the rate of solids content, relative to the respective panels of downward and upward tapping, has not significantly varied.

The sucrose content, independently of the clone, did not significantly vary between the downward and upward tapping panels. The sucrose contents of the latex were high and moderate in GT 1 and PB 260 clones, respectively. For the downward and upward tapping panels, the sucrose was high and statistically identical in the clone GT 1. In contrast, in the PB 260 clone, the downward and upward tapping panels showed low and high sucrose levels, respectively.

The average inorganic phosphorus contents of the latex were high, in GT 1 and PB 260 clones, regardless of the direction of tapping (downward tapping and upward tapping). These levels were statistically identical, with respect to the downward and upward tapping panels.

According the reference values, the contents of thiol groups were relatively high. Moreover, in clone GT 1, the panels of downward and upward tappings showed, moderate (0.7 mmol.l^{-1}) and very high (0.9 mmol.l^{-1}) thiol group contents respectively. Conversely, at the level of the PB 260 clone, the downward tapping and upward tapping panels displayed high thiol group contents (0.79 mmol.l^{-1}) and relatively high (0.75 mmol.l^{-1}) respectively.

The latex micro-diagnosis, through the analysis of Table 5, shows that the physiological profiles of the trees were well balanced, regardless of the clone and the tapping system.

Table 5. Parameters and Physiological Profiles of GT 1 and PB 260 Clones, on Downward Tapping and Upward Tapping Panels

Tapping Panels	Physiological Parameters of Latex								Physiological Profile	
	Clone GT 1				Clone PB 260				Clone GT 1	Clone PB 260
	Ex.S (%)	Sac (mmo.l^{-1})	Pi (mmo.l^{-1})	RS-H (mmo.l^{-1})	Ex.S (mmo.l^{-1})	Sac (mmo.l^{-1})	Pi (mmo.l^{-1})	RS-H (mmo.l^{-1})		
Downward	50.5 a	10.3 a	19.4 a	0.7 b	55.0 a	6.4 b	22.4 a	0.79 a	Well balanced	Well balanced
Upward	46.5 a	11.5 a	16.1 a	0.9 a	50.8 a	8.4 a	20.0 a	0.75 a	Well balanced	Well balanced

In each column, the assigned values of the same letter are not significantly different (Kruskal Wallis test at 5% for ExS, Newman-Keuls test at 5 % for Sac, Pi and R-SH). ExS: dry rubber content; Suc: sucrose; Pi: inorganic phosphorus; R-SH: thiol groups; mmol.l^{-1}: millimole per liter

Relationship between Rubber Productivity of the Downward Tapping and that of Upward Tapping of the GT 1 and PB 260 Rubber Tree Clones

The production of rubber at the tree and the tapping of the downward and upward tappings of the GT 1 and PB 260 clones follows a linear regression of general expression:

$$\text{kg. ha}^{-1}\text{.year}^{-1}{}_{\text{upward tapping}} = \text{a kg.ha}^{-1}\text{.year}^{-1}{}_{\text{downward tapping}} + \text{b}$$

Thus, the give for GT 1 and PB 260 clones is the following:

$$\text{kg.ha}^{-1}\text{.year}^{-1}{}_{\text{upward tapping}} = 727\ \text{kg.ha}^{-1}\text{.year}^{-1}{}_{\text{downward tapping}} + 1407 \text{ (Figure 2).}$$

In downward tapping, the GT 1 clone exhibited a yield lower than that expressed by the PB 260 clone. The same was true of the upward tapping system.

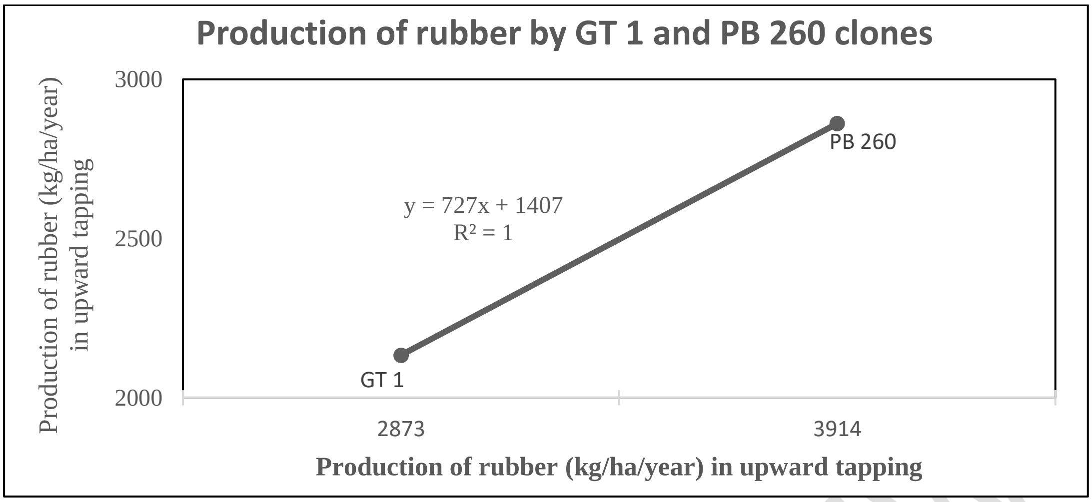

Figure 2. Correlation between the tapping direction and rubber production of the GT 1 and PB 260 rubber tree clones

kg/ha/year: kilogram per hectare per year

DISCUSSION

The results relating to agronomic parameters, in particular those of the average annual production of dry rubber, with more than 35 % increase in productivity from the upward tapping panel (HO) to the downward tapping panel (BO), regardless of the clone, show that the panels of upward tapping panel are more productive than those of the downward tapping panel, previously operated for nine years.

These results corroborate those of Obouayeba *et al*. [13] that have already highlighted the rubber productivity performance of the high panel (≥ 25 %). In light of these rubber productivity results of the downward and upward tapping panels, one wonders what is the origin of this important benefit of upward tapping on the downward tapping. Tapping, regardless of the clone metabolism, the direction of tapping (downward or upward) and the stimulant product, is a potential source of energy [24, 25].

In fact, Obouayeba *et al*. [15] have shown and qualified tapping as a physical or mechanical stimulant and is one of the three sources of activation of the laticigenic metabolism. This is, through the activation of the tonoplastic ATPase which alkalinizes the cytosol, at the origin of the latex production and its increase [18, 26]. It is therefore probable that the downward tapping is at the origin of the productivity superiority of the upward tapping over the downward tapping. This hypothesis is more plausible because Obouayeba *et al*. [15] have shown that the rubber productivity of the upward tapping at the opening is statistically lower than or equal to that of the downward tapping. They concluded that the rubber productivity of the upward tapping is more proven to be preceded by at least 4 years of downward tapping.

In addition, the conclusions of very recent studies [13] have been corroborated by those of Obouayeba *et al*. [15] but better still, they have specified that the plausible downward tapping time is 5 years. On the other hand, our radial vegetative growth results show a superiority of the low panel over the high panel. This highlights an antagonism between these two important agronomic parameters, resulting in the fact that, the higher the rubber productivity of a tapping panel, the lower the isodiametric growth of the tree trunk corresponding to the tapping panel. This explained by competition between the production of primary biomass and that of secondary biomass [27]. To this end, our results are an illustration of the fact that, the more the tree produces rubber, the less it grows, confirming and / or corroborating the conclusions of the work of many authors [17, 18, 28-32]. Our results of rubber production and radial vegetative growth explain this situation, that is, the evolution in the opposite direction of rubber production and radial vegetative growth.

Tapping panel dryness was expressed by the trees, but not significant regardless of clone and tapping direction (downward tapping or upward tapping). This implies that the rubber production of the two tapping panels had no effect on the sensitivity of these clones to the tapping panel dryness syndrome. These levels thus expressed (3.9 %) are good because generally clones of the fast metabolic class, in this case PB 260, are considered more sensitive to tapping panel dryness than clones of the other metabolic classes and often display rates higher than 5% [18]. The data present in this study are indicative of a very good level of resistance to tapping panel dryness syndrome. They also probably and above all express the fact that the latex harvesting systems applied to them are suitable or more appropriate for the two GT 1 and PB 260 clones with moderate and active metabolism respectively.

The analysis of physiological parameters reveals that the level of dry rubber content in both clones are very high, regardless of the direction of tapping practises applied. This explains a good regeneration of the latex during tapping that describe the effectiveness of the isoprenic syntheses within the laticiferous cells (33).

Sucrose content analysis shows that the photosynthetic supply of the trees is from good to very good in clone GT 1 and varies from fairly good to good level in clone PB 260. These characteristics concerning sucrose content thus observed are consistent with those intrinsic to these clones and derive from the metabolic mode of operation of these two clones relative to their metabolic class [25]. Fast-metabolizing clones inherently have a low sucrose content of the latex and a higher initial metabolic energy that sufficiently activates the rubber production metabolism [18]. This runaway productive metabolism has probably resulted in a high utilization of sucrose which results in the high yields of rubber and consequently the low sucrose contents of the latex displayed by the clone PB 260, compared with those presented by clone GT 1.

The average levels of inorganic phosphorus in the latex were high in GT 1 and PB 260 clones, regardless of the direction of tapping. These levels thus reflect the state of energy available for the functioning of isoprenic metabolism, notably its activation, which is probably the cause of the good production of cis-polyisopren, as had already been explained by many authors [7, 34-37].

The thiol groups, for their part, constitute a major parameter of the latex diagnosis. Thiol content reflects the ability of laticiferous to protect themselves from the destructive effects of oxidative of active oxygen (FAO: O_2^-, OH^- and H_2O_2) [19]. These active forms of oxygen generally participate in the senescence of the laticiferous cells [19]. Levels of thiol groups also reflect the intensity of the stress to which trees are subjected to the latex harvest [19]. For this purpose, with an average content of thiol groups of 0.79 $mmol^{-1}$ in GT 1 and PB 260 clones, all tapping panels combined, this average content of thiol groups is good, compared to the reference values established by Jacob *et al*. [19]. It does not therefore constitute a handicap to the subsequent rubber production of these two clones.

The physiological profiles were well balanced regardless of the clone and the direction of tapping. Thus had confirmed that the latex harvesting systems tested are well adapted to GT 1 and PB 260 clones.

CONCLUSION

The agrophysiological advantages of downward tapping on low panel (BO) over the upward tapping on high panel (HO) of GT 1 and PB 260 clones (*Hevea brasiliensis*, Muell, Arg Euphorbiaceae) in Côte d'Ivoire have been proven relative to rubber production and radial vegetative growth. Indeed, this study revealed that, regardless of the clone, upward tapping panels are more productive in dry rubber than those of the downward tapping to which they succeed. However, rubber productivity, relative to clone and tapping direction, is antagonistic to isodiametric growth of tree trunks. Also, the proven agrophysiological advantages of the downward tapping over the upward tapping of the rubber clones GT 1 and PB 260 are probably independent of the rubber clone. On the other hand, this study shows that the downward tapping has no effect either on the tapping panel dryness syndrome or on the physiological profile of the trees tapped in upward.

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