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Assessing Dry Rubber Yield of 12 Rubber Clones Using Three Tapping Systems

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Abstract

Rubber (*Hevea brasiliensis Muell.* Arg.) is a major high-value industrial crop in the Philippines, where latex productivity is strongly influenced by clonal characteristics, tapping systems, and prevailing climatic conditions. This study evaluated the dry rubber (DR) yield of twelve rubber clones subjected to three tapping systems (S2D2, S2D3, and S2D4) and examined their interaction with temperature, relative humidity, and rainfall. The experiment was conducted using a split-plot design arranged in a randomized complete block design with four replications, where tapping systems served as main plots and clones as subplots. Monthly dry rubber yields were recorded over one year (January–December 2023), and corresponding weather data were analyzed on a quarterly basis. Results revealed a highly significant interaction between tapping system and clone, while the main effect of tapping system alone was not significant. Climate had a strong modifying effect on yield expression. Frequent tapping (S2D2) was more effective during warm and relatively dry conditions in the first quarter, whereas longer rest intervals (S2D3 and S2D4) significantly improved yields during periods of high rainfall and relative humidity in the second and third quarters. Elite clones such as PB 260, USM 1, RRIM 2025, and RRIM 3001 consistently produced high DR yields (>1,500 kg ha^{-1} yr^{-1}) when tapping frequency was synchronized with seasonal climatic patterns. Overall, S2D3 emerged as the most climate-resilient tapping system, providing stable yields across fluctuating temperature, humidity, and rainfall conditions. These findings demonstrate that rubber yield is governed by a strong interaction among clone, tapping system, and climate.

Introduction

The rubber sector is one of the ten high-value industrial crops supported by various agencies in the Philippines. Based on the Philippine Rubber Industry Roadmap 2023-2028, Mindanao is home to 98% of the rubber plantations in the country. Among the regions, Zamboanga recorded the largest area planted with rubber in 2021, with 99,088 hectares, representing 41% of the total area of 239,140.50 hectares. SOCCSKSARGEN follows with 64,908 hectares (27%), and BARMM with 39,095 hectares (16%). Other regions in Mindanao showing significant increases in areas planted with rubber include CARAGA with

13,186 hectares (6%) and the Davao Region with 10,449.60 hectares (4%). The remaining regions have areas of less than 10,000 hectares, accounting for less than 4% of the total rubber-planted area in the Philippines.

As of 2023, Cotabato remains the top rubber-producing province in the Philippines, with a total production of 110,764 metric tons (MT) of coagulated cup lump produced. This is followed by Zamboanga Sibugay and Basilan with 108,111 MT and 69,392 MT, respectively. In addition, the first quarter 2024 report of the PSA Regional Statistical Services Office XI (Davao Region) recorded a total production of 12,011.61 MT of rubber cup lump in the region.

The latex yield is a critical factor in selecting *Hevea brasiliensis*. However, other factors such as vigor, bark thickness, resistance to wind and diseases, and management techniques (including tapping systems, planting density, and plant nutrition) also influence the expression of a cultivar's potential production. Enhancing rubber production is one strategy to address these challenges.

Tapping, on the other hand, is a labor-intensive and complex process. While farmers must protect the longevity of the tree, in which the goal is financial gain. Various tapping systems are recommended for rubber, with the S2D2 system being the most widely used in the Philippines. This system compensates for reduced tapping days due to unpredictable weather, but it threatens plantation profitability and requires costly high-tapping labor. To mitigate risks to rubber plantations, low frequency tapping systems have been introduced (Kudaligama et al., 2010. Sainoi et al., 2017). Increasing the tapping interval from the conventional S2D2 tapping system to S2D3 and S2D4 has been reported to reduce tapper requirements and production costs while enhancing both the quality and quantity of latex yield, ultimately leading to higher profits and a longer economic lifespan of rubber production (Zaw, 2023; Sainoi et al., 2017; Chotiphan et al., 2023).

To promote the expansion of rubber production in the Philippines, it is necessary to evaluate promising rubber clones under different tapping systems in terms of dry rubber of cup lump. Thus, this study evaluates the yield of USM rubber clones using different tapping systems. This will help identify potential high-yielding rubber clones, maximize their utilization, and explore their breeding potential.

Materials and Methods

Rubber Clones. A total of 12 rubber clones were used in this study. The detailed profile of each clone is indicated in Table 1.

Table 1: Detailed profile of the rubber clones used in this study.

Clones	Origin Institution/ Country	Reported Resistance (pathogen/issue)	Purpose (Latex/Timber)	Productivity potential
IRCA 331	IRCA/French-associated breeding lines (used in Cote d'Ivoire and West Africa)	Good field performance in West African trials; lower susceptibility to panel dryness/TPD and good vigor under West African conditions. Disease spectra differ in Africa vs Asia.	IRCA 331 has been included in trials assessing both latex and timber potential in Cote d'Ivoire.	High productivity in Cote d'Ivoire trial reports, performed well in West African conditions and used in recommendations for productivity.

Table 1: *Continued...*

Clones	Origin Institution/ Country	Reported Resistance (pathogen/issue)	Purpose (Latex/Timber)	Productivity potential
PB 260	Malaysian PB breeding program (Malaysia)	Noted moderate to good resistance to major leaf diseases in plantations report; viable reaction to tapping panel dryness, root diseases depending on location. Considered to have above average resistance to common foliar diseases in Malaysia trials.	Primary latex clone; sometimes evaluated for wood because of vigour but not a dedicated timber clone.	High productivity in many plantation trials (widely planted in Malaysia; used as female parent in crosses for yield). Trials in Cote d'Ivoire and elsewhere show strong yield potential under appropriate systems.
PB 350	Malaysian PB breeding program (Malaysia)	Show moderate resistance to foliar diseases; formal ratings sparse in open sources.	Mainly latex clone: sometimes tested for wood quality but PB 350 is mainly used for latex	Moderate high productivity observed in plantation reports and compared favorably in many PB vs. RRIM comparison
RRIM 2023	RRIM/ Malaysian Rubber Board (Malaysia)	RRIM 2000 series clones were selected for improved yield /quality specific pathogen resistance.	Generally used as latex clone; some 2000 series clones are evaluated for timber potential but 2023 is principally a latex clone	Moderate high potential in multi-site RRIM trials.
RRIM 2025	RRIM/ Malaysian Rubber Board (Malaysia)	No widely available catalogued major pathogen; resistance rating appears to have reasonable field tolerance.	Latex clone (2000 series)	Reported in some country trial as promising for yield and latex in response to stimulation
RRIM 2027	RRIM/ Malaysian Rubber Board (Malaysia)	No disease resistance profile.	Latex clone	Moderate performance reported in RRIM experimental evaluations.

Table 1: *Continued…*

Clones	Origin Institution/ Country	Reported Resistance (pathogen/issue)	Purpose (Latex/Timber)	Productivity potential
RRIM 3001	RRIM/ Malaysian Rubber Board (Malaysia)	Limited data on pathogen resistance of 3001 specifically trial.	Typically latex; some modern RRIM selections are evaluated for latex-timber potential but 3001 is normally cited for latex	Promising in early growth comparable to established clones in Philippine trial.
RRIM 600	Rubber Research Institute of Malaysia (RRIM) Malaysia	Moderate susceptibility to some leaf diseases and variable susceptibility reported for *Phytophtora* depending on environment; not reported as SALB-resistant: (South American leaf blight).	Generally, a latex clone	Productivity reported high in Malaysia plantations; used worldwide as benchmark in trials
RRIM 928	RRIM/ Malaysian Rubber Board (Malaysia)	Disease resistance ratings not widely assessed; included in RRIM clonal evaluation sets where disease reaction documented as typical of RRIM series	Latex clone (used in yield comparisons) Not widely described a timber clone	Moderate good performance in clonal evaluations; included in RRIM comparative studies showing acceptable yield and latex quality
RRIM 929	RRIM/ Malaysian Rubber Board (Malaysia)	Similar to 928- disease resistance ratings not widely assessed.	Latex clone (not specifically a timber clone)	Moderate- good yields in RRIM evaluation trials; included in modern trial sets
RRIT 251	Rubber Research Institute of Thailand (RRIT), Thailand	Specific pathogen resistance (e.g., *Phytophthora*) varies with environment.	Latex clone (Thailand trials emphasize latex productivity but breeding also considers timber potential for some genotypes	Good productivity in Thai multi-site tests and recommended in Thai performance lists

Table 1: *Continued…*

USM 1	University of Southern Mindanao (USM) Philippines	Local evaluations report reasonable resilience to local pests/diseases. SSR/ molecular studies include USM derived clones in disease/tolerance assessments.	Primarily latex clone; selected for adaptation to Philippine condition (some breeders consider late-stage stem straightness for timber potential but main use in latex)	Good to promising productivity in Philippine trials-listed among top performers for girth/yield in national assessments (e.g., among top clones in non- traditional Philippines sites)

Background of Experimental Area. The trial was consisted of twelve (12) clones where three (3) were NSIC-registered clones served as checks (RRIM 600, PB 260, USM 1) and nine clones (RRIM 928, RRIM 929, RRIM 2023, RRIM 2025, RRIM 2027, RRIM 3001, RRIT 251, PB 350 and IRCA 331) were obtained from major rubber producing countries. These were established following a 6 m × 3 m planting distance. The 0.77 ha clonal trial was set up in University of Southern Mindanao Agricultural Research and Development Center (USMARDC), Kabacan, Cotabato, Philippines in July 2016. Six (6) years after planting, rubber trees were started tapping and data on cuplumps were recorded.

Experimental Design. The experiment was laid out in split plot arranged in Randomized Complete Block Design (RCBD) with four (4) replications. The treatments were composed of three (3) tapping systems served as the main plot (S2D2, S2D3 and S2D4) and the twelve (12) clones as the sub-plot (RRIM 600, PB 260, USM 1 and RRIM 928, RRIM 929, RRIM 2023, RRIM 2025, RRIM 2027, RRIM 3001, RRIT 251, PB 350 and IRCA 331). Each clone consisted of three (3) sample trees per replication with a total of four hundred thirty-two (432) rubber trees used in this study.

Fertilization and Weeding. Fertilization was conducted by applying 300 grams of complete fertilizer (NPK) per tree applied twice a year and evenly distributed into five holes around each tree. This method was carried out after defoliation (wintering), when the leaves began to develop their new foliage. Weeding was performed occasionally as the dense canopy effectively suppressed weed growth.

Tapping of Rubber Trees. Six-year-old rubber trees were newly opened in ½ spiral cut of the trunk for tapping. The trunks of rubber trees were measured to obtain a uniform tapping cut and standard girth of 46 cm circumference. Tapping panel marking was performed by splitting into halves (S2) at 1.10 m from the ground through the incision of a tapping knife. Pre-tapping cut was marked with a depth of approximately 1 mm from the cambium layer. After marking, tapping materials such as latex spouts, wire cup hangers, and latex cups were installed in the trunk.

Tapping was done using the three (3) methods of tapping systems:

a. S2D2- ½ spiral cut of the tapping panel with one day tapped and one day rest, 15 days tapping per month, the usual farmer practice, (Control).
b. S2D3- ½ spiral cut of the tapping panel with one day tapped and two-day rest,10 days tapping per month
c. S2D4- ½ spiral cut of the tapping panel with one day tapped and three-day rest, 7 days tapping per month

In all tapping methods, no latex stimulation was employed.

Cuplump Collection. The coagulated latex yield, known as cuplump, was measured by collecting latex left uncollected in the tapping cups (Figure 1). After each tapping event, latex that remained in the collecting cup was allowed to coagulate overnight by adding a 2% acetic acid solution and stirring the mixture. This process was repeated for each tapping session. The coagulated cuplump in the cups were placed from the base of each rubber tree. A month after tapping, cuplumps were collected from each tree and weighed using a calibrated weighing scale. Data collection was conducted over a 12 month-period, from January to December 2023.

Figure 1. Tapped rubber clones per tapping system.

Yield Calculation and Conversion. The yield data, recorded in grams of dry rubber per tapping per tree (g.t−1 t-1). This measure commonly used to assess the productivity of rubber clones, was the main concern of this study. The g t−1 t−1, however, can also be used to indicate rubber farm performance by converting to kg ha−1 yr−1 using formula below (Ali et al 2020):

$$kg \cdot ha^{-1} \cdot year^{-1} = \frac{g{\cdot}t^{-1}{\cdot}t^{-1} \times planting\ density \times tapping\ days}{1000}$$

Dry rubber (DR) refers to the cup lump yield per tree multiplied by two or 50%, which represents the dry rubber of cuplump. The dry rubber yield per tree per month was computed by dividing the monthly yield according to the tapping system used; thus, S2D2 was divided by 15 tapping days per month, S2D3 by 10 days, and S2D4 by 7 days. The dry rubber yield per tapping per tree was then multiplied by 500 trees per hectare to obtain the dry rubber yield per hectare. The value in grams was converted to kilograms by dividing by 1,000 (1 kg = 1,000 g). The monthly dry rubber yield was multiplied by 15, 10, or 7 tapping days depending on the tapping system (S2D2, S2D3, or S2D4), and subsequently multiplied by 12 months to obtain the corresponding dry rubber yield in kilograms per hectare per year. The resulting monthly average was used to express the yield in kg/ha/year for that specific one-year period.

Data Analysis: Data on DR yield was analyzed using analysis of variance (ANOVA). The analysis was run using Statistical Tool for Agricultural Research STAR, ver 2. The mean separation was done using Tukey's HSD test.

Results

Dry Rubber Yield

As shown in Table 2, a highly significant interaction effect (p-value=0.000) was noted between tapping system (TS) and rubber clone (RC). Similarly, RC main effects were also found significant (p-value=0.000). However, TS was noted insignificant (p-value= .333). The result implies that 12 rubber clones differed significantly in their responses to three tapping systems. The average dry rubber yield in 1 year (kg/ha/year) of 12 rubber clones tapped using three tapping systems is presented in Table 1. Using S2D2, clone PB 260 produced a dry rubber (DR) yield of 1,850.3 kg/ha/yr which was significantly higher than the rest of the clones. Clones USM 1, and RRIM 2025 showed the second higher DR yield of 1,628.1 and 1,658.7 kg/ha/yr, respectively. Three rubber clones (IRCA 331, RRIM 2023, RRIM 929) showed less than 1,000 kilos of DR yield. The rest of the clones had DR yield more than one thousand kg per hectare per year. When S2D3 was employed, the same clone PB 260 showed the highest DR yield of 1,963.9 kg/ha/yr which was higher by 6.147% than those clones when the S2D2 was used. Clone RRIM 2025 produced DR yield of 1,876.2 kg/ha/yr which was comparable to clone PB 260. This was followed by clone USM 1 with DR yield of 1,797.7 kg/ha/yr which was comparable to clone RRIM 2025. In S2D4, was used, clone USM 1 and PB 260 registered DR yield of 1,896.9 and 1,882.6 kg/ha/yr, respectively. These were followed by clone RRIM 3001 and RRIM 2025 with respective DR yield of 1,709.8 and 1,677.7 kg/ha/yr. Five rubber clones were identified to have consistent DR yield regardless of TS used. These are clone PB 260, USM 1, RRIM 2025, RRIM 3001, RRIT 251, and RRIM 2027 with DR yield of more than 1,000 kilos per hectare per year. Among these five clones, three clones (PB 260, USM 1, and RRIM 2025) had more than 1,500 kg dry rubber yield per hectare per year which was far better than the RRIM 600 (582.1 kg/ha/yr), a check clone. Considering this result, S2D3 is better for clone PB 260 and RRIM 2025; S2D4 is for clone USM 1 and RRIM 3001; and S2D2 for clone RRIT 251.

Table 2: Average Dry Rubber Yield (kg/ha/year) of different clones tapped with various tapping systems.

Clone	Average Dry Rubber Yield (kg/ha) in 1 year		
	Tapping Systems[1/]		
	S2D2	S2D3	S2D4
IRCA 331	732.7^{ef}	1077.6^{de}	627.7^{d}
PB 260	1850.3^{a}	1963.9^{a}	1882.6^{a}
PB 350	1415.3^{bc}	1009.4^{de}	868.7^{d}
RRIM 2023	640.5^{f}	560.5^{f}	898.5^{d}
RRIM 2025	1658.7^{ab}	1876.2^{a}	1677.7^{a}
RRIM 2027	1136.2^{cd}	1249.1^{cd}	1342.5^{b}
RRIM 3001	1444.9^{bc}	1477.2^{bc}	1709.8^{a}
RRIM 600	1142.5^{cd}	798.4^{ef}	738.2^{d}
RRIM 928	1029.9^{de}	1126.9^{d}	914.2^{cd}
RRIM 929	977.6^{de}	1088.2^{de}	920.2^{cd}
RRIT 251	1406.2^{c}	1245.9^{cd}	1231.1^{bc}
USM 1	1628.1^{ab}	1797.7^{ab}	1896.9^{a}
SV	**p-value**		
Tapping System	0.33		
Clone	0.00		
Interaction	0.00		

CV (a)= 11.25% CV (b)= 11.05%

1/ Within a column, means having a common letter are not significantly different from each other.

Weather Data (Temperature, Rainfall and Humidity)

Weather data were collected by quarter as indicated in Table 3. Quarter 1 (January-March) was characterized by a progressively warming and drying climate with mean temperature increasing from 27.0°C in January to 28.3°C in March, while relative humidity declined from 77% to 82% and rainfall followed a wet-dry-moderate sequence (185.5mm in January, 88.2 mm in February, and 153.9 mm in March. Under this condition, frequent tapping was most efficient, and S2d2 consistently produced the highest dry rubber yield across most clones, particularly in elite genotypes such as PB 260, RRIM 3001, RRIM 2025 and USM 1.

Quarter 2 (April -June), climatic conditions shifted markedly to a heat-rainfall-humidity interaction. April and May have high temperature (28.5-28.6°C), but the month of May received extremely high rainfall (249.8mm), followed by sustained humidity in June (78% RH). Although high temperature continued to support latex biosynthesis, the excessive rainfall and elevated humidity caused panel wetness, latex-off and dilution, severely reducing the efficient of frequency tapping. As a result, S2D2 yields declined sharply across all clones. In contrast S2D3 and S2D4 showed pronounced yield advantages, particularly in high performing clones such as PB 260, RRIM 2025 RRIM 3001, and USM 1. This longer rest system allowed latex to accumulate during the wet period and be released more efficiently when rainfall subsided.

Quarter 3 (July-September) coincided with the peak of the wet season, characterized by persistently high rainfall (165.9- 258.6 mm per month) and very high relative humidity reaching up to 85% in September, while temperature remained moderate at around 28^{o}C. Under these conditions, transpiration was suppressed, tapping panels remained wet for extended periods, and immediate latex flow after tapping was limited. Consequently, S2D4, which provides the longest rest interval, became the dominant system, followed by S2D3, while S2D2 was least effective. In Q3, overall highest yield was observed in the elite clones such as USM 1, PB 260, RRIM 2025, and RRIM 3001 reflecting their strong capacity to store latex during prolonged wet periods and released it in large volumes when tapped.

Quarter 4 (October-December) marked the transition from the wet season to the dry season. Rainfall declined substantially (103.7mm in October to 66.7 mm in December), relative humidity stabilized around 76-77%, and temperature remained high at 28.4-28.5 ^{o}C. S2D3 emerged as the optimal tapping system, followed by S2D4, whereas S2D2 remained suboptimal for most clones. Intermediate rest interval under S2D3 allowed sufficient latex regeneration, leading to superior yield in clones such as USM 1, RRIM 2025, PB 260 and RRIM 3001.

The result demonstrate that rubber yield is governed by a strong interaction between tapping system and climate. Q1 favors frequent tapping under warm, drying conditions that promote continuous latex flow, Q2 and Q3 favor longer rest intervals under hot, wet and humid conditions that promote latex storage and delayed released; and Q4 favors intermediate tapping frequency during early dry-season recovery period. The high performing clones in this study exhibited climate plasticity, expressing their genetic yield potential only when tapping frequency was properly synchronized with seasonal patterns of temperature, relative humidity and rainfall. This confirms that climate-responsive tapping management is essential for maximizing rubber productivity in tropical environment such as Cotabato, Philippines, where pronounced wet-dry seasonal patterns strongly influence latex flow and tree recovery.

Table 3: Monthly data on temperature, rainfall and humidity

Month	Quarter	Temperature (^{o}C)	Relative Humidity (%)	Rainfall (mm)
January		27.0	82	185.5
February		27.4	81	88.2
March	Q1	28.3	77	153.9
April		28.5	76	157.5
May		28.6	77	249.8
June	Q2	28.2	78	161.5

Table 3: *Continued…*

Month	Quarter	Temperature (°C)	Relative Humidity (%)	Rainfall (mm)
July		27.9	78	165.9
August		28.0	79	193.3
September	Q3	27.8	85	258.6
October		28.4	77	103.7
November		28.5	76	139.2
December	Q4	28.4	76	66.7
Annual Average		**28**	**79**	**160.32**

Table 4 indicates the tapping system sustainability in each rubber based on yield. The results revealed that sustainability of the tapping system per clone requires good tapping practices, fertilization and management practices. Sustainability that requires water control was observed in RRIM 2023 as the yield was generally minimal due to the observed and recorded precipitation. This clone was noted to produce high yield in minimal amount of moisture or during dry season.

Table 4:. Tapping system sustainability of each clone based on their dry rubber yield.

Clone	Highest Yield (kh/ha)	Tapping system used	Sustainability
IRCA 331	1077.6	S2D3	This clone has a low initial yield. It requires consistent monitoring and application of proper nutrition to maintain average and stable productivity.
PB 260	1963.9	S2D3	Sustainability of this system requires careful selection of plantation sites as well as the adoption of tapping practices and appropriate fertilization to ensure long productivity.
PB 350	1415.3	S2D2	Sustainability requires efficiency of tapping practices and expertise.
RRIM 2023	898.5	S2D4	To sustain high yield, minimal water is necessary.
RRIM 2025	1876.2	S2D3	Sustainability requires good nutrition and good tapping practices.

Table 4: *Continued...*

Clone	Highest Yield (kh/ha)	Tapping system used	Sustainability
RRIM 2027	1342.5	S2D4	This can improve long term sustainability of plantation by diversify returns and reduce production risk compared to clones focused only on latex
RRIM 3001	1709.8	S2D4	Sustainability requires good nutrition and good tapping practices.
RRIM 600	1142.5	S2D2	Considered as one of the most important clones globally in rubber cultivation. It produces latex with technological properties considered relatively stable. Rubber quality like DRC, nitrogen and ash content. It shows less susceptibility to climate variation compared to other clone, contributing to its long-term sustainability and productivity
RRIM 928	1126.9	S2D3	Sustainability requires responsible planting and management. It depends heavily on plantation practices and should not be used to replace natural forest.
RRIM 929	1088.2	S2D3	Tapping practices and appropriate fertilization are necessary to ensure long productivity
RRIT 251	1406.2	S2D2	Good growth consistency under correct tapping and management.
USM 1	1896.9	S2D4	The high yielding clone, USM 1 depends strongly on good agronomic and management practices, soil management, tapping and disease control.

Discussion

These rubber trees were tapped six years after planting. The highest dry rubber yields were recorded for the control clones, PB 260 and USM 1, and these were followed by RRIM 2025, RRIM 3001, and RRIT 251. These clones showed stable performance across the different tapping systems, highlighting their high productivity and making them ideal candidates for maximizing rubber production under various rest-day intervals.

In contrast, seven other clones, including RRIM 600 (control), exhibited significantly poorer performance across the tapping systems. Notably, RRIM 600 had consistently low yields, which contrasts sharply with the yields reported in other regions. In Brazil, for instance, RRIM 600 achieved an average yield of 1250 kg/ha/year using a half-spiral tapping system with four daily tappings and seven tappings per month over 11 months in 6-year-old trees over a four-year period (De Souza Gonçalves et al., 2011). In India, the same clone produced 40.00 g/tree/tap over 9 years under a 1/2S d/3 system, opened 7 years after planting (John et al., 2009). However, in Brazil, both RRIM 600 and PB 260 performed well when tapped at eight years of stage, with data collection starting four years later, yielding dry rubber production of 1,371 and 1,434 kg/ha/year, respectively (Da Paes Pereira et al., 2018). Thus, the number of years prior to tapping may have contributed to the results of this study.

Pamplona (2012) reported that in Malaysia, six hybrid clones have been identified as early-maturing and high-yielding latex-timber clones: RRIM 3001, RRIM 928, RRIM 929, RRIM 2027, and PB 350, while RRIM 600 has a longer immature stage of 5.5 years. Notably, PB 350 was used as the standard clone, replacing PB 260, which had earlier replaced RRIM 600. PB 260 yields 300 kg/ha more than RRIM 600, while PB 350 surpasses PB 260 by 280 kg/ha per year. However, the PB 350 in this trial performed poorly in terms of dry rubber. In the Philippines, the recommended high dry rubber yielding clones at the mature stage includes RRIM 600 (2102.54 kg/ha/year), USM 1 (2523.51 kg/ha/year), and PB 260 (2370.00 kg/ha/year) (Cena, 2012). The low dry rubber content (DRC) observed in the RRIM 600 clone may be attributed to small trunk girth at the time of panel opening for latex tapping during the immature phase (3rd to 7th year) which is in agreement with the study of (Das et al., 2015). In this study, RRIM 600 exhibited a low dry rubber yield during the 6th year at opening of tapping. Although, RRIM 600 has been widely cultivated by smallholder farmers in North Cotabato, Philippines, several newly introduced clones have shown superior yield performance compared to RRIM 600. Likewise, RRIM 600 clone is highly susceptible to diseases caused by *Phytophthora* species, which pose a significant threat to latex production and overall tree health (Thanseem et al., 2005). According to Krishnan et al. (2019), *Phytophthora*-induced diseases may result in a yield loss ranging from 38% to 56%.

In Malaysia, high-yielding clones typically have a mean yield above 50 g/tapping/tree. For instance, RRIM 3001, RRIM 2023, and RRIM 928 produced yields of 70.64, 68.73, and 62.71 g/tapping/tree, respectively, while PB 260 yielded 59.34 g/tapping/tree ten years after planting. Conversely, RRIM 2025 and RRIM 2027 had lower yields of 45.16 and 33.77 g/tapping/tree, respectively, at the same stage (Rasyidah et al., 2023).

Over a 10-year tapping period, RRIT 251 demonstrated exceptional performance with the S2D3 tapping system applied with a stimulant, achieving the highest cumulative yield of 100,508.5 g/tree/tapping (Chotiphan et al., 2023). This indicates the effect of specific tapping systems and stimulants on the productivity of rubber clones. In Thailand, the clones RRIT 251 and PB 235 obtained a significantly higher yield than RRIM 600 and responded better than RRIM 600 to the tapping frequency reduction with stimulation, especially in years 2 and 3 (Chantuma et al., 2019).

The choice of rubber clones and tapping systems greatly influences yield outcomes. Clones PB 260, USM 1, RRIM 2025, RRIM 3001, and RRIT 251 are recommended for their high and stable yields. Conversely, clones with lower yields should still be studied based on their adaptability to specific conditions. This finding also suggests that the clones RRIM 2025, RRIM 3001, RRIT 251, and other low-yielding clones have not fully adapted to the agro-climatic conditions in the Philippines, and are still in the process of acclimatization, as these clones were recently introduced to the country. Moreover, Meenakumari et al. (2018) recommends imparting adaptive plasticity to various rubber clones, including the international multilateral clone exchange, due to the occurrence of uncertain stresses in nontraditional regions before commercialization.

Average Yield per Tapping Operations

The comparison of average dry rubber yield (kg/ha/year) across different tapping techniques indicates that S2D3 is the most effective system, with the highest average yield of 2,022.6 kg/ha/year. S2D2 and S2D4 have slightly lower average yields, with S2D2 yielding 1,255.2 kg/ha/year and S2D4 yielding 1,225.7 kg/ha/year. This suggests that S2D3 might be the optimal tapping system overall, balancing productivity and tapping frequency. Moreover, according to Testado (2012), low-frequency tapping system, S/2 D3, produces yields at approximately 85% of the S/2 D2 system, with a slightly higher Dry Rubber Content (DRC) in the latex. In comparison, the S/2 D4 system results in a lower yield but yields latex with a significantly higher DRC.

The reduction in latex productivity is notably influenced by the frequency of tapping. For instance, changes in tapping frequency from D3 to D5 decreased latex productivity by 30-40%, from d5 to d7 by 20-40%, and from D3 to D7 by 60%. However, at lower tapping frequencies, the application of stimulants can increase latex production (Aji et al., 2022).

Over a 10-year period, the RRIT 251 clone demonstrated that the S/2 D3 tapping system, when applied with a stimulant, achieved the highest cumulative yield of 100,508.5 g/tree/tapping. This was followed by S/2 D2 with 94,002.0 g/tree/tapping, while S/2 D4 with a stimulant yielded the lowest cumulative yield of 86,542.1 g/tree/tapping, which is related to the lower number of tappings (Chotiphan et al., 2023). S/2 (half spiral downward) tapping on virgin bark at D3 and D4 frequencies produced higher yields than the D2 frequency on renewed bark for RRIT 251.

Further studies have shown that low-frequency tapping systems (D3) with stimulation result in equivalent cumulative latex production compared to other systems and have higher latex production per tapping (Sainoi et al., 2017). Half (S/2) and third (S/3) spiral cuts downward at low-frequency tapping systems (D3) showed the highest yield per tree and per tapping, indicating that reducing tapping frequency with stimulation can compensate for cumulative yield per tree with higher yield per tapping. Similarly, Esekhade et al. (2019) found that S2D3 not only produced the highest rubber yield but also offered the highest gross margin per hectare per year, recommending its use for improved tree lifespan, labor maximization, and economic returns.

During the first three years of tapping, the S/2 D3 tapping system was effective in increasing average yield and reduction in tapping frequency with stimulation responded better in years 2 and 3 (Chantuma et al., 2019). This is consistent with findings by Sainoi et al. (2017), where a rest period of three days marked the highest yield per tree and per tapping, showing that reducing tapping frequency with stimulation can compensate for cumulative yield per tree with higher yield per tapping. Rodrigo et al. (2011) concluded that increasing yield per tree per tapping with low-frequency tapping systems have ethylene stimulation could compensate for the cumulative yield per year.

In Guatemala, Chapuset et al. (2016) found that reducing tapping frequencies (every 4, 5, 6, or 7 days) combined with stimulant (ethephon, 2.5% a.i) applications, varying from 8 to 14 applications a year, decreased yields per tree per year while increasing yield per tapping as tapping frequency decreased. Different regions adopt various tapping practices; for example, Sri Lanka and India favor alternate-day tapping (d/2), while China uses low-frequency tapping (LFT) systems like d/3 and d/5. Studies by Vijayakumar (2000), Karunaichamy (2001), have shown promising results for LFT systems, which aim to reduce tapper requirements by extending intervals between tappings.

In Sri Lanka, the d/3 + ET system, tapping once every three days with stimulation, has been recommended since 1994 (Nugawela et al., 2000). This system significantly reduces tapper requirements and lowers tapping costs. Conversely, the S2D4 practice, with three days' rest, offers diminishing returns, providing the least average yield among the three systems. This indicates that while rest periods are crucial for tree recovery, excessive rest can reduce overall productivity.

S2D3 stands out as the most effective tapping system, offering the highest average yield and economic benefits. Meanwhile, excessive rest intervals, as seen in S2D4, can lead to reduced productivity, underscoring the need for balanced tapping frequencies to optimize rubber yield and economic returns.

Performance of Tapping System in Relation to Weather Data

Across all seasons, the S2d3 tapping system consistently have high dry rubber yields, confirming its superiority over the more intensive S2d2 and the less frequent S2d4 system. Thus, this tapping system can address issues related to reduced yield due to the fluctuating weather condition which supported by the claim of Chotiphan et al. (2023) that low tapping frequency can compensate losses due weather variability. In addition, moderate tapping frequency provided the optimal balance between latex extraction and physiological recovery, preventing bark depletion while maintaining regular harvest intervals. This agrees with findings by Rodrigo, 2010; Rodrigo et al. (2011) and Gohet et al. (2003). Highlighted that S2d3 enhances productivity while maximizing risks of bark stress and tapping panel dryness (TPD). The effectiveness of S2d3 remained evident even during the wettest months, when yield peaked due to enhanced latex turgor under higher humidity (79-85%). By contrast, lower humidity in the first quarter (Q1) likely reduced metabolic activity and latex flow contributing to lower seasonal yields.

Conclusion

The performance of rubber clones varies significantly, with PB 260, USM 1 and RRIM 2025 being the standout performers, demonstrate consistently high yields, across all tapping systems making it the prime candidates for maximizing rubber production. Clones such as RRIM 3001, and RRIT 251 also show consistent performance and offer reliable output, considering productivity and adaptability. Tailoring the choice of clones and tapping systems to specific conditions and performance patterns can optimize rubber yield. Conversely, other seven clones that exhibit lower productivity can still be utilized for further evaluation in terms of resistance to pests, diseases, and natural disturbances, and can be used for future breeding studies.

The performance of tapping operations varies significantly depending on the clone and the tapping system used. S2D3 generally provides the highest overall yield, but the best system for each specific clone varies. By choosing the optimal tapping system for each clone, rubber yield can be maximized, leading to more efficient and productive rubber production. This suggests that the additional rest day in S2D3 allows for better tree recovery and enhanced latex production. Similar findings from previous studies support the notion that reducing tapping frequency can compensate for cumulative yield per tree with higher yield per tapping. Adopting S2D3 tapping system for clones PB 260 and RRIM 2025, S2D4 for clones USM 1 and RRIM 3001, and S2D2 for clone RRIT 251 could significantly enhance rubber yield. This approach optimizes latex production by providing adequate recovery time without excessively prolonging rest periods. Farmers who currently using the S2D2 tapping system can potentially increase their productivity by shifting to S2D3 or S2D4 because these systems provide a better balance between latex extraction and tree recovery. Less frequent tapping reduces bark consumption and physiological stress on the trees, allowing to regenerate latex more efficiently over time. In addition, the adoption of the S2D3 or S2D4 systems would provide several advantages, including enabling tapper to engage in additional tapping tasks or to participate in other agricultural activities such as corn or rice farming. In large-scale plantations, the implementation of these systems could also allow plantation owners to reduce labor costs and associated benefits, while offering corresponding incentives or compensation to the tappers. Therefore, evaluating and adopting this system can lead to more sustainable and profitable rubber production.

General recommendation

The data collected in this study was limited from a single year only. Therefore, it is important to validate the yield performance across different tapping systems over multiple years to account for variability and ensure more reliable results.

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Statement of Conflict of Interest

The authors state that there is no conflict of interest.

References

Aji, M., Supijatno, N., & Santosa, E. (2022). Latex production of some recommended rubber clones on low tapping frequency. IOP Conference Series. Earth and Environmental Science, 974(1), 012014. https://doi.org/10.1088/1755-1315/974/1/012014.

Cena, R.L. (2012). Recommended rubber clones and establishment of budwood garden in Tangonan, R.G. (Ed), 2012, Rubber production and management in the Philippines. DA-Bureau of Agricultural Research – University of Southern Mindanao, Kabacan, Cotabato, 312 pp.

Cena, R.L. (2018). Nationwide clonal adaptation trial and innovation of propagation techniques on newly-introduced high yielding and promising rubber clones. University of Southern Mindanao. Terminal Report, DOST-PCAARRD in 2018.

Chantuma, P., Lacote, R., & Gohet, E. (2019). Low tapping frequency to increase productivity in Thailand. IRRDB.

Chapuset, T., Anleu Morales, J.V., Snoek D., Palu S., Najera C.A. (2016). Improving rubber tree productivity by reducing tapping frequencies in Guatemala. In: Industrial crops: promoting sustainability. Berti M.T. & Alexopoulou E. (ed.). AAIC. Rochester: AAIC, Résumé, p. 75. Association for the Advancement of Industrial Crops International Conference, Rochester.

Chotiphan, R., Musigamart, N., Suwannalert, S., Chehsoh, J., Lerksamran, T., Lacote, R., & Sajjaphan, K. (2023). Long term effect of low frequency tapping systems applied to rubber tree (Hevea brasiliensis), Clone RRIT 251, on Agronomic Performance in Upper Southern Thailand. Trends in Sciences, 20(11), 6868. https://doi.org/10.48048/tis.2023.6868.

Da Paes Pereira, J., Leal, A.C., & Ramos, A.L.M. (2018). Evaluation of rubber tree clones under different tapping systems in northwestern Paraná state, Brazil. Brazilian Archives of Biology and Technology, 61(0). https://doi.org/10.1590/1678-4324-2018160232.

Das, G., Meenakumari, T., Meti , S., Kumar, S., & K. Mydin, K. (2015). Growth and yield of new generation clones of Hevea under the agroclimatic of sub-Himalayan West Bengal. Journal of Plantation Crops, 43(2), 126-130. https:// updatepublishing.com/journal/index.php/JPC/article/download/5670/4985.

De Souza Gonçalves, P., Júnior, E.J.S., Martins, M.A., Moreno, R.M.B., Branco, R.B.F., & Gonçalves, E.C.P. (2011). Assessment of growth and yield performance of rubber tree clones of the IAC 500 series. Pesquisa Agropecuária Brasileira, 46(12), 1643–1649. https://doi.org/10.1590/s0100-204x2011001200009.

Esekhade, T.U., Okore, I.K., Idoko, S.O., Mesike, C.S., Idehen, C.N., & Idobor, C. (2019) IRRDB-RRIN-B02 Effect of rubber tapping systems on the profitability of rubber plantation. Proceedings of the 2019 International Rubber Workshop, Benin City, Nigeria 2nd-5th September 2019.

Jacob, J.L, Serres, E., Prévôt, J.C, Lacrotte, R., Vidal, A., Eschbach, J.M., & d'Auzac, J. (1988). Development of hevea latex diagnosis. Agritrop 12, 97–115.

John, A., Varghese, Y.A., & Mushrif, S.K. (2009). Performance of indigenous and exotic clones of rubber in India. Journal of Plantation Crops, 37(2), 97–101. https://www.cabdirect.org/abstracts/20103048736.html.

Karunaichamy, K., Vijayakumar, K.R., Thomas, K.U., Rajagopal, R. & Kumar, D.A. (2001). Response of rubber trees (Hevea brasiliensis Muell. Arg., clone RRII 105) to low frequency tapping (LFT) systems. Indian Journal of Natural Rubber Research 14(2), 79-87.

Krishnan A, Joseph L, Roy CB (2019) An insight into Hevea Phytophthora interaction: the story of Hevea defense and Phytophthora counter defense mediated through molecular signalling. Curr Plant Biol 17:33–41.

Meenakumari, T., Meenattoor, J.R., Thirunavoukkarasu, M., Vinod, K., Krishan, B., Gireesh, T., Thomas, V., Mydin, K.K., & Jacob, J. (2018). Dynamics of long-term adaptive responses in growth and rubber yield among Hevea brasiliensis genotypes introduced to a dry sub-humid climate of Eastern India. Industrial Crops and Products, 119, 294–303. https://doi.org/10.1016/j.indcrop.2018.02.066.

Nugawela, A., Peries, M.R.C, Wijesekera, S., & Samarasekera, R.K. (2000). Evaluation of d/3 tapping with stimulation to alleviate problems related to d/2 tapping of Hevea. Journal of the Rubber Research Institute of Sri Lanka 83,49-61.

Obouayeba, S., Soumahin, E.F, Dobo, M., Lacote, R., Gabla, O.R., and Doumbia, A. (2009). Agronomic performance of the clone IRCA 111 of Hevea brasiliensis under different frequencies of tapping and stimulation in south-west Côte d'Ivoire. J. Rubber Res. 12, 93–102.

Pamplona, P.P. (2012). The rubber industry – past, present, and future in Tangonan, R.G. (Ed), 2012, Rubber production and management in the Philippines. DA-Bureau of Agricultural Research – University of Southern Mindanao, Kabacan, Cotabato, 312 pp.

Rasyidah, M.R., Nurmi, R.A.H., & Zarawi, A.G. (2023). Study on rubber clones' performance and stability across locations for selection of latex timber clones. Transactions of Persatuan Genetik Malaysia, No. 12, 2023, e-ISBN 978-629-97968-0-0.

Rodrigo, V.H.L. (2010). Adoption of different tapping systems in the rubber industry of Sri Lanka with special reference to low frequency tapping. Journal of the Rubber Research Institute of Sri Lanka. 88. 10.4038/jrrisl.v88i0.1814.

Sainoi, T., Sdoodee, S., Lacote, R., & Gohet, E. (2017). Low frequency tapping systems applied to young-tapped trees of Hevea brasiliensis (Willd. ex A. Juss.) Müll. Arg. in Southern Thailand. Agriculture and Natural Resources, 51(4), 268–272. https://doi.org/10.1016/j.anres.2017.03.001 .

Silpi, U., Chantuma, P., Kasemsap, P., Thaler, P., Thanisawanyangkura, S., Lacointe, A., Améglio, T., & Gohet, E. (2006). Sucrose metabolism distribution patterns in the lattices of three Hevea brasiliensis clones: effects of tapping and stimulation on the tree trunk. J. Rubber Res. 9, 115–13.

Testado, A.M. (2012) Latex harvesting in Tangonan, R.G. (Ed), 2012, Rubber production and management in the Philippines. DA-Bureau of Agricultural Research- University of Southern Mindanao, Kabacan, Cotabato, 312pp.

Thanseem, I.; Joseph, A.; Thulaseedharan, A. 2005. Induction and differential expression of β-1,3-glucanase mRNAs in tolerant and susceptible Hevea clones in response to infection by Phytophthora meadii. Tree Physiology 25: 1361-1368.

Vijayakumar, K.R., Mohd. Akbar Md. Said, Pichit Sopchoke, Do Kim Thanh, Rodrigo, V.H.L & Mak Sopheaveasna. (2005). Recommendation and practices in exploitation technology of hevea trees in different countries of Asia. IRRDB Workshop on Transfer of Technology, 4-6. April 2005, Kuala Lumpur.

Vijayakumar, K.R., Thomas, K.U., & Rajagopal, R. (2000). Tapping. In: Natural rubber - agro-management and crop processing, pp. 239-249 (Eds. P.J. George and C.K. Jacob) Rubber Research Institute of India.

Zaw, Z. N. (2023). A review of low-frequency latex harvesting systems that lessen the tapper shortage problem of the smallholders' natural rubber production. Kultivasi, 22(2), 210-217. 10.24198/kultivasi.v22i2.48317