Sustainable rubber production through good latex harvesting practices: An update on mature rubber fertilization effects on latex cell biochemistry and rubber yield potential.

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ABSTRACT

From 2008 to 2012, under a joint funding by the "Institut Français du Caoutchouc" (IFC) and its affiliated societies (Michelin, SIPH and Socfinco), a network of large scale experiments has been set up and followed up in 5 agro-industrial plantations to study the influence of a gradient of fertilization of mature rubber trees on latex physiological parameters and rubber yield potential. Experiments were set up on clone PB260 (Socfindo Tanjung Maria and Aek Pamienke plantation in North Sumatra, Indonesia, SAPH-Toupah and SOGB-Grand Bereby plantations in Côte d'Ivoire) and on clone IRCA109 (RENL-Osse River plantation in Nigeria). During the first 3 years (2008/09 to 2010/11), the trees were tapped downward in S/2 d4. During the 4^{th} year (2011/12), the trees were tapped upward in S/4 d4. Each experiment has been designed with a similar protocol: Split plot design with stimulation intensity as the main treatment and fertilizer rate as secondary treatment, with 4 replications. The 3 stimulation intensities (main plots) were INT_1 (normal stimulation intensity adapted to the clone, according to Cirad stimulation recommendation grid), INT_2 (intensified stimulation: INT_1 + 2 stimulations/y) and INT_3 (intensified stimulation: INT_1 + 4 stimulations/y). The 4 fertilization rates (secondary plots) were IF_0 (No fertilization control), IF_1 (single dose as the standard Cirad recommendation : 50g N, 40 g P_2O_5, 90 g K_2O per tree per year, applied in a single application 45 to 60 days after complete refoliation), IF_2 (double dose : 100 g N, 80 g P_2O_5, 180 g K_2O per tree per year) and IF_3 (triple dose : 150 g N, 120 g P_2O_5, 270 g K_2O per tree per year). The 12 main plots (4 replications x 3 stimulation intensities) were fitted to 12 tapping tasks selected for their homogeneity (girth and production) before trial implementation. After 4 years, maximum cumulative production (kg/ha) was always observed with a fertilized treatment (IF_2 or IF_3) combined with intensified stimulation (INT_2 or INT_3). Without fertilization (IF_0), intensification of stimulation (INT_2 or INT_3) resulted in a decreased production (overexploitation) or in a reduced response to stimulation. However, these effects of combined intensification and fertilization were often below +10% when compared to the production of the unfertilized control (INT_1 x IF_0) and therefore hardly statistically significant at a 5% risk. Regarding the latex physiological parameters, the average latex sucrose level was significantly increased by fertilization when compared to the absolute control, even though the increased production, showing a positive physiological change in latex sugar loading or in latex metabolism. Pi and RSH latex contents were also generally increased but less significantly. This indicates that an accurate NPK fertilization might sustain a good latex physiological profile in case of intensified ethephon stimulation and would help to prevent any risk of overexploitation, likely mainly because of an improved sugar translocation towards the latex sink, due to K+ likely. This opens the way to specific recommendations of clonal stimulation recommendations depending on fertilization practices.

1 Introduction

Among latex harvesting technologies, effect of fertilization of tapped rubber trees (mature phase) has been poorly scientifically documented. Very often, mature fertilization recommendations exist, but they are very often empiric, poorly scientifically sounded and generally not adapted to the local conditions (climate, soil, clone, latex harvesting system, first planting or replanting…). When they exist, these recommendations may be systematic or may be reasoned depending on leaf analysis results, although direct relations between these leaf nutrients contents and rubber production have almost never been established, due to the absence of acknowledged and scientifically sounded link between these leaf mineral contents and the physiological functioning of the latex regeneration sink. They may also be reasoned as compensation of exported biomass based on rather empiric conversion equations between achieved yields and theoretically required mineral restitutions. The reasons for this relative absence of scientific knowledge on the physiological bases of interactions between fertilisation and rubber production are mainly the high costs of such experiments: protocols are often complicated, experimental costs are high due to the fertilizer costs. Required experimental areas to study their interactions are large, often not available in research stations, as such studies require multifactorial experiment designs (split plot, latin squares, factorial…). For all these reasons, this rubber research area has been almost neglected during the last 30 years, as most of all literature references studying these interactions between fertilization and yield potential and tapping system intensification date from the 70's in Malaysia (Pushparajah *et al*., 1971, Sivanadyan *et al*., 1972) or in Côte d'Ivoire (Compagnon, 1973, Du Plessix *et al*., 1973).

Nowadays, in a period of high volatility of rubber prices, the interactions between mature rubber fertilization and natural rubber production have to be studied again. In periods of high rubber prices, it is important to maximize plantation benefits by using accurate fertilization plans to optimize the local yield potential in a sustainable way. Conversely, it is as well so important to optimize the use of fertilizers and to prove that it is really useful and profitable when rubber prices are low, in order not to add useless financial charges to planters when their financial condition is bad. As a matter of fact, the costs of manpower and fertilizers are consistently increasing in all rubber producing countries. Moreover, the growing environmental concern by human societies requires to ensure that all cultural practices, and particularly fertilizer applications, must be optimized in order to reduce the external inputs (mineral nutrients, pesticides…) and to reduce environmental impacts as water pollutions (rivers or water tables) observed after uncontrolled leaching, as well as GHG emissions.

A multi-local experiment network aiming at increasing the knowledge on these particular interactions between fertilization of mature rubber plots and their yield potentials, was set up in 2008. This study was set up and funded under the umbrella of a research agreement between Cirad, Institut Français du Caoutchouc (IFC) and IFC affiliate companies: Michelin, SIPH and Socfinco. This communication presents only its main conclusions. Detailed results will be published later in peer reviewed referenced scientific journals.

2. Materials and Methods

From 2008 to 2012, a multi-local network of large scale agronomic experiments has been set up and followed up in 5 agro-industrial plantations to study the influence of a gradient of fertilization of mature rubber trees on latex physiological parameters and rubber yield potential. Experiments were set up on clone PB260 (Socfindo Tanjung Maria and Aek Pamienke plantations in North Sumatra, Indonesia, SAPH-Toupah and SOGB-Grand Bereby plantations in Côte d'Ivoire) and on clone IRCA109 (RENL-Osse River plantation in Nigeria). Experiments were not set up at opening but after 7 years of tapping completed (SAPH), 8 years of tapping (RENL) or 9 years of tapping (SOGB, Tanjung Maria, Aek Pamienke). During the first 3 years under experiment (2008/09 to 2010/11), the trees were tapped downward in S/2 d4. During the 4th year (2011/12), the trees were tapped upward in S/4 d4. Each experiment was designed with a similar protocol: Split plot design with stimulation intensity as the main treatment and fertilizer rate as secondary treatment, with 4 replications. The 3 stimulation intensities (main plots) were INT_1 (normal stimulation intensity adapted to the clone, according to Cirad stimulation recommendation grid), INT_2 (intensified stimulation: INT_1 + 2 stimulations/y) and INT_3 (intensified stimulation: INT_1 + 4 stimulations/y). The 4 fertilization rates (secondary plots) were IF_0 (No fertilization control), IF_1 (single dose as the standard Cirad recommendation : 50g N, 40 g P_2O_5, 90 g K_2O per tree per year, applied in a single application 45 to 60 days after complete refoliation), IF_2 (double dose : 100 g N, 80 g P_2O_5, 180 g K_2O per tree per year) and IF_3 (triple dose : 150 g N, 120 g P_2O_5, 270 g K_2O per tree per year). The 12 main plots (4 replications x 3 stimulation intensities) were fitted to 12 tapping tasks selected for their homogeneity (girth and production). For each of the 48 elementary plots of each trial, productions (fresh cuplumps) and DRC were recorded per elementary plot at each tapping and converted either in Kg/ha. An annual latex diagnosis was performed in September or October, as well as an annual leaf mineral content analysis (N, P, K, Ca, Mg) performed in July, 3 months after completed refoliation. Leaves were sampled according to the standardized leaf sampling method for leaf diagnosis (sampling of 3 months old shade leaves). On each site, each elementary plot was characterized at the beginning of the trials (2008) by an extensive and complete soil analysis (profile, structure, texture, pH, mineral and organic characterization). Unfortunately, the SOGB trial had to be stopped in 2011 due to security troubles which resulted in impossibility to respect the fertilizer application protocol, and therefore its results will not be presented here.

3. Main results and discussion

3.1. Leaf mineral nutrients analyses

TOTAL		FERTILIZATION RATE				
INTEXP	Element	IF0	IF1	IF2	IF3	Average
INT1	**N**	**3.626**	**3.652**	**3.668**	**3.721**	3.67
	P	0.229	0.233	0.227	0.231	0.23
	K	**1.261**	**1.293**	**1.278**	**1.296**	1.28
	Ca	**1.008**	**0.999**	**0.979**	**0.950**	0.98
	Mg	**0.371**	**0.369**	**0.363**	**0.362**	0.37
INT2	N	3.669	3.650	3.704	3.672	3.67
	P	0.233	0.234	0.232	0.231	0.23
	K	1.245	1.233	1.275	1.258	1.25
	Ca	**1.018**	**1.040**	**0.963**	**0.958**	0.99
	Mg	**0.378**	**0.369**	**0.360**	**0.365**	0.37
INT3	**N**	**3.591**	**3.648**	**3.670**	**3.732**	3.66
	P	**0.231**	**0.235**	**0.235**	**0.239**	0.24
	K	**1.255**	**1.264**	**1.306**	**1.315**	1.29
	Ca	**1.050**	**0.989**	**0.984**	**0.960**	1.00
	Mg	**0.375**	**0.371**	**0.367**	**0.364**	0.37
Total N		**3.629**	**3.650**	**3.680**	**3.710**	3.67
Total P		0.231	0.234	0.232	0.234	0.23
Total K		**1.253**	**1.263**	**1.286**	**1.290**	1.27
Total Ca		**1.025**	**1.009**	**0.976**	**0.955**	0.99
Total Mg		**0.375**	**0.370**	**0.363**	**0.364**	0.37

TOTAL		FERTILISATION RATE				
INTEXP	ratios	IF0	IF1	IF2	IF3	Average
INT1	**N/P**	**15.83**	**15.67**	**16.14**	**16.09**	15.93
	N/K	2.88	2.82	2.87	2.87	2.86
	K/P	**5.51**	**5.55**	**5.62**	**5.60**	5.57
	Mg/P	**1.62**	**1.58**	**1.60**	**1.57**	1.59
	K/Mg	**3.40**	**3.51**	**3.52**	**3.58**	3.50
INT2	**N/P**	**15.76**	**15.59**	**15.93**	**15.87**	15.79
	N/K	2.95	2.96	2.91	2.92	2.93
	K/P	**5.35**	**5.27**	**5.48**	**5.44**	5.38
	Mg/P	**1.62**	**1.58**	**1.55**	**1.58**	1.58
	K/Mg	**3.30**	**3.34**	**3.54**	**3.45**	3.41
INT3	**N/P**	**15.53**	**15.54**	**15.60**	**15.63**	15.57
	N/K	2.86	2.89	2.81	2.84	2.85
	K/P	**5.43**	**5.38**	**5.55**	**5.51**	5.47
	Mg/P	**1.62**	**1.58**	**1.56**	**1.52**	1.57
	K/Mg	**3.34**	**3.40**	**3.56**	**3.62**	3.48
Total N/P		**15.71**	**15.60**	**15.89**	**15.86**	15.76
Total N/K		2.89	2.89	2.86	2.88	2.88
Total K/P		**5.43**	**5.40**	**5.55**	**5.51**	5.47
Total Mg/P		**1.62**	**1.58**	**1.57**	**1.56**	1.58
Total K/Mg		**3.35**	**3.42**	**3.54**	**3.54**	3.46

Table 1: Average leaf nutrients analysis content (N, P, K, Ca, Mg, expressed in % dry matter, left) and average leaf nutrients ratios (N/P, N/K, K/P, Mg/P and K/Mg, right). Averages of all sites (4 years data).

Under an increasing NPK fertilization gradient, and independently from the stimulation intensity, leaf N and K contents increase while leaf Ca and Mg contents decrease. Leaf P remains almost constant, except when a high stimulation intensity is applied (INT3). Regarding ratios between elements, an increasing NPK rate leads to a regular increase of N/P, K/P and K/Mg ratios, while Mg/P decreases. These trends have been observed whatever the site, whatever the clone, and for each year. They fit with the available knowledge and confirm the antagonism regarding uptake of monovalent cations (K^+) and bivalent cations (Ca^{2+}, Mg^{2+}). These results confirm an accurate nutrient uptake following fertilizer application and therefore confirm the accuracy of the fertilizer application methods, which were fitted to each planting design of each experimental site (application in the interrow, at a distance to the planting line depending on each planting design).

3.2. Rubber production

Considering all fertilization rates confounded (Table 2), no significant effect of stimulation intensification on production could be observed on PB260 after 4 years of tapping (this effect was null in Aek Pamienke and Tanjung Maria and only +5% in SAPH Toupah). This effect was conversely very significant on RENL experiment on IRCA109 clone (+14%).

All fertilization (IF)		**INT$_1$**	**INT$_2$**	**INT$_3$**	**Total**
SOC Aek Pamienke	PB260	7302	7145	**7362 (+1%) NS**	7270
SOC Tanjung Maria	PB260	8854	8822	**8950 (+1%) NS**	8875
SAPH Toupah	PB260	11771	**12347 (+5%) NS**	12054	12057
RENL ORREL	IRCA109	9643 c	10292 b	**10952 (+14%) a**	10295

Table 2: Cumulative production after 4 years (Kg/ha). Comparison of productions obtained with the different stimulation intensities, all fertilization rates confounded. At 5% risk, differences between INT treatments are significant only in RENL (IRCA 109 clone).

Considering all stimulation intensities confounded (Table 3), the highest cumulative productions (Kg/ha) were always obtained with IF_1 fertilization rate on PB260 clone (Aek Pamienke: +5%, Tanjung Maria: +6% or SAPH Toupah: +2%). The average effect of fertilization rate on IRCA109 was almost null, not because this effect did not exist but because of interactions between fertilizer rate and stimulation intensities, cancelling any visible effect of fertilization in average. However, differences between treatments were never significant at a 5% risk.

All stimulation INT	IF_0	IF_1	IF_2	IF_3	Total
SOC Aek Pamienke	7134	**7489 (+5%) NS**	7194	7263	7270
SOC Tanjung Maria	8555	**9095 (+6%) NS**	8983	8867	8875
SAPH Toupah	11909	**12200 (+2%) NS**	12185	11935	12057
RENL ORREL	10331	10262	**10345 (+0%) NS**	10245	10295

Table 3: Cumulative production after 4 years (Kg/ha). Comparison of productions obtained with the different fertilization rates, all stimulations confounded. At P<5%, differences are not significant.

After 4 years of experiment, the maximum productions (Table 4) were obtained, on all experiments, with an intensified stimulation (INT_2 or INT_3) combined with a fertilizer application (IF_2 or IF_3).

Production (kg/ha)		Control	Maximum production		% Control
		INT_1 x IF_0	INT_i x IF_j		
SAPH	PB260	11997	**INT_2 x IF_2**	**12656 NS**	**105%**
RENL	IRCA109	9893 a	**INT_3 x IF_3**	**11183 b**	**113%**
SOC AP	PB260	7543	**INT_3 x IF_3**	**8013 NS**	**106%**
SOC TM	PB260	8895	**INT_3 x IF_2**	**9566 NS**	**108%**

Table 4: Intensification of stimulation WITH fertilization; Cumulative production after 4 years (Kg/ha). Comparison of productions (Control and treatment (INTixIFj) obtaining the maximum production). At 5% risk, differences with the control are significant only for RENL (IRCA109).

Conversely (Table 5), the same intensification of stimulation without fertilization (IF_0) on clone PB260, leads to a drop in production (overexploitation in the case of Aek Pamienke or Tanjung Maria) or a total absence of response to stimulation (SAPH). In the case of IRCA 109, the response to stimulation exists, as the clone IRCA109 has a higher sugar loading capacity than PB260, but this response is decreased compared to the equivalent fertilized treatment.

Production (kg/ha)		Control	Stim P_{max} without fertilization		% Control
		INT_1 x IF_0	INT_i x IF_0		
SAPH	PB260	11997	**INT_2 x IF_0**	**11911 NS**	**99%**
RENL	IRCA109	9893 a	**INT_3 x IF_0**	**10809 b**	**109%**
SOC AP	PB260	7543 a	**INT_3 x IF_0**	**6243 b**	**83%**
SOC TM	PB260	8895	**INT_3 x IF_0**	**8450 NS**	**95%**

Table 5: Intensification of stimulation WITHOUT fertilization; Cumulative production after 4 years (Kg/ha). Comparison of productions (Control and treatment (INT_ixIF_0), where Inti is as in table 5). At 5% risk, differences with the control are significant only for Aek Pamienke (PB260) and RENL (IRCA109).

3.3. Latex physiological parameters

In average after 4 years of experiment (2008/2012), on clone PB260 (SAPH, Socfindo Aek Pamienke and Socfindo Tanjung Maria plantations), latex physiological profile was improved by association of an intensified ethephon stimulation plus adapted NPK fertilization when compared to the control treatment (normal stimulation without fertilization (Table 6). Latex sucrose content was increased significantly at 5% risk in all 3 sites, latex Pi content was significantly increased in Tanjung Maria site and latex RSH content was significantly increased in Tanjung Maria site and Aek Pamienke site. Latex TSC remained unchanged in all sites when compared with the control.

Latex Sucrose ($mM.l^{-1}$)		**Control**	**Maximum Production**		**% Control**
		INT_1 x IF_0	**INT_i x IF_j**		
SAPH	PB260	3.58 b	**INT_2 x IF_2**	**5.32 a**	**149%**
SOC AP	PB260	3.04 b	**INT_3 x IF_3**	**4.31 a**	**142%**
SOC TM	PB260	3.05 b	**INT_3 x IF_2**	**3.99 a**	**131%**

Latex Pi ($mM.l^{-1}$)		**Control**	**Maximum Production**		**% Control**
		INT_1 x IF_0	**INT_i x IF_j**		
SAPH	PB260	22.28	**INT_2 x IF_2**	**24.12 NS**	**108%**
SOC AP	PB260	21.42	**INT_3 x IF_3**	**21.35 NS**	**100%**
SOC TM	PB260	24.21 b	**INT_3 x IF_2**	**29.13 a**	**120%**

Latex RSH ($mM.l^{-1}$)		**Control**	**Maximum Production**		**% Control**
		INT_1 x IF_0	**INT_i x IF_j**		
SAPH	PB260	0.47	**INT_2 x IF_2**	**0.48 NS**	**101%**
SOC AP	PB260	0.34 b	**INT_3 x IF_3**	**0.39 a**	**116%**
SOC TM	PB260	0.37 b	**INT_3 x IF_2**	**0.44 a**	**121%**

Latex TSC (%)		**Control**	**Maximum Production**		**% Control**
		INT_1 x IF_0	**INT_i x IF_j**		
SAPH	PB260	48.86	**INT_2 x IF_2**	**49.59 NS**	**101%**
SOC AP	PB260	53.03	**INT_3 x IF_3**	**52.94 NS**	**100%**
SOC TM	PB260	52.08	**INT_3 x IF_2**	**50.79 NS**	**98%**

Table 6: Intensification of stimulation and fertilization; Latex physiological parameters (Suc $mM.l^{-1}$, Pi $mM.l^{-1}$, RSH $mM.l^{-1}$) and TSC (%) averages during 4 years, Clone PB260 : SAPH, Socfindo Aek Pamienke and Socfindo Tanjung Maria plantations). Comparison of physiological profiles (Control and treatment (INTixIFj) obtaining the maximum production).

Under increased stimulation + fertilization, and although an increased production, latex sucrose content is increased (figure 1) and overall physiological profile is improved as well: increased latex sucrose, increased latex Pi and increased latex RSH. This is a remarkable result as usually, an increase in production following intensification of stimulation results in the contrary in a decrease of latex sucrose and RSH contents. Pi and RSH latex contents were also generally increased but less significantly. This likely indicates that an accurate NPK fertilization might sustain a good latex physiological profile in case of intensified ethephon stimulation. This would result in an enhanced response to stimulation and would also limit the risks of overexploitation and yield drops due to over-stimulation. This effect is likely depending on the effect of potassium or potassium x nitrogen interaction on sugar translocation towards the latex regeneration sink, resulting in a significant increase in latex sucrose content. This effect of potassium, enhancing the sucrose translocation towards sinks, has been extensively described in many other crops whose productions are vegetative sinks or reproductive sinks.

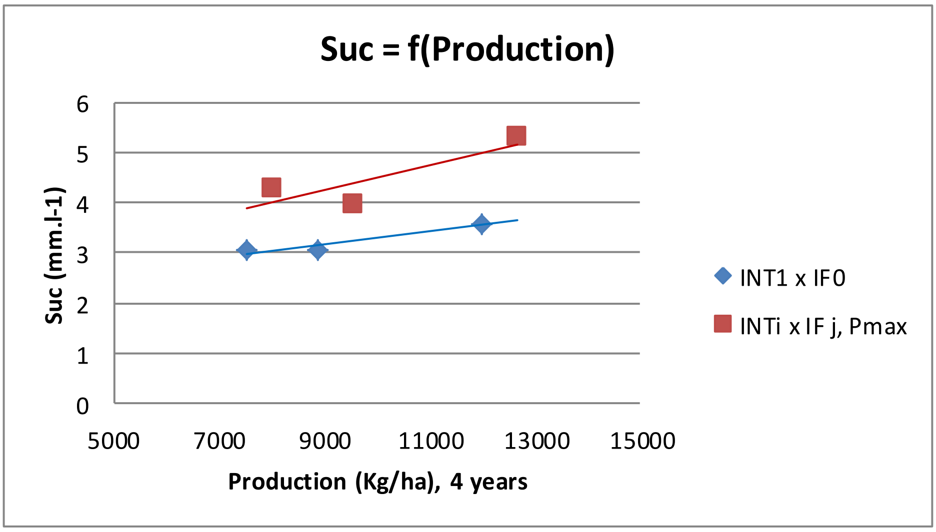

Figure 1: Relationship between Latex sucrose content (Suc, mM.l^{-1}) and production (Kg/ha). Combination of an increased stimulation and associated fertilization leads to a simultaneous increase of production and latex sugar content (red curve) when compared to the control (blue curve).

4. Discussion and conclusion

All observed production differences remain quantitatively small (5 to 10% potential increase) and are therefore hardly statistically significant. It is therefore more accurate and cautious to consider them as trends. As a matter of fact, under the split plot experimental design that we used in this study (or any other standard agronomic design), statistical evidence to demonstrate an effect which appears lower than a + 10% response is actually difficult to establish, even though this effect is suspected.

Nevertheless, an improvement of plot yield potentials by 5 to 10% may be highly economically interesting for planters, depending on rubber prices and fertilization associated costs, and may be the ultimate way to maximize plot productivity.

Under such precautions, an accurate fertilization application, fitted to the stimulation intensity, seems to enhance the response to stimulation (IRCA109) or to limit the risks of yield drop following overexploitation due to an excess of stimulation (PB260), likely because of an improvement of the latex physiological profile (increase of latex Suc, Pi and RSH, stability of TSC).

This result supports former results already published in the 70's (Pushparajah *et al*., 1971, Sivanadyan *et al*., 1972, Compagnon 1973, Du Plessix *et al*., 1973), which all concluded that potassium, in interaction with nitrogen, could improve the response to ethephon stimulation.

According to our results, this effect is likely depending on the effect of potassium or potassium x nitrogen interaction on sugar translocation towards the latex regeneration sink, resulting in a significant increase in latex sucrose content. This effect of potassium, enhancing the sucrose translocation towards sinks, has been extensively described in many other crops whose productions are vegetative sinks (tubers…) or reproductive sinks (fruits, seeds…). If further validated in the case of the latex regeneration sink of the rubber tree, such hypothesis would have foreseeable consequences for a further possible optimization of fertilization in mature rubber during the plantation lifespan: acting on latex sugar content, the potential effects of mature rubber fertilization based on this nitrogen x potassium interaction would therefore be depending on the latex sugar content variations inside the latex regeneration area, during the whole economic lifespan of the tapped tree. It would therefore depend on:

- The tapping system (for instance downward tapping system, upward tapping system, ethylene stimulation systems…), as these different tapping systems significantly differ regarding their sucrose supply conditions to the latex regeneration area (Gohet *et al.,* 1991).

- The intensity of the tapping system (tapping frequency, stimulation frequency and concentration, type of stimulation…), as intensification results in a decrease of latex sugar content as a result of increased latex regeneration (Gohet 1996, Gohet *et al.*, 1996, Lacote *et al.*, 2010).

- The tapping panel management, as the tapping cut position and the tapping sequence of these cut positions on the trunk strongly influence the latex sugar content (Gohet *et al.*, 1991, Gohet 1996, Gohet *et al.,* 1996, Lacote *et al.*, 2004). Responses to fertilization would therefore depend on tapping cut positions and on their specific sucrose supply conditions.

- The clone, as clones may differ considerably regarding their latex sugar content (Jacob *et al.*, 1995, Gohet 1996, Gohet *et al.*, 1996, Gohet *et al.*, 2003), depending on their latex metabolic functioning.

- The age of tapping, especially as the yield obtained during the first years of tapping mainly depends on the speed of latex metabolic activation, much more than on the latex sugar content.

Even if these trends seem clear enough, these potential effects of fertilization on production remain rather quantitatively small. Therefore the decision to fertilize or not to fertilize should be taken depending on the cost of fertilizer application (cost of fertilizer, cost of application, transport, storage and financial immobilization) and the expected or possible financial outcome, mainly depending on the rubber price, after an economic calculation and simulation.

More research seems required to optimize these mature rubber fertilization schemes and to adapt them to the local conditions (climate, soil condition…), to the cultural practices adopted by planters (clones, tapping systems and stimulation intensity, panel management…), to the planting histories (first planting, replanting, cropping system history…) and to planters yield objectives, in order to maximize the plantation sustainability and ensure that the fertilization practices do not result as well in negative environmental externalities such as water or soil pollutions or increased GHG emissions.

However and from now, this opens the way to specific recommendations of clonal ethephon stimulation depending on fertilization practices and levels, as accurate fertilization may result in significant improvement of latex physiological profiles allowing an intensification of the tapping system, mainly obtained from ethephon stimulation.

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