Original Research Article

Influence of tapping depth on rubber yield and tapping quality in rubber tree plantations in southeastern Côte d'Ivoire

ABSTRACT

Aims: Rubber tree (*Hevea brasiliensis Muell Arg*.) is the main source of natural rubber. Its cultivation generates significant income for several companies and farmers around the world. However, its exploitation is threatened by the considerable drop in rubber yield which is due to the ignorance of tapping criteria in particular the optimal tapping depth. This study aims at improving rubber yield.
Place and Duration of Study: The study was carried out in agro-industrial plantations of rubber tree in southeastern Côte d'Ivoire from june 2020 to january 2021.
Methodology: The study took place in two phases: the first consisted in assessing the tapping depth of the plantations and the second in studying the influence of the different tapping depths on rubber yield and tapping quality. The first study was carried out with 347 tappers in 954 tapping tasks. The second study focused on 4 rubber tree clones (PB 217, IRCA 41, IRCA 230 and IRCA 18) belonging to the three metabolic activity classes. These clones were subjected to 4 treatments (T0: tapping to a depth of 0 to 1.5 mm; T1: tapping to a depth of 1 to 2 mm; T2: tapping to a depth of 1 to 1.5 mm, T3: tapping to a depth of 1.5 to 2 mm) in a completely randomized block design with 4 repetitions. This comparative study was carried out on the basis of yield and tapping quality parameters (bark consumption, wounds).
Results: The results of the first study showed that the average tapping depth of the plantations inspected is 1.44 mm in half-spiral downward tapping and 1.82 mm in a quarter-spiral upward tapping. The tapping depth is influenced by the height of the tapping panel and by the clone. The results of the second study showed that tapping depth influences rubber yield and tapping quality. Indeed, tapping to a depth between 1 and 1.5 mm from the cambium induces the most significant yields but causes poor tapping quality. In contrast, tapping to a depth between 1 and 2 mm from the cambium gives lower yields but makes it possible to show better tapping quality.
Conclusion: The tapping depth is influenced by the height of the tapping panel and by the clone. The tapping depth influences rubber yield and tapping quality.

Keywords: rubber tree, tapping depth, tapping quality, rubber yield.

1. INTRODUCTION

Agriculture has long been one of human main activities. Rubber tree cultivation, which started in the Amazon basin, current Brazil, two centuries ago, has now become an important economic activity throughout the world, because it generates enormous income. More than 90% of the dry rubber content of the rubber tree consists of rubber [1]. Natural rubber is an important raw material in industry. It is 70% involved in the manufacture of tires in the tire industry [2], also in the manufacture of joints and anti-seismic supports in the construction industry, and in the manufacture of catheters, surgical gloves in the biomedical industry [3].

In Côte d'Ivoire, rubber tree cultivation is one of the main cash crops providing export earnings and tax revenue. With 950,000 tons produced in 2020, Côte d'Ivoire is the leading producer of natural rubber in Africa and the fourth globally. Côte d'Ivoire produces 80% of African natural rubber [4].

To produce natural rubber, tapping is performed, which consists in making a cut or incision in the tree's bark [5]. The yield in quantity and the sustainability of the exploitation of rubber trees require compliance with certain criteria qualified as tapping quality criteria [1]. The tapping quality criteria include incision depth, bark consumption, wounds and general aspects that include maintenance, cleanliness and discipline [6]. The aspect incision depth in tree bark represents an important yield but also quality criterion for increasing rubber yield in rubber trees. Indeed, it emerges from the monitoring missions of technical support to farmers that despite the support of technical supervisory operators, some plantations are completely destroyed due to poor tapping practices [7]. These include, among others, non-compliance with tapping standards. The tappers, generally paid according to their yield in rubber, tend to tap very deeply in order to maximize their profits. These poor tapping practices cause damage to rubber tree bark due to poor regeneration of the latter, making them unsuitable for subsequent tapping. These facts lead to a reduction in the economic life of rubber trees. This results in drops in rubber yield and low tapper yields [5]. These factors durably affect the farmer's business and threaten its sustainability. In order to improve rubber tree yield, it is therefore wise to assess an important tapping parameter, namely tapping depth, both for rubber yield and tapping quality.

The overall purpose of this study is to improve rubber yield. The specific purposes are the following:

- assess the level of tapping depth in rubber tree plantations;
- determine the effect of different tapping depths on rubber yield and tapping quality.

2. MATERIAL AND METHODS

2.1. Study Site

The study took place in the agro-industrial plantations in the southeastern Côte d'Ivoire. The relief of this area is very uneven with a dominance of plains and low plateaus. Of ferralitic type, the soil has a sandy-clay texture and has a gravelly horizon. The area has a humid tropical climate characterized by heavy rainfall. Four seasons including two rainy seasons are observed with a large one from April to July and a small one from October to November and two dry seasons with a small one from August to September and a large one from December to March. The annual rainfall varies between 1200 and 1700 mm with a good distribution and an annual average of 1660 mm [8].

2.2. Material

2.2.1. Plant material

The plant material used consisted of rubber tree *(Hevea brasiliensis)* clones, belonging to three metabolic activity classes. These included clones IRCA 41, PB 217, IRCA 18 and IRCA 230 (Table 1).

Table 1: Characteristics of some rubber tree clones

Clones	Geographical origin	Genetic origin	Year of planting	Annual yield of dry rubber (kg/ha)	Metabolic class
PB217	Malaysia	PB 5/51 x PB 6/9	1955	2500-3000	Moderate
IRCA41	Côte d'Ivoire	GT 1 x PB 5/51	1974	2000-2500	Low
IRCA230	Côte d'Ivoire	GT 1 x PB 5/51	1976	2500-3000	Active
IRCA18	Côte d'Ivoire	PB5/51 x RRRIM605	1974	2000-2500	Active

2.2.2. Technical material

The technical material consisted of all the tools and devices used to collect data in plantation. The field material essentially consisted of a stainless steel ruler for measuring wounds and bark consumption, a 2-level punch (1.5 mm; 3 mm) for measuring tapping depth, a spring scale for weighing rubber yield, a tape measure for measuring tree girth, a digital camera for taking pictures, industrial chalk for marking trees, knives and tapping gouges for tappers, buckets for

collecting latex, whetstones for sharpening tappers' knives and gouges, raincoats, boots, goggles for tappers' protection, a paintbrush for applying the stimulating product, yellow, green, red and blue strips to delimit the different treatments.

2.3. Methods

2.3.1. Assessment of tapping depth in agro-industrial plantations

Measurements of tapping depth were made using a punch at two levels (1.5 mm and 3 mm) in order to know what level of tapping depth is reached in agro-industrial plantations in southeastern Côte d'Ivoire. Tapping depth data was collected with 347 tappers of southeastern. For each portion of tapping surveyed, tapping depth was measured on 5 trees tapped by alternating tapping per day. The average tapping depth was determined for each tapper (Table 2).

Table 2: Number of tapping portions surveyed per division

Number of tappers inspected	Number of tappers by tapping frequency			Number of tasks inspected
	d4	d5	d6	
347	165	162	26	954

d4: tapping every 4 days; d5: tapping every 4 days; d6: tapping every 4 days

2.3.2. Effect of different tapping depths on rubber yield and tapping quality

2.3.2.1. Experimental design and treatment

The experimental design used was in complete randomized blocks (CRB), consisting of 4 treatments in total randomization in each block with 4 repetitions. The alternations represented the repetitions. The experiment was conducted on 4 blocks grown at a spacing of 6 m x 3 m (that is, a density of 555 trees/ha). On each block was assigned a tapper tapping the 4 treatments. The trial comprised 10 trees x 4 treatments x 4 repetitions (blocks), that is, 160 trees. The trees were selected on the basis of the homogeneity of their girth at 1.70 m above the ground, the homogeneity of tapping panels, their health condition, the regularity of the trunk and their tapping panel dryness rate (0%). In each block, the treatments were the following:

T0: tapping to a depth between 0 mm and 1.5 mm from the cambium,
T1: tapping to a depth of 1.0 mm to 2 mm from the cambium,
T2: tapping to a depth of 1.0 mm to 1.5 mm from the cambium,
T3: tapping to a depth of 1.5 mm to 2 mm from the cambium.

2.3.2.2. Tree tapping

The latex from tapping was collected in plastic cups. The tapping of the rubber trees studied was carried out every day during the trial by four tappers for all the blocks, using a knife or a tapping gouge. The tapping system used was half-spiral downward (S/2) and quarter-spiral upward (S/4U) at d5 (tapping every 5 days) and d6 (tapping every 6 days) frequencies.

2.3.2.3. Hormonal stimulation

The active ingredient of the stimulant used was chloro-2-ethylphosphonic acid or Ethephon. The application of the stimulating product was carried out using a paintbrush. The stimulating paste was evenly spread over a 1-cm wide strip, both on the regenerating panel and on the tapping cut. The trees were stimulated with 2.5% Ethephon in downward tapping and 5% Ethephon in upward tapping.

2.3.2.4. Measurements carried out

Rubber yield

Rubber yield was recorded per tapper, per treatment and per block. The coagula or cup lumps, removed at the next tapping, were collected, weighed using a precision balance, on a daily basis. Rubber yield was recorded per treatment for each block, at a rate of one weighing every day except Sunday (rest day). The transformation coefficient (CT) made it possible to switch from farm-gate weight (FW) to dry weight (DW), with TC = 0.56. The yield was then expressed in grams per tree.

The dry weight (DW) was determined by the following relation:

$$DW = FW \times TC \quad (1)$$

With DW: Dry weight, FW: Fresh weight and TC: Transformation coefficient

Tapping quality control

During the trial, all the tappers were controlled so as to assess the impact of each treatment on tapping quality. Each tapper had 250 points per alternating control. They thus had 750 points for the three alternations to be controlled. Penalty points were deducted from these points according to the defects observed. The number of residual points constituted the tapper's monthly quality score (Table 3).

Table 3: Distribution of points for tapping quality control

Tapping quality criteria	**Point credits**
Incision depth	50
Panel wounds	75
Bark consumption	75
Cleanliness and discipline	50
Total	250

Tapping depth

During the control, tapping depth was measured using a punch graduated in mm for each tapper. A penalty was applied when the tapper tapped outside the recommended tapping depth standard (Table 4).

Table 4: Penalties imposed to tappers according to the tapping depth standard

Treatments	Penalties per tapping depth standard			
T0 (0-1.5 mm)	Between 0-1.5 mm: penalty 0	Between 1.5-3 mm: penalty 6	>3 mm: penalty 10	
T1 (1-2 mm)	Between 0-1 mm: penalty 2	Between 1-2 mm: penalty 0	Between 2-3 mm: penalty 6	>3 mm: penalty 10
T2 (1-1.5 mm)	Between 0-1 mm: penalty 2 and 6 points in case of wound	Between 1-1.5 mm: penalty 0	Between 1.5-3 mm: penalty 6	>3 mm: penalty 10
T3 (1.5-2 mm)	Between 0-1.5 mm: penalty 2 and 6 points in case of wound	Between 1.5-2 mm: penalty 0	Between 2-3 mm: penalty 6	>3 mm: penalty 10

Bark consumption
During tapping quality control, bark consumption was measured on tapping panel height, using a graduated short ruler perpendicular to the tapping cut in each tapping task.

Wounds
During the control, wounds were controlled over a band of approximately 1 cm above the downward tapping cut, or below the quarter-spiral in upward tapping cut.

Calculation of tapping quality scores and indexes
Each month, the tappers were the subject of 3 written controls so as to assess their tapping quality. The 3 controls were carried out in different tapping tasks and entitled them to a total of 750 points with 250 points per tapping task.
After the 3 controls which were scored out of 750 points, the tapper's final quality control score (FQCS) was determined by the following relationship:

$$FQCS = \frac{(\sum CS)}{3} \quad (2)$$

With FQCS: Final Quality Control Score; ∑NC: Sum of Scores for each Control.
Then, the quality index (QI in %) of the tapper was determined by the following relation:

$$QI = \frac{FQCS}{750} \times 100 \quad (3)$$

2.3.3. Statistical analyses
STATISTICA software version 7.1 for Windows was used to perform the analysis of variance (ANOVA) of the average depth data and rubber yield of the rubber tree clones studied. In the event of a significant difference at 5% threshold, Duncan's test made it possible to identify the different homogeneous groups. Thus, if the probability $P > 0.05$, then the means were not significantly different. In contrast, if the probability $P < 0.05$, then the means were significantly different.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Assessment of tapping depth in rubber tree plantations

Table 5 shows the tapping depth values of the plantations inspected. The tapping depth assessment for the half-spiral downward tapping (S/2) revealed that 131 tappers (that is, 58% of the tappers) had tapping depth between 1 and 1.5 mm from the cambium, 15 tappers (that is, 6.5% of tappers) had tapping depth below 1 mm from the cambium, 81 tappers (that is, 35.5% of tappers) had tapping depth above 1.5 mm from the cambium.

The quarter-spiral upward tapping revealed that 28 tappers (that is, 23% of tappers) had tapping depth ranging between 1 and 1.5 mm from the cambium, 2 tappers (that is, 2% of tappers) had tapping depth below 1 mm from the cambium and 90 tappers (that is, 75% of tappers) had tapping depth above 1.5 mm from the cambium.

Table 5: Number of tappers depending on tapping depth levels in mm

Tapping depth	Tapping systems	
	S/2	S/4U
Tapping depth < 1 mm	15 (6.5%)	2 (2%)
Tapping depth between 1 and 1.5 mm	131 (58%)	28 (23%)
Tapping depth > 1.5 mm	81	90 (75 %)
	(35.5%)	
Number per tapping system	227	120
Average tapping depth	1.44	1.82

Table 6 shows the effect of clones on tapping depth. The analysis of this table makes it possible to divide the clones into two groups. The first group was represented by clones IRCA 41, PB 217, PR 107, GT1 and IRCA 18. The average tapping depth value of these clones was between 1.66 and 1.85 mm. The second group was made up of clone RRIC 100. This clone showed an average tapping depth value of 2.02 mm. From one group to another, the difference between the average tapping depth values of the clones was significant (P = 0.000603).

Table 6: Average tapping depths depending on clones

Clones	Average tapping depth	Signification P < 0.05
IRCA 41	1.82b	0,000603
PB 217	1.80b	
PR 107	1.66b	
RRIC 100	2.02a	
GT1	1.78b	
IRCA 18	1.85b	

The results assigned the same letter are not significantly different (Duncan's test at 5%).

Table 7 shows the effect of tapping panels on tapping depth. The analysis of this table makes it possible to divide the tapping panels into two groups. The first group was represented by panels C12, C22, C21 and C11. The average tapping depth value of these panels was between 1.45 and 1.82 mm. The second group consisted of panels D12 and D22. These panels showed an average tapping depth value of 1.91 and 2.08 mm, respectively. From one group to another, the difference between the average tapping depth values of the panels was significant (P = 0.000000).

Table 7: Effect of tapping panels on tapping depth.

Tapping panels	Average tapping depth	Signification P < 0.05
C12	1.73b	
C22	1.45b	
C21	1.75b	
D12	1.91a	0.000000
D22	2.08a	
C11	1.82b	

The results assigned the same letter are not significantly different (Duncan's test at 5%).
With C12: 1st year of tapping on the second panel of C, C22: 2nd year of tapping on the second panel of C, C21: 2nd year of tapping on the first panel of C, D12: 1st year of tapping on the second panel of D, D22: 2nd year of tapping on the second panel of D, C11: 1st year of tapping on the first panel of C.

3.1.2. Impact of tapping depths on rubber yield and tapping quality of the rubber tree clones studied

3.1.2.1. Impact of tapping depths on rubber yield in grams per tree (g/t) in half-spiral downward tapping

Table 8 shows the effect of tapping depths on dry rubber yield depending on tapping frequency. At d5 tapping frequency, treatment T2 (149 g/t) showed the highest rubber yield, statistically identical to that of treatments T0 (138.5 g/t) and T3 (136.5 g/t) and significantly higher than that of treatment T1 (129.85 g/t). Treatment T1 gave the lowest rubber yield, statistically equivalent to that of treatments T0 and T3.

At d6 tapping frequency, treatments T0, T1 and T2 recorded rubber yields that were statistically identical to each other (203.0; 199.5; 204.75 g/t, respectively) and significantly higher than that of treatment T3 (177 .22 g/t).

Table 8: Average dry rubber yield (in g/t) depending on the different treatments

Tapping frequencies	Treatments	Average dry rubber yield (g/t)	Signification P < 0.05
d5	T0	138.50ab	0.036263
	T1	129.85b	
	T2	149.00a	
	T3	136.50ab	
d6	T0	203.00a	0.013845
	T1	199.50a	
	T2	204.75a	
	T3	177.22b	

The results assigned the same letter are not significantly different (Duncan's test at 5%).

3.1.2.2. Impact of tapping depths on rubber yield in grams per tree (g/t) in quarter-spiral upward tapping

Table 9 shows the effect of tapping depths on dry rubber yield (g/t). At d5 frequency, treatment T2 showed the highest rubber yield (161.41 g/t) significantly higher than those of treatments T0, T1 and T3 (140.0; 141.64; 130.12 g/t, respectively). The rubber yields of the latter treatments were statistically identical to each other.

At d6 tapping frequency, treatment T2 gave rubber yield (290.5 g/t) significantly higher than that of treatments T0, T1 and T3 (259.0; 273.5; 231.0 g/t, respectively). Treatments T0, T1 and T3 recorded statistically equivalent rubber yields.

Table 9: Average dry rubber yield (in g/t) depending on the different treatments

Tapping frequencies	Treatments	Average dry rubber yield (g/t)	Signification P < 0.05
d5	T0	140.00b	0.028572
	T1	141.64b	
	T2	161.41a	
	T3	130.12b	
d6	T0	259.00b	0.000688
	T1	273.50b	
	T2	290.50a	
	T3	231.00b	

The results assigned the same letter in the same tapping frequency are not significantly different (Duncan's test at 5%).

3.1.3. Impact of tapping depths on tapping quality

3.1.3.1. Impact of tapping depths on the tapping quality index of half-spiral downward tapping

Table 10 shows the effect of treatments on tapping quality. At d5 tapping frequency, treatment T1 showed the highest tapping quality index (97%), significantly higher than that of treatments T0, T2 and T3 (94; 92; 94%, respectively).

At d6 tapping frequency, the tapping quality indexes of treatments T1, T2 and T3 were statistically identical to each other (91%) and significantly higher than that of treatment T0 (87%).

Table 10: Effect of treatments on tapping quality score and quality index in half-spiral downward tapping

Frequencies	Treatments	Depth score	Consumption score	Wound score	Cleanliness and Discipline score	Total quality score	Quality index	Meaning p < 0.05
d5	T0	138	195	225	150	708b	94%b	0.000030
	T1	150	203	225	150	728a	97%a	
	T2	126	201	215	150	692b	92%b	
	T3	122	213	225	150	710b	94%b	
d6	T0	150	131	225	150	656b	87%b	0.000250
	T1	150	161	225	150	686a	91%a	
	T2	150	155	225	150	680a	91%a	
	T3	120	185	225	150	680a	91%a	

The results assigned the same letter in the same tapping frequency are not significantly different (Duncan's test at 5%).

3.1.3.2. Impact of the different treatments on tapping quality score of each tapping quality criterion in half-spiral downward tapping

Table 11 shows the effect of the treatments on quality score of each tapping quality criterion in half-spiral downward tapping. At d5 tapping frequency, the tapping depth criterion made it possible to divide the different treatments into two groups. The first group was formed by treatment T1. The average value of quality score for this treatment was 50. The second group was made up of treatments T0, T2 and T3 which respectively showed average values of quality score of 46.00, 42.00 and 42.67. The analysis of variance from one group to another showed a significant difference between the average values of quality score of the treatments (P = 0.000000). The bark consumption criterion made it possible to divide the different treatments into two groups. The first group was formed by treatment T0. The average value of quality score for this treatment was 65.00. The second group was made up of treatments T1, T2 and T3, showing average values of quality score of 67.67, 67.00 and 71.00, respectively. The analysis of variance from one group to another showed a significant difference between the average values of quality score of the treatments (P = 0.000811). The wound criterion made it possible to divide the different treatments into two groups. The first group was formed by treatment T2. The average value of quality score for this treatment was 71.67. The second group consisted of treatments T0, T1 and T3 which showed an average value of quality score equal to 75.00. The analysis of variance from one group to another showed a significant difference between the average values of quality score of the treatments (P = 0.000443).

At d6 tapping frequency, the tapping depth criterion made it possible to divide the different treatments into two groups. The first group was formed by treatment T0. The average value of quality score for this treatment was 35.73. The second group consisted of treatments T1, T2 and T3 which showed average values of quality score of 42.00, 41.33 and 40.00, respectively. The analysis of variance from one group to another showed a significant difference between the average values of quality score of the treatments (P = 0.000476). The bark consumption criterion made it possible to divide the different treatments into two groups. The first group was formed by treatment T0. The average value of quality score for this treatment was 43.67. The second group was made up of treatments T1, T2 and T3 which showed average values of quality score of 53.67, 51.67 and 61.67, respectively. The analysis of variance from one group to another showed a significant difference between the average values of quality score of the treatments (P = 0.009137). The wound criterion

did not make it possible to divide the different treatments. The analysis of variance did not show a significant difference between the average values of quality score of the treatments (P = 0.121739).

Table 11: Effect of treatments on tapping quality score for each tapping quality criterion in half-spiral downward tapping

Criteria	Treatments	Tapping quality score			
		d5	Signification P < 0.05	d6	Signification P < 0.05
Tapping depth	T0	46.00b	0.000000	35.73b	0.000476
	T1	50.00a		42.00a	
	T2	42.00b		41.33a	
	T3	42.67b		40.00a	
Bark consumption	T0	65.00b	0.000811	43.67b	0.009137
	T1	67.67a		53.67a	
	T2	67.00a		51.67a	
	T3	71.00a		61.67a	
Wound	T0	75.00a	0.000443	75.00a	0.121739
	T1	75.00a		75.00a	
	T2	71.67b		75.00a	
	T3	75.00a		75.00a	

The results assigned the same letter in the same tapping frequency and the same quality criterion are not significantly different (Duncan's test at 5%).

3.1.3.3. Impact of the different treatments on the score and the tapping quality index of rubber trees in quarter-spiral upward tapping

Table 12 shows the effect of treatments on tapping quality. The d5 frequency made it possible to divide the different treatments into two groups. The first group was formed by treatment T1. The average value of quality index of this treatment was 93%. The second group consisted of treatments T0, T2 and T3 which showed an average quality index value of 88%, 78%, 83%, respectively. The analysis of variance from one group to another showed a significant difference between the average values of quality index of the treatments (P = 0.000695).

The d6 frequency did not make it possible to divide the different treatments. The analysis of variance showed no significant difference between the average values of quality index of the treatments (P = 0.054712).

Table 12: Effect of treatments on the score and the tapping quality index in quarter-spiral upward tapping

Frequencies	Treatments	Depth score	Consumption score	Wound score	Cleanliness and Discipline	Total quality	Quality index	Meaning

		e			score	score		p < 0.05
d5	T0	126	188	198	150	662b	88%b	0.000695
	T1	142	180	223	150	695a	93%a	
	T2	124	126	219	150	586b	78%b	
	T3	120	185	225	150	619b	83%b	
d6	T0	150	66	161	150	527a	70%a	0.054712
	T1	124	63	189	150	526a	70%a	
	T2	92	81	163	150	486a	65%a	
	T3	96	57	201	150	504a	67%a	

The results assigned the same letter in the same tapping frequency are not significantly different (Duncan's test at 5%).

3.1.3.4. Impact of the different treatments on quality score of each tapping quality criterion in quarter-spiral upward tapping

Table 13 shows the effect of the treatments on quality score for each tapping quality criterion in quarter-spiral upward tapping. At d5 frequency, the tapping depth criterion made it possible to divide the different treatments into two groups. The first group was formed by treatments T0 and T1. The average values of quality score of the treatments were respectively 42.00 and 47.33. The second group was made up of treatments T2 and T3 which showed average values of quality score of 40.00 and 41.33, respectively. The analysis of variance from one group to another showed a significant difference between the average values of quality score of the treatments (P = 0.000239). The bark consumption criterion made it possible to divide the different treatments into two groups. The first group was formed by treatments T0 and T1. The average values of quality score of the treatments were 62.67 and 60.00, respectively. The second group consisted of treatments T2 and T3 which showed average values of quality score of 51.00 and 42.00, respectively. The analysis of variance from one group to another showed a significant difference between the average values of quality score of the treatments (P = 0.000128). The wound criterion made it possible to divide the different treatments into two groups. The first group was formed by treatments T1 and T3. The average values of quality score of the treatments were 74.33 and 73.00, respectively. The second group was made up of treatments T0 and T2 which showed average values of quality score of 66.00 and 54.33, respectively. The analysis of variance from one group to another showed a significant difference between the average values of quality score of the treatments (P = 0.003139).

At d6 frequency, the tapping depth criterion made it possible to divide the different treatments into two groups. The first group was formed by treatments T0 and T1. The average value of quality score of the treatments was respectively 50.00 and 41.33. The second group consisted of treatments T2 and T3 which showed average values of quality score of 30.67 and 32.00 respectively. The analysis of variance from one group to another showed a significant difference between the average values of quality score of the treatments (P = 0.000000). The bark consumption criterion did not make it possible to divide the different treatments. The analysis of variance did not show any significant difference between the average values of quality score of the treatments (P = 0.286075). The wound criterion made it possible to divide the different treatments into two groups. The first group was formed by treatments T1 and T3. The average values of quality score of the treatments were respectively 63.00 and 67.00. The second group consisted of treatments T0 and T2 which showed average values of quality score of 53.67 and 54.33, respectively. The analysis of variance from one group to another showed a significant difference between the average values of quality score of the treatments (P = 0.000006).

Table 13: Effect of treatments on quality score for each quality criterion of quarter-spiral upward tapping

Criteria	Treatments	Tapping quality score			
		d5	Signification P < 0.05	d6	Signification P < 0.05
Tapping depth	T0	42.00a	0.000239	50.00a	0.000000
	T1	47.33a		41.33a	
	T2	40.00b		30.67a	
	T3	41.33b		32.00a	
Bark consumption	T0	62.67a	0.000128	22.00a	0.286075
	T1	60.00a		21.00a	
	T2	51.00b		27.00a	
	T3	42.00b		19.00a	
Wound	T0	66.00b	0.003139	53.67b	0.000006
	T1	74.33a		63.00a	
	T2	54.33b		54.33b	
	T3	73.00a		67.00a	

The results assigned the same letter in the same tapping frequency and the same quality criterion are not significantly different (Duncan's test at 5%).

3.2. Discussion

3.2.1. Assessment of the depth in agro-industrial plantations of southeastern Côte d'Ivoire

The assessment of the depth of agro-industrial plantations in southeastern Côte d'Ivoire showed that a majority of tappers (54%) who tap in half-spiral downward (S/2) tap between 1 mm and 1.5 mm from the cambium while a minority of tappers (23%) who tap in quarter-spiral downward (S/4U), tap between 1 mm and 1.5 mm from the cambium. This result shows that the direction of the tapping (downward or upward) influences the tapping depth. Indeed, the tapping depth is influenced by the height of the tapping panel relative to the ground. In downward tapping, the height of the panel relative to the ground being within easy reach of the tapper, this makes the task of tapping easy. However, in upward tapping, some panels located at a great height above the ground make the task more difficult. These results confirm those of Abe [9] who showed that the higher the panel is located from the ground, the less efficient the tapper is in his work.

3.2.2. Impact of tapping depth on rubber yield in rubber trees

The results of the trial on the average dry rubber yield in grams per tree (g/t) showed a significant difference between treatments T0 (tapping to a depth of 0 and 1.5 mm from the cambium), T1 (tapping to a depth of 1 and 2 mm from the cambium), T2 (tapping to a depth of 1 and 1.5 mm from the cambium) and T3 (tapping to a depth of 1.5 and 2 mm from the cambium) with an average yield of T2 significantly higher than that of T0, an average yield of T1 significantly identical to that of T0 and an average yield of T3 significantly lower than that of T0. This result confirms that treatment T2 is more yielding for these clones. Indeed, young laticifers resulting from the differentiation of cambium cells are in large numbers in this area of the bark, which favors an increase in latex production. This observation is confirmed by the work of several authors ([10]; [1]; [11]; [12]; [13]; [14]) who have shown that tapping depth between 1 and 1.5 mm from the cambium represents the most yielding depth in rubber. Indeed, according to these authors, it is this very narrow zone belonging to the conductive phloem (secondary phloem) very close to the cambium which remains functional to ensure the supply of photosyntats to the laticifer mantles. This arrangement explains the influence of this zone on the abundance of latex flow.

Treatment T3 had a significantly lower yield than the other treatments because at this level of depth, the laticifer vessels are older, resulting in a relatively low yield in rubber quantity with a flow of latex whose stoppage over time is accelerated by the wind. These results are in agreement with those of Hebant and de Fay [14] who showed that the oldest laticifer mantles are gradually pushed back towards the hard outer parts of the bark where they are then compressed in clumps of sclerotic cells. The laticifers then become disorganized, then degenerate. Following their histological observations, Hebant and de Fay [14] showed that the major part of the functional laticifer mantles (70% to 90%) are located in the non-conductive phloem constituting the bulk of the bark in *Hevea brasiliensis*.

Treatment T0 has a relatively lower yield than treatment T2 because the tapping interval includes level zero; which causes wounds during tapping and which has the consequence of creating cuts in the secondary phloem and the cambium which respectively limit the descent of the elaborated sap and prevent the regeneration of the severed tissues. This result is in line with the work of De Jonge [15], Compagnon [1] and MRB [16] who showed that the incision in the bark should not reach the cambium, the fragile generative layer ensuring tissue regeneration after tapping. If this last one is touched during tapping, this prevents the regeneration of the severed tissues and leads to a healing reaction, causing more or less accentuated bulges.

3.2.3. Impact of tapping depth on tapping quality in rubber trees

The analysis of the results shows that treatment T1 (tapping to a depth of 1 and 2 mm from the cambium) leads to a better quality of tapping compared to the other treatments (T0: tapping to a depth of 0 and 1.5 mm from the cambium; T2: tapping to a depth of 1 and 1.5 mm from the cambium and T3: tapping to a depth of 1.5 and 2 mm from the cambium). Indeed, treatment T1 shows a tapping interval at the fingertips of tappers because the extent of the treatment interval has on the one hand a deep tapping between 1 and 1.5 mm from the cambium and on the other hand a less deep tapping between 1.5 and 2 mm from the cambium; this allows tappers to comply with tapping depth while reducing wounds and bark consumption. Treatment T1 therefore does not negatively impact the other criteria such as wounds and bark consumption. Treatments T0 and T2 induce an increase in tapping wounds. These results are in line with the work of Abe [9] who showed that quality criteria influence tapper performance. Moreover, he proved that the criteria were highly significant on top of each other. As a result, the tapper who knows and masters tapping quality criteria will be more efficient because he himself will be able to judge the quality of his work.

4. CONCLUSION

At the end of the study on the influence of tapping depth on the yield and tapping quality in rubber trees, it appears that the average tapping depth of the agro-industrial plantations in southeastern Côte d'Ivoire inspected is 1.44 mm in half-spiral downward tapping and 1.82 mm in quarter-spiral upward tapping. The tapping depth is influenced by the height of the tapping panel (high panel in upward tapping or low panel in downward tapping) and by the clone (clone with thick or less thick bark).

Concerning rubber yield, the results showed that it is influenced by tapping depth. Indeed, treatment T2 (tapping to a depth between 1 and 1.5 mm from the cambium) makes it possible to have the highest yields whatever the tapping frequency and the height of the tapping panel. However, this treatment induces poor tapping quality. Treatment T1 (tapping depth between 1 and 2 mm from the cambium), less yielding, shows the best tapping quality. This treatment reduces bark consumption and tapping wounds.

This study is not exhaustive. It would be wise to pursue it along the following lines:

- Pursue this study over a longer period;
- Assess the influence of tapping depths on bark regeneration.

CONSENT

Not applicable.

ETHICAL APPROVAL

Not applicable

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