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The Merits of Using Advanced Planting Materials in Rubber Forest Plantation

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The growth of three types of planting materials, namely buddings and seedlings with different number of whorls and 'core' stumps, in a rubber forest plantation system was studied in three trials. In the first trial, two- and four-whorled buddings of three clones (RRIM 2020, RRIM 2025 and RRIM 2027) were compared. The second trial compared growth of seedlings (PBIG GG 4, 5 and 6) and three- and six-whorled buddings of RRIM 2001 and RRIM 2026. In another trial, the growth of three types of planting materials namely two- and six-whorled buddings and 'core' stumps were also compared. Generally, buddings planted as advanced planting materials (with four or six whorls) had better girth than two- or three-whorled buddings or seedlings. However, advanced seedlings did not indicate the same trend. Clone RRIM 2020 had significantly better girth than RRIM 2027 in the first trial. The girth superiority of 'core' stumps over those of two-whorled buddings was maintained for 2.5 years after planting whilst the six-whorled buddings caught up with the 'core' stumps in girth size as early as two years after planting. The significance of these findings in relation to the use of advanced planting materials to reduce the period of immaturity of rubber and for rubber forest plantation is discussed.

Key words: planting materials; buddings; seedlings; rubber forest; RRIM 2025; RRIM 2027; RRIM 2020; 'core' stumps; girth size; PBIG GG4; PBIG GG5; PBIG GG6; immaturity period

The Malaysian government recently encouraged the establishment of rubber forest plantations as an alternative source of rubberwood[1] for the furniture industry. It is projected that there will be a shortage of the supply of rubberwood for furniture manufacturing in the future due to the declining hectarage of land planted with rubber nationwide. There are differences in the agronomic practices between the conventional rubber plantations and rubber forest plantations. Rubber forest plantation targets timber as its primary product, and agronomic inputs are specially designed and recommended towards lower in-puts and costs such as lower manuring rates and frequency of herbicide application[2].

The long period of immaturity of rubber is one of the main economic disadvantage of commercial rubber plantations. Research at the Malaysian Rubber Board has improved tree vigour through the use of precocious clones[3], horticultural techniques[4,5] and improved agro-management practices such as planting of leguminous covers, correct application of fertilisers, tillage and use of mulch[6,7]. The enhanced vigour contributes to reducing the

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period of immaturity of rubber. The reduction in the period of immaturity was also achieved by lowering the tappable girth of opening from 50 cm to 45 cm[8–10]. Under the current agronomic practices using two-whorled young buddings as planting materials and prodigious clones, it is most common that a rubber stand reaches maturity at about 4.5–5.5 years after planting.

The use of advanced planting materials which were raised to an advanced stage in the ground nursery has been shown to reduce the immaturity period[11–14]. The earliest type of advanced planting material, the stumped buddings, in which buddings were raised in the nursery for 1.5 to 2.5 years before field planting as bare root stumps[11], though has been shown to be capable of reducing the immaturity period[15], has not been widely accepted by rubber growers. The stumped buddings where active root mass is absent are dependent on wet weather for successful transplanting. Subsequently, 'core' stumps were introduced[13,16]. The 'core' stumps were raised in polybags in the ground nursery for 2–2.5 years thus allowing generation of active root mass that resulted in better success at field planting. The 'core' stumps reduced the immaturity period to 4.5–5 years of field planting. More advanced budded plants in larger polybags were also reported to reduce the period of immaturity of rubber[14].

Whilst much is known about the performance of various planting materials in conventional rubber plantation, it is important to develop planting materials suitable for rubber forest plantation system. Bearing in mind that agronomic practices for rubber forest plantations deviate from the practices for conventional plantations, it cannot be assumed that the planting materials for conventional rubber plantation would automatically be suitable for rubber forest plantation. For instance, with reduced weeding rounds in the rubber forest plantation systems, the two-whorled young buddings in polybags which are standard planting materials for conventional rubber plantation may not be able to compete with the weeds. Planting material suitable for rubber forest is important as it has economic implication. Therefore, this study is initiated to compare growth performance of various planting materials, ranging from seedlings to advanced planting materials, with the objective ultimately to identify the most appropriate planting materials for rubber forest plantation in Malaysia.

MATERIALS AND METHODS

Treatments

Three experiments were established at (1) Ladang Chikus, Bidor, Perak, (2) the Rubber Research Institute of Malaysia Experimental Station (RRIES) Kota Tinggi, Johor and (3) RRIES Sg Buloh, Selangor—all located in Peninsula Malaysia. In the trial at Bidor, two- and four- whorled buddings of clones RRIM 2020, RRIM 2025 and RRIM 2027 were planted at a planting distance of 4 m × 4 m giving a planting density of 625 trees per hectare. The weeds were controlled with glyphosate and metsulfurom methyl mixtures (Round-up® and Ally 20DF® at 3L and 150 g per hectare, respectively) applied at either two or four rounds per year. The experimental design was a split plot with the clones being used as the main plot, planting material as the sub-plot and frequency of herbicide application as the sub-sub plot. The trial consisting of 60 plants per plot was replicated twice.

In the trial at Kota Tinggi, three- and six-whorled buddings of clones RRIM 2001 and RRIM 2026 and PBIG GG 4, 5 and 6 seedlings were planted at a planting distance of 4 m × 4 m (625 trees per hectare). The experimental design was a randomised block design with three replicates and 100 to 150 plants per plot. The herbicides glyphosate and metsulfurom methyl (Round Up® and Ally 20DF®) were applied at the rate of four rounds per year during the first year, three to four rounds per year during the second year and one to two rounds per year thereafter, as recommended for rubber forest planting[17].

In the trial at Sg Buloh, the advanced planting materials consisting of 'core' stumped buddings and the six-whorled young buddings and the two- whorled young buddings were planted. The clones for the 'core' stumps were RRIM 2001 and RRIM 2026. Seventeen-month-old young buddings of RRIM 2025 were raised to six whorls. Five-month-old young buddings of clones RRIM 2001 and RRIM 2026 with two whorls of leaves and grown in normal-sized polybags (177 mm × 380 mm × 0.09 mm) were used as controls. The experiment was arranged in a randomised block design with three replicates and 56 plants per plot.

Preparation of Planting Materials

The 'core' stumps were raised in large polybags (254 mm × 508 mm × 0.12 mm) in the ground nursery for two and a half years (from time of seed germination) according to the method of Leong and Yoon[13]. Advanced planting materials with at least four whorls of leaves in the Bidor and Kota Tinggi trial were grown in above average-sized polybags measuring 200 mm × 457 mm × 0.12 mm. Buddings with less than four whorls of leaves were grown in normal-sized polybags. Buddings were prepared using the young budding technique[5]. No budgrafting was carried out on the PBIG GG seedlings. The preparation of each type of planting material was staggered so as to ensure that they could be planted in the field at the same time.

Management and Data Collection

Unless otherwise stated, the trial areas were managed as for rubber forest plantation with respect to weed control, pruning and manuring. Growth parameters evaluated were girth and girth increments. Girth was measured at height of 100 cm from the ground during the first two years after planting; thereafter, the measurement was made at 150 cm from the ground.

The data were analysed using a two-way analysis of variance.

RESULTS

Growth

Girth measurements of six-whorled buddings and 'core' stumps during the first year of field establishment at Sg Buloh are shown in *Table 1*. Measurements of two-whorled buddings were not included in this evaluation since the plants were too small for girth measurement during this period. At the time of planting, 'core' stumps of clones RRIM 2001 and RRIM 2026 had larger girth than the six- whorled buddings. During the first six months of field establishment, 'core' stumps of both RRIM 2001 and RRIM 2026 gained 0.3 cm to 0.4 cm in girth whilst six-whorled buddings recorded almost double girth increment (0.7 cm). During the next six months, 'core' stumps gained about 2.6 cm to 3.0 cm girth whilst six-whorled buddings gained 4.5 cm girth.

The girth measurements at 1.5 to 3 years after field planting are presented in *Table 2*. At 1.5 years after planting, 'core' stumps of RRIM 2001 and RRIM 2026 had the largest girth followed by six-whorled buddings of RRIM 2025. They were significantly larger than the two-whorled buddings. Amongst the

TABLE 1. GIRTH MEASUREMENTS (CM) OF ADVANCED PLANTING MATERIALS DURING THE FIRST YEAR OF FIELD ESTABLISHMENT AT SG. BULOH

Treatment	Months after planting		
	0	6	12
RRIM 2001 core-stumps	9.6 a	9.9 a	12.9 a
RRIM 2026 core-stumps	9.4 a	9.8 a	12.4 a
RRIM 2025 6W	4.8 b	5.5 b	10.0 b
Probability level	***	***	**

F-test significant at P<0.01 (**) or 0.001 (***), respectively
Means with same letters within columns are not significantly different
6W = Six-whorled young buddings.

TABLE 2. GIRTH (CM) AT 1.5–3.0 YEARS AFTER PLANTING AT SG. BULOH

Treatment	Years after planting			
	1.5	2.0	2.5	3.0
RRIM 2001 'core' stump	16.6 a	21.3 a	25.3 a	32.3 a
RRIM 2026 'core' stump	15.9 a	19.0 a	22.1 a	27.4 bc
RRIM 2025 6W	13.8 b	19.7 a	23.7 a	31.6 ab
RRIM 2001 2W	10.8 c	15.0 b	18.1 b	23.8 cd
RRIM 2025 2W	9.6 cd	13.6 bc	17.0 b	24.2 cd
RRIM 2026 2W	7.9 d	10.8 c	14.0 b	20.5 d
Probability level	***	***	***	***

F-test significant at P<0.001(***)
Means with same letters within columns are not significantly different
2W = Two-whorled young buddings; 6W = Six-whorled young buddings.

two-whorled buddings, RRIM 2001 had the largest girth. At two and two and a half years after planting, 'core' stumps of RRIM 2001 and RRIM 2026 and six-whorled buddings of RRIM 2025 had comparable girth and were significantly larger than the two-whorled buddings.

The girth increments of various planting materials at 2–3 years after planting at Sg Buloh are shown in *Table 3*. Six-whorled buddings of clone RRIM 2025 had the highest girth increment followed by 'core' stumps of clone RRIM 2001 and 2-whorled buddings of RRIM 2025. The increments were significantly higher than those of two-whorled buddings of RRIM 2001 and RRIM 2026 and 'core' stumps of RRIM 2026.

The survival rates of various planting materials in the trial at Sg. Buloh determined several times within the first two years after planting are presented in *Table 4*. Two-whorled buddings of RRIM 2001 and RRIM 2026 had the higher casualties (12%–15%) due to contact with herbicide compared to advanced planting materials. The advanced planting materials died due to other causes.

Girth of various planting materials in the Kota Tinggi trial are shown in *Table 5*. At one year after planting, there were some differences in the girth measurements of plants originating from different planting materials whereby the six-whorled planting materials had significantly larger girth than three-whorled

TABLE 3. GIRTH INCREMENT AT 2–3 YEARS AFTER PLANTING AT SG. BULOH

Treatment	Intervals after planting (year)	
	2.0–2.5	2.5–3.0
RRIM 2025 6W	4.05 a	7.8 a
RRIM 2001 'core' stump	3.99 a	7.0 abc
RRIM 2025 2W	3.54 ab	7.2 ab
RRIM 2026 2W	3.18 b	6.6 bc
RRIM 2026 'core' stump	3.15 b	5.3 d
RRIM 2001 2W	3.06 b	5.8 cd
Probability level	***	***

F-test significant at $P<0.001$ (***)
Means with same letters within columns are not significantly different
2W = Two-whorled young buddings; 6W = Six-whorled young buddings.

TABLE 4. DEATH OF PLANTING MATERIALS AT SG. BULOH TWO YEARS AFTER PLANTING

Treatment	Total planted	Percentage casualties due to			
		H	F/T	D	TS
RRIM 2026 2W	166	12.0(20)	–	–	–
RRIM 2001 2W	167	15.0(25)	0.6(1)	–	–
RRIM 2025 2W	168	5.4(9)	–	0.6(1)	1.8(3)
RRIM 2001 CS	166	–	8.4(14)	–	–
RRIM 2026 CS	168	–	7.7(13)	–	–
RRIM 2025 6W	168	–	4.2(7)	0.6(1)	–

Plant casualities were attributed to: H = Herbicide poisoning, F = Flooding, T = Termite attack, D = Dieback or TS = Trunk snap
Figures in brackets are number of plants affected in a treatment.

TABLE 5. GIRTH (CM) OF VARIOUS PLANTING MATERIALS IN KOTA TINGGI TRIAL

Treatment	Years after planting					
	1.0	1.5	2.0	2.5	3.0	3.5
RRIM 2026 (6W)	9.9 a	13.0 a	18.3 a	23.1a	27.3 a	31.7 a
RRIM 2001 (6W)	9.1 b	12.6 ab	17.9 ab	23.0 a	26.1ab	30.5 ab
Seedling[a] (6W)	9.0 b	10.4 d	13.7 d	17.4 c	19.9 c	23.8 d
RRIM 2026 (3W)	8.6 b	11.6 bc	16.7 bc	21.5 ab	25.5 ab	28.9 bc
Seedling[a] (3W)	8.4 bc	10.0 d	13.4 d	17.2 c	19.7 c	23.5 d
RRIM 2001 (3 W)	7.6 c	10.6 cd	15.7 c	20.5 b	23.8 b	27.6 c
Probability level	**	***	***	***	***	***

[a]PBIG GG seedlings
The plants were planted out either at stage of three- (3W) or six-whorls (6W) of leaves
Means with same letters within columns are not significantly different
F-test significant at $P<0.01$ (**) or 0.001 (***), respectively.

planting materials for RRIM 2001 and RRIM 2026. The superiority in girth of the advanced planting materials of both clones over the less advanced materials was also recorded at 3.5 years after planting. In contrast, seedlings planted from plants with three- or six-whorls of leaves were significantly smaller compared to both the advanced and the three-whorled buddings.

The girth increment of three- and six-whorled planting materials of RRIM 2001 and RRIM 2026 were comparable and better than the seedlings during the first two years of field establishment (*Table 6*). These differences were maintained until the 3–3.5 year except for three-whorled RRIM 2026 which had the lowest girth increment.

The conicity of stem of seedlings is indicated in *Table 7*. As expected, the stem of seedlings had higher percentage of tapering (25%–27%) than stems of budded plants (15%). The variability in girth of various planting materials in the Kota Tinggi trial at 3.5 years after planting is shown in *Table 7*. CV values which can be used as a uniformity indicator of a stand, ranged from 18.3% for six-whorled RRIM 2001 to 29.4% for three-whorled seedlings. The seedlings had higher variability than the advanced budded plants. In the case of three-whorled budded plants, the variability differed between clones.

A census on the survivality of the planting materials established in the Bidor trial was carried out at one year after planting (*Table 8*). Plant survival was significantly affected by planting material and four-whorled materials had better survival percentage than two-whorled materials. Neither clone nor frequency of herbicide application had any significant influence on plant survival.

The effects of various planting materials and frequency of herbicide application on girth of three *Hevea* clones in the Bidor trial are presented in *Table 9*. At one year after planting, girth was not significantly affected by any of the variables studied. Clonal differences in girth were evident at 1.5–2.0 years after planting with RRIM 2020 clone giving the largest and RRIM 2027 clone the smallest girth. At 2.5 years after planting, the clones were only marginally different ($P<0.10$) with respect to stem girth. With the exception of the first year of establishment, girth was consistently influenced by type of planting material throughout the period of observation where the differences ranged from significant ($P<0.05$) to very highly significant ($P<0.001$). Generally, advanced planting materials (four-whorled buddings) produced significantly better girth than the less advanced materials (two-whorled buddings). Significant interaction between clones and planting materials was also evident during this period with RRIM 2027 and RRIM 2025 clones planted at stage of four whorls of leaves having better girth than the less advanced materials. However, RRIM 2020 did not conform to this pattern.

Frequency of herbicide application significantly influenced girth. Four rounds of herbicide spraying per year resulted in better girth than two rounds (*Figure 1*).

The effects of various planting materials and frequency of herbicide application on girth increment of three *Hevea* clones in the Bidor trial are presented in *Table 10*. Clonal differences in girth increment was only evident at the 2–2.5 year intervals. Unlike girth, effects of planting material and interaction between planting material and clone on girth increment were only evident during the first 2 to 3 years after field planting. Advanced planting material of the three clones generally had better girth increment during the first two years of growth in the field. With the exception of the 1–1.5 year interval where higher frequency of herbicide application (4 rounds

TABLE 6. GIRTH INCREMENT (CM) IN KOTA TINGGI TRIAL

Treatment	Intervals (years) after planting				
	1.0–1.5	1.5–2.0	2.0–2.5	2.5–3.0	3.0–3.5
RRIM 2001 (6W)	3.6 a	5.2 a	5.1 ab	3.6 ab	4.4 a
RRIM 2026 (6W)	3.1 a	5.3 a	4.8 b	4.1 a	4.4 a
Seedling[a] (3W)	1.5 b	3.4 b	3.6 c	2.6 bc	3.8 ab
Seedling[a] (6W)	1.5 b	3.2 b	3.8 c	2.4 c	3.9 ab
RRIM 2001 (3W)	3.0 a	5.1 a	5.2 ab	3.4 abc	3.9 ab
RRIM 2026 (3W)	2.9 a	5.0 a	5.6 a	3.9 a	3.3 b
Probability level	***	***	***	*	*

[a]PBIG GG seedlings
The plants were planted at stage of three- (3W) or six-whorls (6W) of leaves
Means with same letters within columns are not significantly different
F-test significance at P<0.01 (**) or P<0. 001 (***), respectively.

TABLE 7. VARIATION IN CONICITY OF TRUNK AND GIRTH AT KOTA TINGGI

Treatment	% Tapering	Coefficient of variation in girth
Seedling[a] (3W)	27.6 a	29.4 a
Seedling[a] (6W)	25.3 a	26.0 ab
RRIM 2026 (3W)	16.3 b	26.3 ab
RRIM 2001 (6W)	15.7 b	18.3 c
RRIM 2026 (6W)	15.7 b	20.0 c
RRIM 2001 (3W)	15.5 b	21.6 bc
Probability level	***	**

F-test significant at P< 0.01 (**) or 0.001 (***), respectively. Values within a column not followed by common letters are significantly different
The materials were planted at stage three- (3W) or six-whorls (6W) of leaves.

TABLE 8. SURVIVABILITY OF PLANTS TAKEN AT ONE YEAR AFTER PLANTING AT BIDOR[a]

Planting material	% Survival	Standard deviation	Probability level
Two-whorled buddings	85.2	7.39	*
Four-whorled buddings	92.8	6.82	

[a]The trial had two replicates.

TABLE 9. GIRTH (CM) OF VARIOUS PLANTING MATERIALS IN BIDOR TRIAL.

Clone	Planting material	Years after planting 1	1.5	2	2.5	3	3.5	4	4.5	5
RRIM 2027	2 WB	1.9 (0.17)	6.1 (0.46)	7.4 (0.84)	10.21 (1.49)	6.6 (1.12)	18.5 (2.0)	21.6 (2.05)	23.9 (3.04)	27.0 (3.2)
	4 WB	2.4 (0.23)	7.0 (0.74)	9.1 (1.07)	12.4 (2.07)	18.9 (2.19)	21.7 (3.2)	24.8 (3.23)	27.5 (4.07)	30.5 (5.03)
Clone (mean)		2.1 (0.32)	6.5 (0.76)	8.3 (1.30)	11.3 (2.06)	17.8 (2.04)	20.1 (2.99)	23.2 (3.04)	25.7 (3.84)	28.7 (4.34)
RRIM 2020	2 WB	2.4 (0.29)	7.9 (0.64)	11.4 (0.86)	16.5 (1.00)	22.2 (1.12)	25.1 (1.29)	28.7 (0.99)	31.1 (1.6)	34.0 (1.72)
	4 WB	2.8 (0.19)	8.7 (0.66)	11.8 (1.09)	16.8 (1.46)	22.1 (1.32)	24.2 (1.46)	27.4 (1.56)	29.9 (1.78)	32.4 (1.63)
Clone (mean)		2.6 (0.29)	8.3 (0.77)	11.6 (0.93)	16.6 (1.17)	22.2 (1.13)	24.7 (1.35)	28.1 (1.37)	30.5 (1.69)	33.2 (1.75)
RRIM 2025	2 WB	3.0 (0.58)	6.1 (0.52)	8.4 (0.78)	12.1 (1.24)	17.6 (2.22)	19.7 (1.71)	22.5 (1.44)	25.4 (1.66)	28.8 (1.93)
	4 WB	3.5 (1.2)	8.4 (0.72)	12.0 (1.26)	17.0 (1.29)	22.6 (1.86)	25.9 (1.96)	28.6 (2.24)	32. 0 (2.13)	36.3 (1.90)
Clone (mean)		3.3 (0.92)	7.2 (1.38)	10.2 (2.16)	14.5 (2.83)	20.1 (3.24)	22.8 (3.75)	25.6 (3.70)	28.7 (3.92)	32.6 (4.35)
Planting material (mean)	2 WB	2.6 (0.97)	6.7 (1.01)	9.1 (1.95)	12.9 (2.99)	18.8 (2.91)	21.1 (3.35)	24.3 (3.57)	26.8 (3.8)	29.9 (3.76)
	4 WB	2.7 (0.44)	8.1 (1.01)	11.0 (1.72)	15.4 (2.64)	21.2 (2.36)	23.9 (2.79)	27.0 (2.77)	29.8 (3.2)	33.1 (3.86)
Probability level	Variable									
	Clone (C)	NS	*	*	#	NS	NS	NS	NS	NS
	Herbicide (W)	NS	NS	*	*	NS	NS	*	NS	NS
	PM	NS	***	***	***	*	*	*	**	**
	C X W	NS	NS	NS	NS	NS	NS	NS	NS	NS
	C X PM	NS	*	*	*	#	#	*	*	*
	W X PM	NS	NS	NS	NS	NS	NS	NS	NS	NS
	C X W X PM	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS, #, *, **, ***: F-test non-significant or significant at P<0.10, 0.05, 0.01 or 0.001, respectively
Type of planting materials: 2 WB = 2-whorl budding; 4 WB = 4-whorl budding; PM = Planting material
Each value is a mean of 2 replicates
Figures in bracket are standard deviations.

TABLE 10. GIRTH INCREMENT (CM) OF VARIOUS PLANTING MATERIALS IN BIDOR TRIAL

Clone	Planting material	Yearly interval after planting 1.0–1.5	1.5–2.0	2.0–2.5	2.5–3.0	3.0–3.5	3.5–4.0	4.0–4.5	4.5–5.0
RRIM 2027	2 WB	4.2 (0.49)	2.1 (0.38)	3.0 (0.34)	3.9 (0.32)	3.7 (0.47)	3.1 (0.37)	2.4 (1.32)	3.04 (0.36)
	4 WB	4.6 (0.51)	2.6 (0.61)	3.9 (0.82)	4.8 (0.78)	3.4 (0.32)	3.1 (1.08)	2.7 (1.1)	3.0 (1.18)
Clone (mean)		4.4 (0.53)	2.3 (0.53)	3.4 (0.74)	4.4 (0.72)	3.5 (0.42)	3.1 (0.75)	2.5 (1.14)	3.0 (0.81)
RRIM 2020	2 WB	5.4 (0.37)	3.8 (0.38)	5.0 (0.20)	5.3 (0.49)	3.4 (0.61)	3.6 (0.59)	2.4 (0.72)	2.9 (0.24)
	4 WB	6.0 (0.49)	3.3 (0.78)	5.1 (0.47)	5.1 (0.58)	2.8 (0.57)	3.2 (0.21)	2.5 (0.38)	2.5 (0.38)
Clone (mean)		5.7 (0.50)	3.6 (0.63)	5.1 (0.34)	5.2 (0.51)	3.1 (0.64)	3.4 (0.46)	2.5 (0.53)	2.7 (0.35)
RRIM 2025	2 WB	2.5 (0.95)	2.8 (0.32)	3.9 (0.47)	5.0 (0.72)	2.9 (0.12)	2.9 (0.31)	2.9 (1.12)	3.4 (0.95)
	4 WB	5.4 (1.27)	3.8 (0.37)	5.1 (0.43)	5.6 (0.58)	3.5 (0.31)	2.7 (0.79)	3.1 (0.51)	4.3 (0.38)
Clone (mean)		4.0 (1.85)	3.3 (0.62)	4.5 (0.76)	5.3 (0.69)	3.2 (0.37)	2.8 (0.56)	3.0 (0.81)	3.9 (0.82)
Planting material (mean)	2 WB	4.0 (1.37)	2.9 (0.81)	4.0 (0.91)	4.8 (0.79)	3.3 (0.53)	3.2 (0.51)	2.6 (1.0)	3.1 (0.6)
	4 WB	5.3 (0.95)	3.2 (0.76)	4.7 (0.80)	5.2 (0.68)	3.2 (0.50)	3.0 (0.74)	2.8 (0.71)	3.3 (1.1)
Probability level	Variable								
	Clone (C)	NS	NS	*	NS	NS	NS	NS	#
	Herbicide (W)	*	NS	#	NS	NS	NS	NS	NS
	PM	**	*	**	#	NS	NS	NS	NS
	C X W	NS	NS	NS	NS	NS	*	NS	NS
	C X PM	*	**	NS	NS	*	NS	NS	NS
	W X PM	NS	*	NS	NS	#	NS	NS	NS
	C X W X PM	NS	NS	NS	NS	NS	NS	NS	NS

NS, #, *, **: F-test non-significant or significant at P<0.10, 0.05 or 0.01, respectively
Type of planting materials: 2 WB = 2-whorl budding; 4 WB = 4-whorl budding; PM = Planting material
Values in brackets are standard deviations.

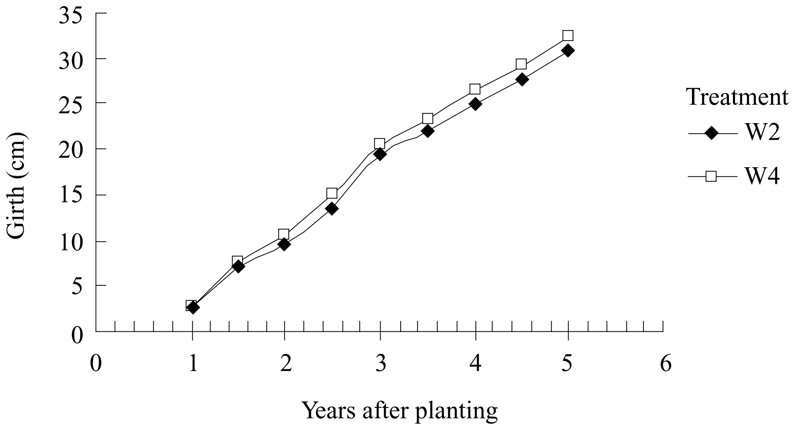

Figure 1. Effect of frequency of herbicide application on girth in the Bidor trial. Herbicide was applied at two rounds per year(W2) or four rounds per year(W4). (*Standard deviation of treatments can be found in* Table 10).

per year) resulted in higher girth increment (3.3 cm) than did the lower frequency (2.9 cm), there did not seem to be any effect of the rate of herbicide application on girth increment at other intervals.

Economic Analysis

The costs of nursery production and field establishment of different planting materials in the three trials are presented in *Table 11*. Costs of land clearing, construction of sand beds for seed germination and field establishment are not included in this analysis since they were similar for all techniques. The total cost of producing various planting materials varied with types of planting materials and the period retained in the nursery. It costs more to produce buddings than seedlings and more advanced planting materials than less advanced planting materials. Additional expenditure was incurred on inputs such as manuring, pruning, watering and weed controls to prepare advanced planting materials. The three-whorled seedlings were the cheapest material to produce and the cost increased with increasing number of whorls. The costs of raising advanced planting materials were RM3.12 for 'core' stumps, RM2.05 for six-whorled buddings, RM1.70 for four-whorled buddings and RM1.53 for six-whorled seedlings.

At the time of field establishment, the differences in cost was due to the differences in transport charges which were generally higher for the more advanced materials. At a cost of RM1606 per hectare or RM2.57 per plant, two-whorled buddings were the cheapest material until field establishment at Sg Buloh. This cost increased to RM1832 per hectare or RM2.93 per plant when planted at Bidor which is about 150 km from the nursery at Sg Buloh. At Sg Buloh, planting of 'core' stumps costed RM4282 per hectare or RM6.85 per plant; this makes 'core' stumps the most expensive planting material at field planting followed by six-whorled buddings (RM2156 per hectare or RM3.45 per plant). The cost at establishment of six-whorled buddings increased to RM2586 per hectare or RM4.14 per plant when planted at Kota

Tinggi. The six-whorled seedlings were the next costly material (RM2259 per hectare or RM3.61 per plant) followed by three-whorled buddings (RM2055 per hectare or RM3.29 per plant).

DISCUSSION

Practicality and economics will be important factors in deciding the use of any type of planting materials for rubber forest plantation. In addition, the planting materials should also be appropriate with the agronomic practices adopted for the rubber forest system. The main advantage of using advanced planting materials with at least four whorls of leaves is high initial vigour resulting from prolonged upkeep in the nursery that leads to a headstart in growth after field establishment (*Tables 2, 5* and *9*). The advanced planting materials maintained superior growth in terms of height[18] and girth over the less advanced planting materials (two-whorled buddings) up to five years as seen in the Bidor trial (*Table 9*). Unfortunately, the advantage varied with clone. For instance, the advanced planting materials of RRIM 2020 and seedlings did not confer any growth advantage over the less advanced materials at Bidor and Kota Tinggi trials, respectively (*Tables 5* and *9*). There were consistent and significant interaction between planting materials and clones with respect to girth and girth increment (*Tables 9* and *10*). Based on the poor growth of seedlings at Kota Tinggi trial, the suitability of seedlings as planting materials for rubber forest plantation needs further confirmation. Seedlings were relatively cheaper to produce than buddings with comparable whorls of leaves (*Table 11*). However, the inherent conicity of seedlings would affect log volume and the growth of seedlings was not uniform (*Table 7*). This is similar to reports given elsewhere[19].

As a measure to increase the economics of rubber forest plantation, minimal agro-management inputs were adopted especially the lower input of fertiliser and weed control. The advanced planting materials permits the use of chemical herbicides safely in rubber forest plantation as the less advanced materials with green stem can be easily damaged by certain herbicides especially in the first year of planting. This is amply shown in the RRIES and Bidor trials where the advanced planting materials suffered less damage by herbicides compared to two-whorled buddings (*Tables 4* and *8*). The less supplies needed for advanced planting materials would ultimately result in a more uniform stand than the less advanced buddings (*Table 7*).

This study indicated the advantages of using advanced planting materials especially in competition with the weeds and thus suffer less casualties. For rubber forest plantation, the use of advanced planting materials (with at least four whorls of leaves) could be considered and four rounds of herbicide applied within the first 2.5 years of field establishment (*Figure 1* and *Table 9*). The non-existent interaction between planting material and weed control treatment in the Bidor trial with respect to girth (*Table 9*) indicated that a blanket weed control treatment, currently recommended at a rate of four rounds per year during the first year of establishment reducing to 1–2 rounds after the fifth year[2], could be applied to all types of planting materials.

By far, the most important use of advanced planting material in conventional rubber plantations and rubber forest plantations too, is its potential to reduce the period of immaturity of rubber since the intensively-raised nursery plants can reach tappable girth within a few years of field establishment[9,10]. However, planters may be discouraged from using advanced planting material due to its high cost of preparation, transport and planting. 'Core' stumps, being the most vigorous planting materials at establishment in this study was the most advanced planting materials ever

TABLE 11. UNIT COST[a] FOR NURSERY PRODUCTION AND FIELD ESTABLISHMENT OF VARIOUS PLANTING MATERIALS IN ALL TRIALS

	Planting material						
	2-whorl buddings	3-whorl buddings	4-whorl buddings	6-whorl buddings	'core' stumps	3-whorl seedlings	6-whorl seedlings
Nursery (sen/plant)	130.47	149.11	170.27	205.02	312.05	114.97	152.77
Field planting (sen/plant)							
a. RRIES	122.7	–	–	140	373.0	–	–
b. Bidor	162.7	–	181.7	–	–	–	–
c. Kota Tinggi	–	181.7	–	208.7	–	181.7	208.7
Total production cost (sen/plant) (nursery + field planting)							
a. RRIES	253.17	–	–	345.02	685.05	–	–
b. Bidor	293.17	–	351.97	–	–	–	–
c. Kota Tinggi	–	330.81	–	413.72	–	296.67	361.47
Total cost (RM) @ 625 plants per hectare							
a. RRIES	1606.06	–	–	2156.38	4281.56	–	–
b. Bidor	1832.31	–	2199.81	–	–	–	–
c. Kota Tinggi	–	2055.38	–	2585.75	–	1854.19	2259.19

[a]Costs were calculated in Malaysian currency where 1 Ringgit Malaysia (RM) = 100 sens. At the time of writing, 1 USD = RM3.6

produced for rubber growers besides stumped buddings. However, despite claims of being a more flexible version of its predecessor stump buddings and with purported abilities to reduce the period of immaturity of rubber[13,16], 'core' stumps has not been taken up by the industry . This study showed that 'core' stumps had the highest cost of production amongst the planting materials studied (*Table 11*). The production of 'core' stumps also requires large area of ground nursery and skilful workforce[16]; these factors contributed to their poor adoption. Advanced buddings in large polybags containing 23 kg of soil, another potential advanced planting material[14] with growth at field planting being reported to be equivalent to 'core' stumps, is rather inconvenient and impractical to use and difficult to handle especially on steep and hilly terrain. This study showed that young buddings with six whorls of leaves in medium-sized polybags (200 cm × 457 cm) and containing 5 kg of soil, offered cheaper alternative (*Table 11*) to these two types of advanced planting material as they required a shorter time span in the nursery (1.5 years compared to at least 2 years for 'core' stumps). More important is that the advanced polybag plants were able to catch up in growth with 'core' stumps as early as two years after field planting (*Tables 1* and *2*). This was possible because photosynthesis continued unabated in the six-whorl buddings since the shoots were not decapitated at any stage of their preparation thus ensuring the plants with adequate photosynthates for growth after transplanting. In contrast, 'core' stumps which were devoid of green shoots at field planting, experienced a setback in growth for at least 6 months, although they started out with 95% to 100% larger girth than the six-whorl buddings (*Tables 1* and *2*). Similar setback in growth after transplanting has been reported for 'core' stumps and bare-root stump buddings[12–14]. It remains to be seen whether the six-whorled buddings can be opened for tapping at four years after field establishment since the trial is now at three years after planting. Our results showed that the six-whorled buddings and 'core' stumps had attained girth in the range of 27.4 cm and 32.3 cm at 3 years after planting (*Table 2*); thus it is quite reasonable to expect these planting materials to attain girth in the region of 40 cm at 4 years after planting, a tappable girth when the trees could be opened for tapping. Finally, when using six-whorled buddings in normal sized polybags to reduce the period of immaturity of rubber, it is important that stringent selection be carried out in the nursery so that only buddings of uniform girth size are chosen for field planting[9]. This is to ensure that the advanced buddings have higher tappability at opening which enabled them to attain tappable girth within four years of field planting. After field establishment, the growth advantage of the six-whorled buddings must be maintained and enhanced by adhering to proper agronomic inputs such as manuring, irrigation and weed control.

CONCLUSION

For rubber forest plantation, advanced planting materials were more advantageous than two-whorled buddings as the advanced planting materials established well with minimum setback, and could accomodate chemical weed control and were vigorous during the immature phase. Advanced planting materials incurred more cost to prepare but was cost-effective in the long run, given the minimal need for supplies. Six-whorled buddings in medium-sized polybag could be used instead of 'core' stumps to reduce the period of immaturity of rubber trees since at two years after planting, the advanced buddings had attained girths similar to those of 'core' stumps.

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