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DETAILS ON THE DEVELOPMENT OF THE CLONE RRISL 2000 (1976 HP-8)

T T D Dahanayake, K K Liyanage, B W A N Baddewithana and N S Jayasinghe

INTRODUCTION

Rubber (*Hevea brasiliensis* Muell. Arg.) has been extensively grown for several decades as it is one of the most important economic crops in the world. Therefore, the genetic improvement of the rubber tree is vital, and these works began in Sri Lanka decades back (Lam *et al.*, 2012 & Liyanage, 2007).

Breeding programs have traditionally relied on generating crosses and progeny lines and screening them for further selective breeding. The introduction of hybridization techniques which paved the way for the crossing of selected parents, was a huge milestone in *Hevea* breeding (Baptist, 1966). Being a heterozygous outbreeding species, it produces a wide range of genotypes facilitating superior selections. Seedling progenies derived from hybridization are subjected to a series of evaluation steps to produce a new clone. The breeding cycle takes 20-25 years. This cycle can speed up effectively using more parameters to evaluate the genotypes and clones, focusing on growth, yield attributed and anatomical characters.

RRISL 2000 series comprises seven clones, namely, RRISL 2000, RRISL 2001, RRISL 2002, RRISL 2003, RRISL 2004, RRISL 2005 and RRISL 2006. Among them, RRISL 2000 clone is a successful creation of the 1976 hand pollination programme. At the beginning of the screening, 52 promising seedlings were selected from 232 seedlings, and those selections were multiplied in bud wood nurseries prior to the establishment of Small-Scale Clone Trials (SSCT). In 1984, 29 selections were bud grafted, and those selections were planted in two small scale clonal trials (SSCT) at Tempo division of Hill stream state plantation in 1985 with RRIC 100, 102, 103, and 121 as control clones. The selections were laid out in randomized block design with four replicates and four plants per plot to evaluate the yield, vigour and disease resistance.

Parentage and the characters of the parents

RRISL 2000 clone is an outcome of crossing RRIC 100 (Female) and RRIC 101 (Male) in the 1976 hand pollination program. The two parents are high performing clones developed in early breeding programmes by crossing foreign clones; RRIC 101 (Ch 26 X RRI and C 7), RRIC 100 (PB 86 X RRIC 52) (Fig. 1).

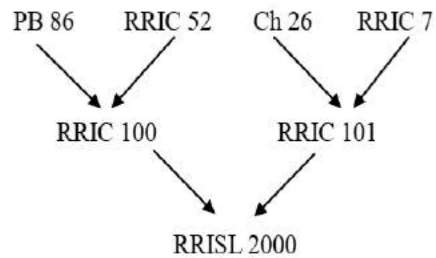

Fig. 1. Pedigree of RRISL 2000

Small Scale Clone Trial (SSCT)

The genetic potential of selected genotypes multiplied at bud wood nursery under small scale experimental level is evaluated during this stage. This trial follows the basic experimental principles, as genotypes need to be replicated and randomized and they have to be evaluated compared to control clones which are already performing well in the rubber industry.

During this phase data records on growth rate by means of annual girth measurements are taken. At immature phase girth is taken at the height of 120 cm from the bud union and after commencement of tapping it is taken at 150 cm from the bud union. Data records on yield (test tapings) through cup coagulation are taken on monthly basis. Each individual tree is coagulated by mixing a few drops of 5% formic acid and labelled cup lumps are dried in the smoke-house. Weight of dried cup lumps is recorded individually up to 10-12 years until A and B panels (virgin barks) are completed as an initial screening to assess the genetic potential of a clone. Average yield and girth data recorded for the HP 76-8 (RRISL 2000) and the control clones RRIC 121 in the trial during the thirteen years denoted in Table 1. Girth measurements recorded in this trial showed that HP 76-8 had better initial girth growth as in the better performing control clone RRIC 121(Fig. 02). Under small scale evaluation, this genotype has recorded the average yield potential above 54 dry rubbers (g) as g/tree/tapping (g/t/t) during the first 12 years of tapping.

Table 1. *Average yield and the girth of the clone 76 - 8 (RRISL 2000) at SSCT at Tempo division – Hill stream estate established in 1984*

Year	Tempo Division – Hill stream Clone HP 76-8 (RRISL 2000)		Tempo Division – Hill stream Control Clone (RRIC 121)	
	Average Girth (cm)	Average Yield (g/t/t)	Average Girth (cm)	Average Yield (g/t/t)
1	16.8	Immature	18.0	Immature
2	28.8	Immature	28.8	Immature
3	43.9	Immature	40.4	Immature
4	58.8	-	53.3	-
5	68.9	-	61.6	-
6	74.4	37.4	68.0	49.4
7	79.6	29.7	72.8	34.7
8	84.0	47.9	78.1	53.3
9	87.6	54.3	81.1	57.4
10	89.2	51.9	86.6	55.8
11	90.0	55.5	86.7	72.1
12	93.4	69.4	89.9	72
13	95.3	72.2	90.6	59.2

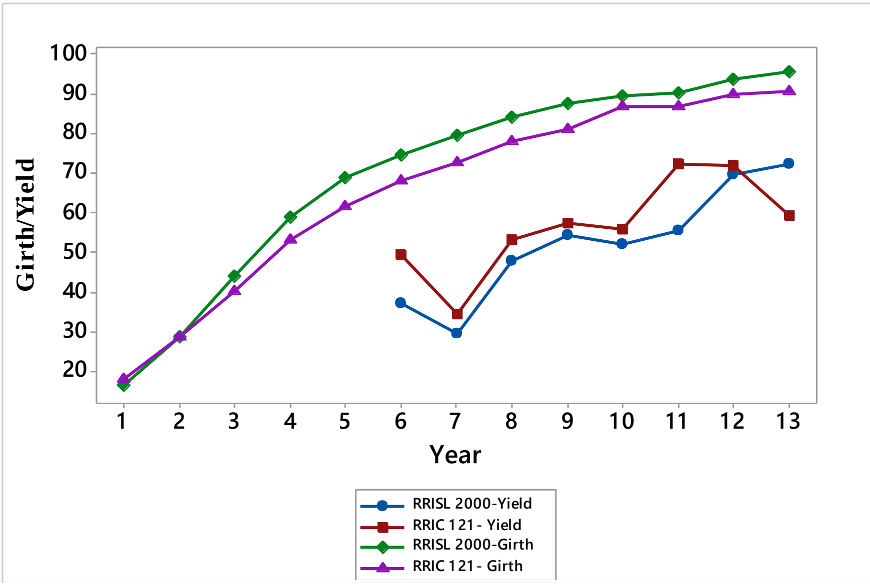

Fig. 2. Average yield and the girth of the clone 76 - 8 (RRISL 2000) and control clone RRIC 121 at SSCT at Tempo division – Hill stream estate established in 1984

Yield data of Estate – RRI Collaborative Clone Trials (ECT)

Two ECT trials were established at Nivithigalakele and Kuruwita to evaluate the performance of the clone 76-8 at commercial level. The yearly girth and the yields obtained from ECT trials are given in Table 02. The clone RRISL 2000 showed outstanding performance in yield under commercial scale evaluation (Fig. 03). Data have shown that HP 76-8 is a promising clone for large-scale testing, and therefore, it has been registered as the clone RRISL 2000 (Attanayake, 2000).

Table 2. *Average girth and yield of the clone RRISL 2000 in ECT's established at Kuruwita and Nivithigalakele*

Year	Nivitigalakele (YOP 2001)		Kuruwita (YOP 2005)	
	Girth (cm)	Yield (g/t/t)	Girth (cm)	Yield (g/t/t)
1	8.68		12.9	
2	18.8		19.7	
3	30.6		30.5	
4	43.6		43.4	
5	52.2		50.3	
6	58.9	36.1	54.5	13.78
7	60.1	43.5	58.6	9.30
8	62.5	54.0	61.7	9.91
9	64.5	45.6	65.1	15.52
10	66.2	38.7	66.9	25.92
11	-	-	69.1	33.60
12	-	-	71.3	45.80
13	-	-	73.5	40.17

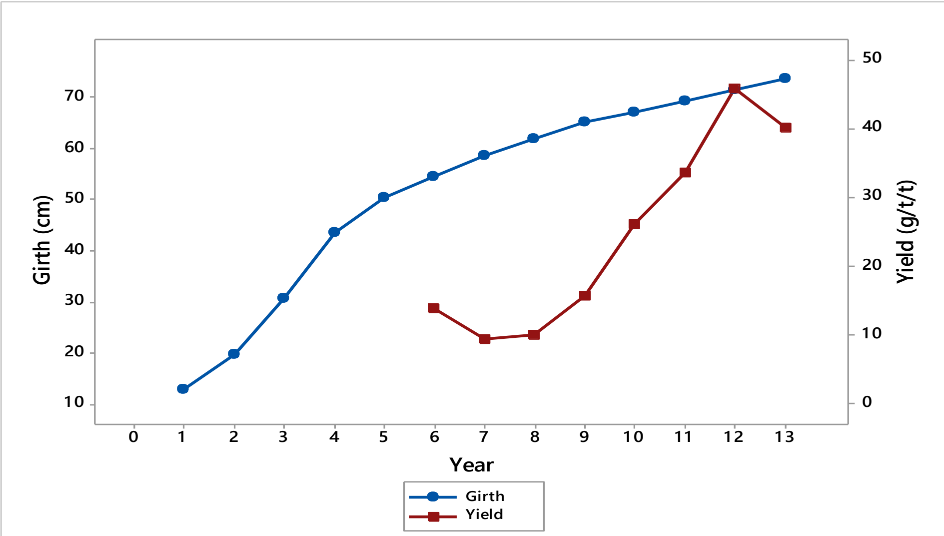

Fig. 3. Average girth and yield variation of the clone RRISL 2000 in ECT established at Kuruwita (cm)

The monthly variation in yield of clone RRISL 2000 over the four years in ECT (Fig. 04) showed that February to May was the lean period with a sharp drop in yield below the average in April and May. The yield was found to peak in August, then drop in October, gradually increasing towards December, and attained a higher peak in January. It is well documented that this yield depression could be attributed to the stress imposed on the rubber tree due to the dry period coupled with wintering (Wijesuriya *et al.,* 1997).

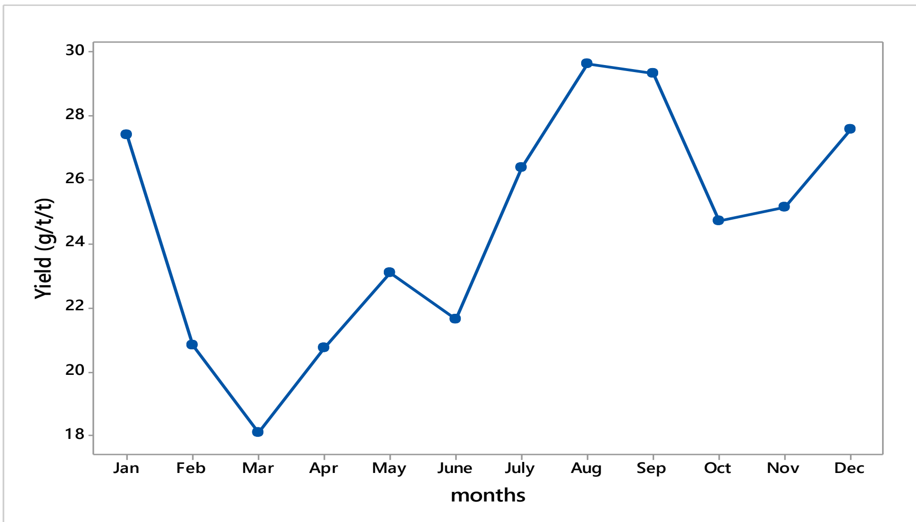

Fig. 4. Monthly average yield variation over seven years of the clone RRISL 2000 at ECT level

Use of RRIC 102 in Clone Recommendation

The clone RRISL 2000 was first introduced into the advisory circular on clone recommendation in 2004 and was first recommended as a Group III clone for small scale planting at the plantation sector. Afterwards, the clone recommendation was revised several times, but clone RRISL 2000 remained unchanged in group III due to lack of enough data for upgrading (Table 03).

Table 3. *Use of RRISL 2000 in Clone Recommendation*

Year of recommendation	Group included	Guide for recommendation
2004	Group III	Estate/RRI collaborative clone trials. each clone up to 2ha
2007	Group III	Estate/RRI collaborative clone trials. each clone up to 2ha
2013	Group III	Estate/RRI collaborative clone trials. each clone up to 2ha

Raw rubber properties of RRISL 2000

In the clone selection process; the raw rubber properties of clones will play a major role in selecting superior clones, which will ultimately be beneficial for sustainable rubber cultivation in Sri Lanka. The raw properties; Initial plasticity number, Plasticity retention index, Mooney viscosity, Lovibond Colour, Ash %, and Nitrogen % of the clone RRISL 2000 in comparison to a Group I recommended rubber clone, RRIC 121 are denoted in

Table 04. The overall raw rubber properties of clone RRISL 2000 performed better as in RRIC 121. According to the results, RRISL 2000 is a high yielder hence better to tap with a lower intensity without stimulation. However, long term investigations are needed to confirm the behavior of RRISL 2000 clone for long term sustainability.

Table 4. *Raw rubber properties of the clone RRISL 2000 (Coefficients of variation are in parentheses)*

Clone	Initial plasticity number (Wallace units)	Plasticity retention index	Mooney viscosity (ML 1+4 @ 100°C)	Lovibond Colour	Ash % (w/w)	Nitrogen% (w/w)
Standard value	30 (min)	60 (min)	75-85	1.5units (max)	0.2 (max)	0.35 (max)
RRISL 2000	44(6.82)	69(4.89)	85(6.88)	1.6(30.16)	0.12(34.08)	0.38(14.89)
RRIC 121	52 (11.54)	63(28.57)	89(4.49)	1.6(27.67)	0.14(28.57)	0.45(15.56)

(Kudaligama *et al,* 2010)

Assessment on disease resistance

Vigor or growth rate and tolerance to important foliar diseases causing fungus *Corynespora*, *Oidium*, *Phytopthora* and *Gloeosporium* is an important factor to be considered in clonal screening. Disease screening was carried out for the initial 29 selections at the SSCT level with the help of the Plant Pathology & Microbiology Department. *Corynespora* disease was not observed among the 29 selections at SSCT level. Moreover, according to the scoring system used by RRISL to evaluate the disease incidence in bud wood nursery and mature fields indicated that the RRISL 2000 clone is resistant to CLF disease. Also, it showed a below average susceptibility to *Oidium* and *Phytopthora* leaf fall (Jayasinghe, 2004-2009; Silva, 2010; Fernando, 2011-2019).

Identification of the clone RRISL 2000 based on morphological characters.

Characterization of rubber clones based on morphological characters has played an important role in *Hevea* breeding as well as in other tree crop breeding. Although most of the clones do not exhibit distinct variations, they do exhibit minor, but more or less stabilized characters for clear identification. Meantime, knowledge on a particular clone about their consistent morphological features will enable a planter to identify clones recommended for planting (Liyanage, 2021; Anushka *et al,* 2017). Hence proper identification of the characters of RRISL 2000 clone is important. The immature and matured tree morphological characters used for identification of clone RRISL 2000 are listed and illustrated in table 05, figure 05 and 06.

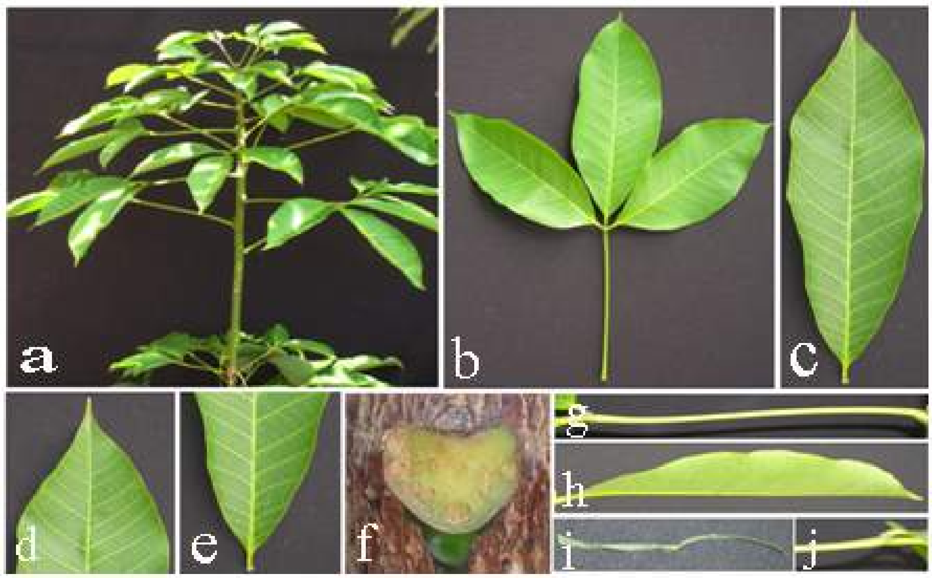

Fig. 5. Morphological features of clone RRISL 2000 at immature stage

a: Leaf Storey - conical in shape, well separated from each other by the bare stem, Low density of leaves in the storey, Intermediate canopy

b: Leaf - Leaf is palmately compound and consists of a pulvinus, leaf stalk (petiole), three leaflets which are attached by petiolule to the distal end of the petiole. At that point, extrafloral nectaries the nectar secreting glands are present.

c: Shape of leaf blade - Leaflets is normal elliptical in shape. The leaf margin is irregular wavy. Veins are prominent and light green in colour. The luster of the leaf is dull and smooth in texture.

d & e: Leaf apex and leaf base - Leaf apex is acuminate, and leaf base is cuneate.

f: Leaf scar – Heart shape with protruded margin and the axillary bud is normal and visible.

g: The Longitudinal sectional appearance of a leaf – Flat and it is judged by viewing the leaflets from the side

h: Petiole and orientation of petiole - The orientation is upward, and the shape of the petiole is "S" shaped

i: Petiolule - It is the short stalk connecting the leaf lamina to the petiole. The orientation of petiolule is horizontal and wide with inter petiolule angle.

j: Cross-sectional appearance of a leaf - It is viewed by looking at the tip towards the direction of the base, and it is boat shaped.

Fig. 06. Morphological features of clone RRISL 2000 at mature stage

a: Mature plantation - The tree trunk is more or less rounded and nodule appearance in the main trunk.

b and d: Branching habit - Low set branching and balanced. They are spreading closely with a narrow-angle to the main trunk, the strait in appearance and dissolve in the continuity. The density of branching is average.

d: Canopy - Broom shape sparse density canopy

e: Appearance of bark – Bark of the main trunk is smooth and light in colour

Table 5. *Morphological characters of the clone RRISL 2000*

At immature stage (<2 years)	
Discriptor	**In clone RRISL 2000**
1) Leaf (Middle leaflet)	
Shape	Normal elliptical
Colour	Green (7.5 GY 3/4)
Luster	Dull
Texture	Smooth
Leaf base	Cuneate
Leaf Apex	Acuminate
Leaf Margin	Irregular wavy
Longitudinal Section	Flat
Cross Section	Boat shaped
Degree of leaflet separation	Well separated
2) Petiolule	
Length	Medium (1.2 – 1.6cm)
Orientation	Horizontal
Angle between Petiolule	Wide (55 – 60^0)
3) Petiole	
Shape	"S" shape
Length	Medium (22 – 28 cm)
Orientation	Horizontal
Pulvinus	Swollen
Nectar Gland	Normal
4) Leaf Storey	
Shape	Conical
Separation	Well separated
Appearance	Intermediate canopy
5) Stem	
Appearance	Straight
Surface	Smooth
Leaf Scar Size	Small
Leaf Scar Shape	Heart shape
Auxillary bud appearance	Protruded
Auxillary bud distance from petiole	Closed
Latex Colour	White
At mature stage (>5 years)	
1) Trunk	
Vigour	Good
Continuity	Persistent
Height	Tall
Shape	Round

Surface	Smooth
Colour	Dark
Appearance	Straight
Virgin bark thickness	Average (8.5mm)
Bark hardness	Hard
Scar	Present
Bleeding	Present
2) Branching	
Position	Low (3 – 3.5m)
Habit	Clustered
Spreading	Close
Angle	Narrow
Continuity	Dissolve
Appearance	Straight
Density	Average
3) Crown	
Shape	Broom shaped
Size	Narrow
Density	Sparse
Height	Moderate
Position	Balanced
Colour	Green

(Liyanage, 2021)

Other important characteristics of clone RRISL 2000

The average bark thickness of the clone RRISL 2000 is greater than 10 mm, therefore, it should be tapped deeper to get its maximum potential yield when compared to the control clone RRIC 121. The clone RRISL 2000 is recommended as a d2 clone and therefore it should be tapped on every other day.

Another important feature is that RRISL 2000 is sensitive to the fertilizer application. Therefore, it is essential to add recommended dosage of fertilizer at recommended intervals to get its maximum potential yield.

The growth vigor after the commencement of tapping (post tapping growth increment) is also an important indicator of high yield in the later years of exploitation. Clone RRISL 2000 has around 1.8 – 2.0 cm girth increment during the post tapping period. The estimated timber value of RRISL 2000 is around 0.411 m^3/tree and it is almost similar volume compared to RRIC 121(*i.e.* 0.406 m3/tree).

The data showed that RRISL 2000 is a vigorous clone, reached the tappable girth at the age around 4-5 years under small scale and 5 years at commercial scale. Tapping at early stages and initial high yields are only possible with clones having vigorous growth. In general, RRISL 2000 is considered as a latex- timber clone.

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THE HYBRIDIZATION PROCEDURE FOR THE DEVELOPMENT OF *HEVEA* CLONES

T T D Dahanayake, K K Liyanage, B W A N Baddewithana and N S Jayasinghe

INTRODUCTION

The Wickham collection of rubber tree (*Hevea brasiliensis* (A. Juss.) Muell. Arg.) was introduced to Sri Lanka in the year 1876, and the seeds and seedlings derived from these trees in 1883 were the foundation germplasm stock for the development of the rubber plantations in Asia (Withanage, 2019).

The key objective of *Hevea* breeding is developing high yielding, disease resistant, stress tolerant clones with desirable characteristics for the rubber sector. At the initial stage of development of the rubber planting materials, unselected seedlings were used as the primary planting material. Then the high-yielders in estates were screened to raise seedlings and used as the planting material. Subsequently, with the introduction of the bud grafting technique by Van Helten in 1918, clones became the primary planting material (Liyanage, 2008).

The next revolution in *Hevea* breeding was the artificial crossing or hybridization technique introduced by Dr C.E. Ford in 1932, which paved the way for crossing selected parental clones (Murray, 1940). Dr Ford initiated a large-scale hand pollination programme in 1939, which resulted in 65000 crosses (Liyanage, 2008). Over 90 years, the annual hybridization program was occupied with diverse local and foreign high performing clones, which resulted a better progeny to the *Hevea* breeding pool. At present, hybridization and selection are the most important methods adapted for crop improvement in *Hevea brasiliensis*. As a result, many heterogenic hybrids have evolved with a combination of desirable traits from both parents.

Like many other perennial trees, it is well known that *Hevea* breeding is a laborious process with an average duration of 20-25 years of field experiments in large areas that are generally required to obtain a new cultivar with reasonably low risks. Propagation through grafting enables the multiplication of elite genotypes as clones. Rubber is usually propagated in the form of grafted trees. The high level of homogeneity in bud-grafted trees exhibits a minimum intra-clonal variation in yield, excluding factors such as soil heterogeneity, the difference in juvenility of buds and different seedling rootstocks.

The *Hevea* breeding cycle in Sri Lanka begins with the annual hand pollination programme (hybridization). It is a well-planned and laborious programme that runs yearly, with an integral part of skilled pollinators. In advance of the annual hybridization programme, selected workers are trained in the technique of hand pollination. The availability of such skilled workers is essential, especially when carrying out the hand pollinations in taller trees, using scaffoldings rather than in a breeding garden.

This review aims to provide researchers with historical background and an overview of hand pollination programme carried out over the years by the Department of Genetics and Plant Breeding, the Rubber Research Institute of Sri Lanka.

Hevea species

Para rubber tree (*Hevea brasiliensis*) belongs to the family Euphorbiaceae. Ten species have been recognized under the genus *Hevea*, *H. brasiliensis*, *H. benthamiana*, *H. camporum*, *H. camargoana*, *H. nitida*, *H. pauciflora*, *H. guianensis*, *H. microphylla*, *H. spruceana* and *H. rigidifolia* (Webster and Paardekooper, 1989; Wycherley, 1992, Liyanage, 2007). These species are highly cross-pollinated, and putative hybrids of natural intercrossing between the species occurred in the natural habitat. One of the ten species of the genus, *Hevea brasiliensis* Willd. Ex A. de Juss. Mull. Arg. is quite exclusively cultivated over 10 million hectares globally to provide the industry with natural rubber.

Morphological features of *Hevea* tree/Floral Morphology and Flowering

Hevea (the Para rubber tree) is a tall deciduous tree (30-40 m high), deciduous, with an orthotropic rhythmic growth. The rubber tree is a flower-bearing tree; it has separate male and female flowers borne in the same inflorescence (Fig. 2b), the latter terminating the main branches of the panicle. They are attached to the axis, the central and the sides. The female flowers are found only at the tip of the axis (central and sides). The sexual parts of the male flowers contain the anther and the pollen grains, while the female contains the stigma and the ovary (Wycherley, 1992). Both male and female flowers appear in the last phase of the defoliation-refoliation process during wintering (dry season). Flowers are pentamerous and a tricarpelar ovary are typical to the family Euphorbiaceae. Flowers are pollinated by the insects, and the fruit is a trilocular capsule that usually contains three seeds. The time taken from pollination to seed fall is approximately five months. Pollination can also be done manually, known as hand pollination, usually used for the breeding purposes.

Male flowers (Staminate flowers)

Staminate flowers have ten anthers arranged over a staminal column in rows of five each. Mature male flower buds, which are to open on the day of pollination, are identified by the yellow colour of the perianth (Fig. 1 & 2b). For the artificial pollination process, panicles bearing such mature male flowers are cut from healthy, disease-free branches of the male parent and brought to the female parent tree on which pollination is to be occurred (Cuco and Bandel, 1998).

Female flowers (Pistillate flower)

Flowers are greenish-yellow, with bell-shaped calyx having five triangular lobes. The pistillate flower consists of the 3-celled ovary with three short sessile stigmas (Fig 1). The mature female flower could be identified due to their bigger size, the brighter yellow perianth, and the green colour of the basal disc (Fig. 2b). In the panicle of *Hevea*, female flowers are fewer in number (5 to 10 numbers) than the male flowers (25 to 30 numbers) (Cuco and Bandel, 1998).

Fig. 1. Floral characteristics of *Hevea*; 1. Enlarged photograph of male flower, 2. Enlarged photograph of female flower (P - perianth, S - staminal column, C - stigmas) (Source; Liyanage, 2007)

Selection of the parent clones

Parents for crossing are selected based on the objective of the hybridization programme, *i.e.* yield improvement, disease tolerance, improved vigor timber properties, drought tolerance *etc.* Healthy trees of the female parent in open spaces with well-exposed, healthy branches and devoid of tapping panel dryness are marked. In cases where the trees are high branching, scaffolds are made around the selected trees to access the panicles (Fig. 2a).

Disease-free environment for hand pollination

Since refoliation and flowering in *Hevea* coincide, the incidence of fungal diseases affecting the tender leaves and flowers are greater during February to March in the wet zone. Avoiding such incidence of diseases is a prerequisite for a hybridization programme to ensure healthy flowers. This is usually carried out by spraying wettable sulphur (2.5g/litre), Mancozeb and Carbendazim (5g/litre) alternatively at two weeks intervals commencing from refoliation up to the completion of the crossing programme.

Preparation of the panicle

Healthy panicles on the female parent bearing 5 to 6 mature female flowers are selected for hand pollination. The immature male flowers may be retained since they do not affect the hybridization process. All other unnecessary immature and opened female flowers and opened mature male flowers are clipped away.

Hand pollination

The perianth of the selected mature male flower is opened, and the staminal column is removed using a pair of forceps. The perianth of the mature female flower is then opened by exerting a slight pressure using the thumb and forefinger, and the excised staminal column is placed on top of the stigma using the forceps (Fig. 2c), taking utmost care to avoid any injury to the floral parts. The perianth of the pollinated female flower is then sealed using a cotton plug to avoid natural pollination from insects (Fig. 2d). The panicle is then labelled approximately starting the pollen donor, number of pollinations, date of pollination and the pollinator (Fig. 2e).

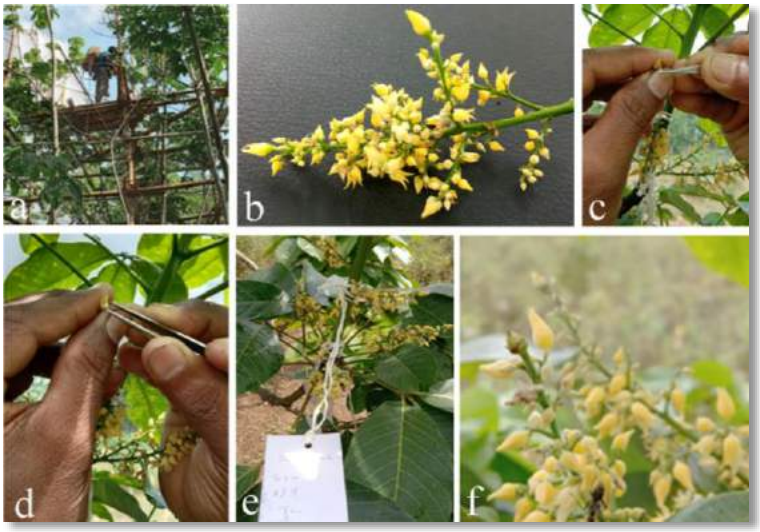

Fig. 2. Hand pollination procedure and seeds formation; a - Scaffoldings establishment to reach the inflorescence of taller trees, **b** - *Hevea* inflorescence containing male and female flowers, **c** - Excised staminal column is placed on top of the stigma using the forceps, **d** - Pollinated female flower is sealed using a cotton plug, **e** - Panicle is labelled starting the pollen donor, number of pollinations, date of pollination and the pollinator, **f** - Initiation of the seeds formation

Concept of *Hevea* breeding garden

From the beginning of hand pollination, the process has been carried out by constituting scaffoldings using bamboo to access the flowers of taller *Hevea* trees. This was a laborious and time-consuming process back in the day. With the concept of breeding orchards, this process has become much more manageable. Rubber Research Institute of Sri Lanka has established a breeding garden in the Neuchatal estate, Kalutara where the tree branches are induced at an appropriate height for easy access to flowers convenience in hand pollination (Fig. 3). Presently the *Hevea* breeding garden is comprised of local and foreign clones (Table 1), which used for the annual hand pollination programme.

Table 1. *Clones present at the breeding garden for the purpose of hybridization*

Series	Clones
RRIC 100	RRIC 100, RRIC 101, RRIC 102, RRIC 121, RRIC 130, RRIC 131, RRIC 133
RRISL 200	RRISL 201, RRISL 202, RRISL 203, RRISL 205, RRISL 206, RRISL 208, RRISL 210, RRISL 213, RRISL 215, RRISL 216, RRISL 217, RRISL 219, RRISL 220, RRISL 221, RRISL 222, RRISL 223, RRISL 226
RRISL 2000 & 2100	RRISL 2000, RRISL 2001, RRISL 2002, RRISL 2003, RRISL 2004, RRISL 2100
RRISL Centennial	RRISL CENTENNIAL 1, RRISL CENTENNIAL 2, RRISL CENTENNIAL 3, RRISL CENTENNIAL 4, RRISL CENTENNIAL 5
Foreign Clones	PB 28/59, PB 86, PB 260, PB 217, PR 255, BPM 24, RRIM 600, RRIM 712

Fig. 3. *Hevea* breeding garden constituted at Neuchatal estate Fertilization and seeds formation

When the pollen grains enter the female flower through the stigma, fertilization occurs. This is known as the pollination process. Fertilization usually takes place within 24 hrs. after pollination, and the cotton plug with the perianth falls off in about one week. The initial fruit set is recorded one month after pollination (Fig. 2f). The whole outer hardcover of the rubber seed and fruit is purely made up of female tissue. The embryo, found in the centre of the seed, is the result of the union between the male and the female gametes and inherits the characteristics of both.

Aftercare management

The fruits usually set mature in 3 to 4 months. After recording the final fruit counts, the fruits are enclosed in small net bags to prevent the loss of seeds when they dehisce on maturation. By the time the fruit matures, the rains may set in, and there is the risk of *Phytophthora* infection. To avoid such disease, the steps as discussed in the section 'Disease-free environment for hand pollination' is followed routinely. Mature fruits are harvested by the fifth month after pollination. The seeds are extracted, taking utmost care to maintain the identity of seeds from each cross combination. The seeds are sown family wise on sand beds. These are kept moist for proper germination. Then germinated seeds are planted in family wise in a seedling nursery.

Popular clones produced through the hybridization programs carried out by RRISL since 1957

The annual hand pollination programmes have been carried at different locations including pollination garden at Neuchatal estate and different estates throughout specially the estates in kalutara district of Sri Lanka for the past 20 years. New genotypes were raised using different combinations of outstanding parent clones. The popular clones and the clones that have been included in the RRISL clone recommendation have resulted from various hand pollinated progenies carried out since 1957. Details of the parentage of the clones and the respective years of hand pollination are denoted in Table 2.

Table 2. *Popular clones produced through different hand pollinated programmes carried out over the past years by RRISL*

Series of clones	Clones produced	Parentage	HP Programme Year	Accession No.
RRIC 100	RRIC 100	RRIC 52 X PB 86	1957	663
	RRIC 101	CH 26 X RRIC 7	1957	1174
	RRIC 102	RRIC 52 X RRIC 7	1957	1103
	RRIC 121	PB 28/59 X IAN 45/873	1962	6182
	RRIC 130	IAN 45/873 X RRIC 45	1965	5-270
	RRIC 133	IAN 45/873 X RRIC 52	1965	5-90
RRISL 200	RRISL 201	RRIC 103 X 8501	1974	74 - 41
	RRISL 203	RRIC 100 X RRIC 101	1974	74-193
	RRISL 205	82 X 82	1975	75-143
	RRISL 206	82 X RRIC 101	1975	75-4
	RRISL 208	RRIC 103 X RRIM 623	1979	79-24
	RRISL 210	RRIC 101 X RRIM 600	1979	79-61
	RRISL 211	RRIC 101 X RRIM 600	1979	79-155
	RRISL 217	PB 28/59 X RRIC 121	1981	81-8
	RRISL 219	PB 28/59 X RRIC 102	1981	81-50
RRISL 2000	RRISL 2000	RRIC 100 X RRIC 101	1976	76-8
	RRISL 2001	RRIC 100 X RRIC 101	1976	76-52
	RRISL 2002	RRIC 100 X RRIC 101	1976	76-82
	RRISL 2003	82X RRIC 101	1976	76-182
	RRISL 2004	82 X PB 86	1976	76-158
	RRISL 2005	PB 28/59 X IAN 45/710	1982	82-15
	RRISL 2006	IAN 45/710 X PB 28/59	1982	82-140
	RRISL 2100	RRIC 100 X PR 309	1992	92-358
Centennial Series	Centennial 1	RRIC 100 X GT 1	1987	87-93
	Centennial 2	RRIC 100 X GT 1	1987	87-139

Centennial 3	BPM 24 X RRIC 121	1987	87-370
Centennial 4	RRIC 100 X PB 260	1992	92-124
Centennial 5	RRIC 100 X PB 260	1992	92-132

Hybridization programs carried out by the department over the years

Over the last 90 years, the annual hybridization program was occupied with diverse local and foreign high performing clones, which could result in a good progeny to the rubber sector. At present, a large number of heterogenic hybride been evolved with a combination of desirable traits from both parents. The details of hybridization programme carried out over the last 20 years are presented in table 3.

Table 3. *Summary of hand pollinated data carried out by the Department of Genetics & Plant Breeding, Rubber Research Institute of Sri Lanka over the last 20 years*

Year of pollination	**Mother clone**	**Pollen clone**	**Type of pollination**	**No of pollinations**	**No. of pods harvested**	**Success %**	**No. of seeds**	**No of seedlings obtained**
2000	BPM 24	G.P. 36-104	Normal cross	271	6	2.21	19	19
	,,	PB 235	Normal cross	1501	60	4	180	178
	,,	PB 260	Normal cross	1029	56	5.44	170	142
	,,	RRIC 121	Normal cross	976	60	6.15	179	154
	PB 235	PB 260	Normal cross	1063	22	2.07	67	63
	,,	RRIC 121	Normal cross	1329	128	9.63	387	372
	RRIC 121	**PB 235**	Reciprocal cross	603	70	11.61	209	197
	,,	**BPM 24**	Reciprocal cross	6	0	0	0	0
	,,	**PB 260**	Reciprocal cross	290	38	13.1	114	111
	,,	RRIC 121	Self	209	0	0	0	0
	,,	G.P. 36-147	Normal cross	213	17	7.98	51	49
	PB 260	PB 260	Self	1089	23	2.11	71	60
	,,	**RRIC 121**	Reciprocal cross	576	95	16.49	289	268
	Total			**9155**	**575**	**6.28**	**1736**	**1613**
2001	RRIC 100	RRIM 712	Normal cross	1050	10	0.95	31	29
	,,	PB 260	Normal cross	264	15	5.68	39	38

	RRIM 712	RRIC 130	Normal cross	1494	16	1.07	47	12
	,,	RRIC 121	Normal cross	1602	2	0.12	6	5
	,,	GPS 1	Normal cross	1167	0	0		0
	,,	PB 260	Normal cross	1524	1	0.07	3	0
	,,	G.P. 36-84	Normal cross	370	0	0		0
	RRIC 130	**RRIM 712**	Reciprocal cross	1659	3	0.18	9	7
	,,	**RRIC 121**	Reciprocal cross	41	0	0		0
	BPM 24	RRIC 130	Normal cross	106	7	6.6	21	17
	PB 260	**RRIM 712**	Reciprocal cross	45	4	8.89	12	11
	RRIC 121	**RRIC 130**	Reciprocal cross	636	84	13.21	253	180
	Total			**10245**	**148**	**1.44**	**440**	**315**
2002	RRIC 130	RRIC 121	Normal cross	1452	12	0.83	34	26
		RRISL 2001	Normal cross	901	18	2	54	36
		PB 235	Normal cross	722	10	1.39	30	29
		PB 260	Normal cross	646	6	0.93	18	12
		RRIC 130	Normal cross	49	0	0	0	0
		RRISL 205	Normal cross	114	1	0.88	3	2
	IAN 45/873	GPS 1	Normal cross	108	4	3.7	12	12
		RRISL 2001	Normal cross	128	3	2.34	9	9
	PR 261	GPS 1	Normal cross	85	3	3.53	9	2
		RRISL 2001	Normal cross	161	6	3.73	18	12
		PB 260	Normal cross	120	4	3.33	12	3

	RRISL 2001	**RRIC 130**	Reciprocal cross	1677	8	0.48	24	15
		RRIC 102	Normal cross	436	1	0.23	3	3
		RRIC 121	Normal cross	1041	1	0.1	3	3
		RRISL 205	Normal cross	976	7	0.72	21	13
		GPS 1	Normal cross	972	1	0.1	3	3
	RRISL 205	RRISL 2001	Normal cross	18	6	33.33	20	20
	Total			**9606**	**91**	**0.95**	**273**	**200**
2004	RRIC 121	PB 28/59	Normal cross	2636	195	7.4	589	461
		RRIC 121	Self	2391	4	0.17	12	4
	Total			**5027**	**199**	**3.96**	**601**	**465**
2005 Di allele progeny	RRIC 103	RRIC 103	Self	9731	28	0.29	85	60
	RRIC 100	RRIC 100	Self	1591	1	0.063	3	1
	Total			**11322**	**29**	**0.26**	**88**	**61**
2006	RRIC 100	RRII 105	Normal cross	4148	109	2.63	334	164
	GPS 1	RRIC 100	Normal cross	1542	16	1.04	11	0
		RRIC 121	Normal cross	3246	16	0.49	6	0
	RRIC 100 (Di-allele Prog. Tree No 878)	RRII 105	Normal cross	709	53	7.48	115	22
	RRIC 100 (Di-allele Prog. Tree No 878)	RRIC 100 (Di-allele Prog. Tree No 878)	Self	1438	6	0.42	19	1

		RRIC 103 (Di-allele Prog. Tree No 377)	Normal cross	323	9	2.79	16	0
	RRIC 100 (Di-allele Prog. Tree No 76)	RRIC 100 (Di-allele Prog. Tree No 76)	Self	1076	18	1.67	53	41
	RRIC 103 (Di-allele Prog. Tree No 377)	RRIC 103 (Di-allele Prog. Tree No 377)	Self	102	2	1.96	6	3
	Total			**12584**	**236**	**1.88**	**502**	**253**
2007	RRIC 130	G.P. 22-137	Normal cross	1423	14	0.98	44	29
		G.P. 44 - 24	Normal cross	1284	3	0.23	9	0
		G.P. 21 - 163	Normal cross	901	17	1.89	49	42
		G.P. 1 - 2	Normal cross	804	2	0.25	6	1
		G.P. 10 - 154	Normal cross	14	1	7.14	3	3
		G.P. 22 - 137 or G.P. 44 - 24	Normal cross		1		3	3
	PB 260	IAN 45/710	Normal cross	2266	100	4.41	310	263
	IAN 45/710	**PB 260**	Reciprocal cross	1717	60	3.49	178	125
	Total			**8409**	**198**	**2.35**	**599**	**466**
2008	RRIC 121	PB 28/59	Normal cross	160	12	7.5	36	28

		G.P. 21 - 163	Normal cross	347	18	5.19	55	49
		G.P. 21 - 108	Normal cross	9	0	0	0	0
		G.P. 22 - 271	Normal cross	82	8	9.76	24	17
		G.P. 1 - 47	Normal cross	18	3	16.67	9	5
		G.P. 1 - 4	Normal cross	41	2	4.88	6	5
		G.P. 36 - 160	Normal cross	4	1	25	3	3
	RRIC 100	PB 28/59	Normal cross	1016	53	5.22	150	120
		G.P. 22 - 373	Normal cross	244	18	7.38	54	40
		G.P. 22 - 271	Normal cross	71	3	4.23	6	5
		G.P. 1 - 47	Normal cross	8	0	0	0	0
		G.P. 1 - 4	Normal cross	48	5	10.42	17	17
	PB 28/59	G.P. 36 - 147	Normal cross	46	13	28.26	39	28
		RRIC 121	Reciprocal cross	536	31	5.78	91	9
		IAN 45/873	Normal cross	639	58	9.08	172	28
	Total			**3269**	**225**	**6.88**	**662**	**354**
2010	RRISL 2001	RRISL 2001	Self	503	0	0	0	0
		RRII 105	Normal cross	2037	14	0.69	36	27
		RRISL 211	Normal cross	2019	0	0	0	0
		RRIC 121	Normal cross	1866	6	0.32	18	11

		Uncertain			2		6	6
	RRISL 211	**RRISL 2001**	Reciprocal cross	251	1	0.4	3	0
	Total			**6676**	**23**	**0.35**	**63**	**44**
2011	PB 86	RRIC 102	Normal cross	742	17	2.29	51	39
		RRII 105	Normal cross	1873	70	3.74	206	196
		RRIC 121	Normal cross	1069	3	0.28	9	8
		Uncertain			2		6	6
	RRII 105	PB 86	Reciprocal cross	385	15	3.9	45	44
		RRIC 121	Normal cross	1156	7	0.61	20	15
	Total			**5225**	**114**	**2.18**	**337**	**308**
2012	RRISL 2005	G.P. 22 - 16	Normal cross	411	11	2.68	33	26
		G.P. 22 - 493	Normal cross	403	18	4.47	54	41
		G.P. 22 - 4	Normal cross	392	17	4.34	48	41
		G.P. 11 - 76	Normal cross	45	2	4.44	6	6
		G.P. 22 - 500	Normal cross	225	7	3.11	18	15
		H.nitida * *H.sprusiana*	Normal cross	257	9	3.5	29	29
		IAN 45/710	Normal cross	212	4	1.89	13	9
		G.P. 44 - 24	Normal cross	36	0	0	0	0
		G.P. 22 - 137	Normal cross	86	6	6.98	18	16
		Uncertain			2		3	3

	RRISL 2006	G.P. 22 - 493	Normal cross	8	0	0	0	0
		G.P. 22 - 500	Normal cross	10	0	0	0	0
		H.nitida * *H.sprusiana*	Normal cross	327	1	0.31	3	0
		IAN 45/710	Normal cross	690	2	0.29	6	0
		FX 351	Normal cross	189	0	0	0	0
		G.P. 22 - 137	Normal cross	70	0	0	0	0
	Total			**3361**	**79**	**2.35**	**231**	**186**
2013	RRIC 130	RRISL 2001	Normal cross	1087	13	1.2	39	27
		RRISL 2002	Normal cross	1184	10	0.008	30	22
		RRISL 2003	Normal cross	1082	4	0.003	12	8
		RRISL 2005	Normal cross	189	2	1.05	6	6
		RRISL 2006	Normal cross	3337	3	0.09	9	6
		Uncertain			2		5	4
	Total			**6879**	**34**	**0.49**	**101**	**73**
2014	G.P. 44 - 24	RRISL 2006	Normal cross	1768	59	3.34	169	115
		RRISL 2001	Normal cross	589	16	2.72	45	20
		RRIC 130	Normal cross	237	1	0.42	3	0
		RRIC 131	Normal cross	184	4	2.17	12	11
		G.P. 44 - 24	Self	73		1.37	3	0
		RRISL 2100	Normal cross	161	9	5.59	27	19
	Total			**3012**	**89**	**2.95**	**259**	**165**

2015	RRISL 208	RRISL 2006	Normal cross	867	7	0.81	21	20
		RRISL 203	Normal cross	791	1	0.13	7	6
		RRISL 219	Normal cross	68	0	0	0	0
		RRISL 201	Normal cross	851	3	0.35	6	3
	RRISL 203	**RRISL 208**	Reciprocal cross	488	4	0.82	12	10
		RRISL 2006	Normal cross	228	5	2.19	15	14
		RRISL 201	Normal cross	68	4	5.88	15	13
	RRISL 211	RRISL 2006	Normal cross	327	4	1.22	0	0
		RRISL 203	Normal cross	144	5	3.47	12	2
		RRISL 201	Normal cross	29	4	13.79	12	2
		RRISL 208	Normal cross	36	0	0	0	0
	Total			**3897**	**37**	**0.95**	**100**	**70**
2016	RRISL 208	RRISL 2006	Normal cross	466	4	0.008	12	9
		IAN 45/873	Normal cross	735	3	0.4	9	7
	RRISL 211	IAN 45/873	Normal cross	500	21	4.2	63	52
		RRISL 2006	Normal cross	241	7	2.9	21	9
		RRISL 208	Normal cross	15	1	6.66	3	0
	RRISL 201	RRISL 2005	Normal cross	43	4	9.3	12	8
		RRISL 211	Normal cross	55	1	1.82	3	0
		RRISL 2001	Normal cross	139	11	7.91	32	18
		RRISL CEN: 2	Normal cross	160	6	3.7	18	3
	RRISL 203	IAN 45/873	Normal cross	269	3	1.1	9	6
		RRISL 2006	Normal cross	68	2	2.9	7	6

		RRISL 2005	Normal cross	40	0	0	0	0
	Total			**2731**	**63**	**2.31**	**189**	**118**
2017	RRISL 2006	RRISL 203	Normal cross	260	4	1.54	12	2
	,,	RRISL 201	Normal cross	26	1	3.85	3	1
	RRISL 208	G.P. 11 - 76	Normal cross	307	4	1.95	12	9
	,,	RRISL 2005	Normal cross	857	14	1.63	45	33
	RRISL 201	RRISL 203	Normal cross	213	13	6.1	39	21
	,,	G.P 11 - 76	Normal cross	84	6	7.14	18	9
	,,	RRISL 2005	Normal cross	55	3	5.45	9	5
	,,	RRISL 2006	Normal cross	33	1	3.03	3	3
	RRISL 203	G.P. 11 - 76	Normal cross	620	8	1.29	25	10
	Total			**2455**	**54**	**2.2**	**166**	**93**
2018	RRISL 211	RRISL 203	Normal cross	189	4	2.11	12	4
		G.P. 11 - 76	Normal cross	51	2	3.92	6	2
		RRISL 2006	Normal cross	62	2	3.22	6	4
		RRISL 2005	Normal cross	5	0	0	0	0
	RRISL 2006	RRISL 203	Normal cross	62	3	4.84	9	2
		G.P. 11 - 76	Normal cross	22	1	4.55	0	0
	RRISL 203	RRISL 2005	Normal cross	47	0	0	0	0
		RRISL 2006	Normal cross	75	0	0	0	0
	Total			**513**	**12**	**18.64**	**33**	**12**
2020	RRISL 205	RRISL 2006	Normal cross	53	4	7.55	12	8
	RRISL 203	RRISL 2006	Normal cross	1156	12	1.12	12	31
		RRISL 205	Normal cross	46	1	2.17	3	3

RRISL 2006	RRISL 208	Normal cross	681	2	0.29	6	3
	RRISL 205	Reciprocal cross	271	2	0.74	6	3
	RRISL 203	Reciprocal cross	618	0	0	0	0
RRISL 2005	RRISL 208	Normal cross	38	1	2.63	3	1
RRISL 208	**RRISL 2006**	Reciprocal cross	155	0	0	0	0
RRISL 201	RRISL 2006	Normal cross	105	4	3.81	6	3
Total			**3123**	**26**	**18.31**	**48**	**52**

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DO WE NEED TO THINK OF THE NUTRIENT VALUE OF FIREWOOD?

Lakshman Rodrigo and Rasika Hettiarachchi

We are in a different sphere in the Sri Lankan plantation history. In local currency terms (LKR) raw rubber prices have skyrocketed and so, rubber growers are quite happy despite having some other difficulties under the worst ever economic crisis facing today. Crepe rubber is sold in the Colombo auction for well over 1,000 LKR per kg and also RSS is reaching a four-digit value. With the limited supply of fossil fuel and its cost, the demand for firewood has increased expanding income avenue for rubber growers. At present, the farm-gate price of firewood is about 9 LKR per kg and buying price at factories for the use in the furnace is about 14 LKR per kg. Rubber log value which goes for timber is about 10 LKR per kg at farms and 16 LKR per kg at factories. With such demands, the growers would be driven for income maximization. However, if the overall sustainability of rubber lands is not ensured all stakeholders have to be apologetic about the industry in the future.

Despite the above positive remarks, the plantation industry suffers from the unavailability of chemical fertilizers and in particular, its price! Even at the price of 1,500 LKR for a 50 kg bag, only a few growers applied fertilizer for rubber; then, what would the situation at present be? According to the current market prices, urea fertilizer; the major source of nitrogen (N), is sold at about 765 LKR per kg whilst the selling price of muriate of potash (MOP), the principal source of potassium (K), is at about 780 LKR per kg. The price of ammonium sulfate, another source of N, costs about 389 LKR per kg. The Phosphorous (P) requirement is met by locally available Eppawala Rock Phosphate (ERP) and so, its price has fortunately been limited to 27 LKR per kg. Magnesium is mainly provided in two forms. For immature rubber lands, locally available dolomite is applied whilst imported kieserite is used in tapping fields. The prices of these two remain at about 9.80 LKR and 295 LKR per kg, respectively. Apparently, imported fertilizers are more expensive than local materials; also, they consume forex which we are short of.

Growers always tend to sell all possible products to enhance the income from their rubber lands. The sale of rubber is the principal source of income generation in rubber lands whilst the next source of income is from the sale of tree bole for timber and other parts of the tree for firewood. However, any biomass taken out from the land leads to some level of loss in nutrients. Under such a situation, this article tries to bring up a conceptual analysis to determine the worthiness of selling firewood against its nutritional value.

First, we simply assess the values of nutrients in chemical fertilizers which are still considered to be the cheapest source. As commonly declared, N content in urea and ammonium sulfate is 46% and 21%, respectively whilst P content in the form of P_2O_5 in ERP and K in MOP in the form of K_2O are 30% and 60%, respectively. Also, MgO contents in dolomite and kieserite are 20% and 24%, respectively.

For this conceptual analysis, elementary forms of nutrients were considered for ease of comparison. Having already presented in elementary form, N content in urea and ammonium sulfate does not change; however, P in ERP is only 13.1% and K in MOP is limited to 50% (Table 1). On this basis, Mg in dolomite and kieserite comes down to 12% and 14.4%, respectively. Accordingly, 7.6 kg of ERP is equal to 1 kg of P whilst 2 kg of MOP is needed to provide 1 kg of K. In the case of N, 1 kg is supplied by 2.2 kg of urea and 4.8 kg of ammonium sulfate. Accordingly, at the present market price, the value of 1 kg of N applied as urea and ammonium sulfate is 1683 LKR and 1867 LKR, respectively. In the case of ERP, 1 kg of P costs 205 LKR. The value of 1 kg of K in MOP is as high as 1560 LKR. Similarly, 1 kg of Mg can be valued as 81 LKR and 2036 LKR, in the form of dolomite or kieserite, respectively (Table 1).

Table 1. *Market values of nutrients in general fertilizers used in rubber. Present market value of fertilizers (a) was obtained from the Fertilizer Secretariat*.

Name of the fertilizer	**Present market value (LKR/ kg) (a)**	**% of nutrient content in fertilizer & its form (b)**	**% of elementary nutrient content in fertilizer (c*)**	**Amount of fertilizer (in kg) required to form 1kg of elementary nutrient (1/c*)**	**Market value of elementary nutrient (LKR/kg) (1/c* x a)**	**Remarks**
Urea	765	N - 46%	N - 46%	2.2	1683	Imported
Ammonium sulfate	389	N - 21%	N - 21%	4.8	1867	Imported
Muriate of potash	780	K_2O - 60%	K - 50%	2.0	1560	Imported
Eppawala rock phosphate	27	P_2O_5 - 30%	P - 13.1%	7.6	205	Locally produced
Dolomite	9.80	MgO - 20%	Mg - 12%	8.3	81	Locally produced
Kieserite	295	MgO - 24%	Mg -14.4%	6.9	2036	Imported

c* = atomic weight fraction of the element in the compound multiplied by ‘b’
Atomic weights of the elements concerned are, N -14g; K - 39g; P - 31g; Mg - 24g; O - 16g

Despite some variations, in plant based biomass, the presence of N,P,K and Mg in elementary form is usually about 0.45%, 0.05%, 0.25% and 0.12%, respectively on a dry weight basis (Shorrocks, 1965). In woody components, the moisture content is varying from 35 - 45% (Nurmi *et al.*, 2018 and Chetpattananondh *et al.*, 2017) and so, the nutrient content in such material would be approximately 0.29%, 0.03%, 0.16% and 0.08% with 2.93, 0.33, 1.63 and 0.78 grams in one kilogram, respectively. If these nutrients are supplied as chemical fertilizer, it would cost about LKR 7.54 (Table 2).

Table 2. *Market value of nutrients in rubber firewood compared to chemical fertilizer*

Elementary nutrient	Nutrient content in firewood (%)	Nutrient content in firewood @ 65% dry matter (%)	Nutrient amount in firewood (g/kg)	Cost if applied chemically (LKR)
N	0.45	0.2925	2.925	4.86*
P	0.05	0.0325	0.325	0.07
K	0.25	0.1625	1.625	2.55
Mg	0.12	0.078	0.78	0.06 *
Total				7.54

*Being the cheapest, urea and dolomite were considered for N and Mg, respectively.

Table 3. *Comparison of value as nutrients and biomass*

Type of biomass	Value as biomass (LKR/kg)	Value as nutrient (LKR/kg)	Difference (LKR)
Firewood	9	7.54	-1.46
Timber	10	7.54	-2.46

The exchange rate has a direct influence on the prices of both fertilizers and firewood as the principal components of fertilizer, i.e. urea and MOP, are imported and also the price of firewood depends on the price of fossil fuel. Therefore, the prices of both would behave similarly. Anyway, at the present market price of fertilizer, the firewood value of biomass at the farm gate is only slightly higher than the market value of nutrients (Table 3) indicating that the sale of firewood is not attractive as growers expected. Further, the removal of biomass such as firewood and timber prevents the potential addition of carbon to the soil. Rubber wood is also a sustainable, renewable, ecofriendly and a valuable source of timber material and can be utilized for different industries such as sawn timber, plywood, particle board, handicraft and furniture etc.

If woody components are incorporated into the soil as a soil amendment, the cost involved in overall such operation including chopping them into smaller sizes and field application in large quantities are issues of concern. Obviously, woody components have a low rate of decomposition due to the factors associated with larger particle size, high lignin content and C:N ratio. The slow mineralization process also does not make full amount of nutrients available to plants. Moreover, leaving firewood on the ground where the root diseases prevail, in particular White Root Disease, would result in spreading them fast. Further, we're to be aware that the country needs firewood as a renewable energy source and also to minimize the import of fossil fuels. Therefore, we need to think of balancing the needs of both parties, i.e. growers and firewood users.

Making the growers and other stakeholders aware of the nutrient content in firewood and its economic value seems useful in deciding the market value of firewood through fair bargaining. There could be a significant loss of all major nutrients in the burning process of firewood and it affects mostly nitrogen. In ash, calcium (Ca) is the dominant element; however, there is a significant amount of K and Mg available with a little amount of P (Table 4) (Fuzesla *et al*., 2015; Hamidi *et al*., 2021; Hytonen *et al*., 2019 and Neina *et al*., 2020). If a mechanism can be developed to return ash of burnt firewood to the field, nutrient loss due to the sale of firewood could partially be compensated, particularly K which is one of the major nutrients deficient in most agricultural soil and usually met with the application of MOP which is being imported at a high cost using forex. In addition to its nutrient content, wood ash can help in neutralizing soil acidity. Hence, we all need to put our heads together for developing a pragmatic approach to this concept. In this context, information pertaining to commercial scale users of firewood in Sri Lanka, quantity of ash available with them and whether ash is being used for any other purpose etc. need to be collected.

On average, each rubber tree would provide 600 kg of biomass at end of its lifespan. Having an average amount of 300 trees per hectare at felling and about 20% of tree biomass is used for firewood, total firewood availability per hectare would be 36 MT. Hence, the nutrient loss due to biomass taken away from rubber lands can be estimated as 526.5 kg, 58.5 kg, 292.5 kg and 140.4 kg of N,P,K and Mg respectively/ha as a whole and 105.3 kg, 11.7 kg, 58.5 kg and 28.08 kg of N,P,K and Mg respectively /ha as firewood. If firewood ash is returned back to the land, a significant amount of nutrient can be replenished. The annual average extent of uprooting senile rubber is about 1,500 ha (despite the expected extent to be over 3,000 ha). Hence, the estimated amount of nutrient loss from rubber firewood is as high as 157.95 MT, 17.55 MT, 87.75 MT and 42.12 MT of N,P,K and Mg respectively with a forex value of US$ 1.1 million.

Table 4. *Nutrients in firewood ash*

Elementary nutrient	Amount in ash (%)	Amount in ash (g/kg)	LKR value, if applied chemically
N	0.06	0.6	1.00*
P	0.5	5	1.03
K	3.5	35	54.60
Mg	2	20	1.62*
Ca	15	150	-

*Being the cheapest, urea and dolomite were considered for N and Mg, respectively.

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GROWTH AND YIELD PERFORMANCES OF PB 86 AND RRIC 100 CLONES HARVESTED WITH DIFFERENT TAPPING SYSTEMS UNDER WET CLIMATIC CONDITIONS IN SRI LANKA

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INTRODUCTION

The clone PB 86 was introduced to Sri Lanka from the Prang Beser estate in Malaysia in the late 1930s (Liyanage, 2008). It yielded about 1200kg/ha/y in 1989 by the end of the third year of tapping (Jayasekara, 1989). PB 86 has white latex with a low Mooney Viscosity value (Yapa, 1989) suitable to be utilized for specific products. Nevertheless, this clone was used to produce high-yielding progenies such as RRIC 36 and RRIC 45 (Fernando, 1973), and popular clones such as RRIC 100 and RRIC 103 (Liyanage, 2008). However, it was taken out from the growing list towards the latter part of the 1980s, on one hand as it covered about 80% of the total rubber extent and on the other hand to introduce new clones developed with high performance. Susceptibility to P*hytophthora* leaf disease and bark rot (Seneviratne, 2020) and low yield compared to the 100 series clones were also considered. When the clone RRIC 103 was removed from the list of clone recommendations, the clone PB 86 was re-introduced to fill the gap but removed again in 1989. Although clone PB 86 recorded a low growth rate and low latex yield, the incidence of Tapping Panel Dryness (TPD) was comparatively low when compared to other clones. However, the demand for the clone was there especially among smallholders in the country mainly due to high TPD incidences common in high-yielding new clones. Anyhow, even by 2002, the extent of PB 86 under the Smallholder sector farmers was 67,540 which was 54% and under RPC estates it was 57,999 which was 35% of the total rubber hectarage in the country. The total coverage of this one clone was 43% (Seneviratne *et al*, 2019).

Although the clone RRIC 100 is to produce about 1600 kg/ha/y dry rubber yield with white latex, requires proper usage of fertilizer and immature upkeep for optimum performance (Attanayake, 2001). It was placed in the leading position for yield, growth, and resistance to most foliar diseases that prevailed in those days, in most rubber-growing countries. When the clone composition was surveyed in 2009, it was revealed that the percentage coverage of the clone PB 86 has come down to 29.2% from its 43.6% during the 7 years from 2002. The data itself guarantees that PB 86 has not been planted since 2002. The proportion of clone RRIC 100 has increased from 24.8% to 33% partly due to allowing it for non-traditional areas. The extent of RRIC 121 has reached up to 32.9% and therefore it was necessary to restrict RRIC 121 from further expansion, especially for the estates managed by Regional Plantation Companies (Seneviratne *et al*, 2019).

The clone composition survey done in 2020 gave an alarming result, especially concerning the clone RRIC 121, the total coverage of which was 72.9%. The clone PB 86 covered only about 2% and RRIC 100 about 7.8%. Therefore, it was decided to reintroduce the clone RRIC 100 until it covers 20% of the total extent and the clone PB 86 up to 5% of the extent to get the germplasm back to rubber plantations and also to issue for the smallholder sector as it can withstand daily tapping as reported in Annual Reviews of under Plant Science and Genetics and Plant Breeding Departments during 1970-1980 period (Seneviratne *et al*, 2019).

However, among the smallholder farmers, the demand for the low-yielding PB 86 was always high mainly due to the low incidence of TPD and tolerance to daily tapping, though it was susceptible to Phytophthora disease. It was necessary to demonstrate the true performance of this clone while comparing the growth and yield potentials of newer clones as the remaining trees of PB 86 are about 30-40 years old massive trees and they yield comparatively high volumes due to the longer tapping cuts. Thus, a trial was established in 2013 with the objective of demonstrating the performance of the two clones under the same growth conditions and this article compares the growth and yield data for the readers to get a clear idea of the two clones also under different tapping systems.

MATERIALS AND METHODS

A field was established in 2013 at Galewatta division, Dartonfield Group of Rubber Research Institute of Sri Lanka which is located in wet climatic conditions in Kalutara District. Two rubber clones PB 86 and RRIC 100 were planted as young buddings with the onset of North East monsoon rains (Advisory Circular No. 2016/09). The planting distance was 4.3 m x 4.5m square planting system. This was a commercial scale trial and a tapping task was established from each clone to collect growth data randomly selected 50 trees per clone were used. Growth of the trees was recorded throughout the immature period until 70% of plants reached the tappable girth of 50 cm at 120 height from the bud union. All recommended agro-management practices *i.e.* fertilizing, weeding, and aftercare operations were done according to the recommendations given by the Rubber Research Institute of Sri Lanka (Advisory Circular No. 2016/04 and 2016/07). Tapping commenced in 2021 and test tapping was done initially by using a Completely Randomized Design. Two tapping systems were adopted, S/2 d2 and S/2 d3 with 160 and 107 tapping days, respectively. Only 30 trees were used to collect yield data. Latex volume and Metrolac readings were taken at each test tapping and the total weight of dry rubber yield was calculated accordingly. Total tapping days of each block in two clones were recorded. The latex yields were calculated as grams per tree per tapping (g/t/t) for two clones.

The yield variation pattern in terms of yield per hectare (YPH) was determined by approximating the total number of trees as 500 number per hectare and the number of tapping days as 160 and 107 for d2 and d3 tapping systems, respectively.

RESULTS AND DISCUSSION

Results of the present study revealed that there is a marked difference in plant growth and latex yield of two clones of PB 86 and RRIC 100 which were grown under the same climatic conditions. Figure 1 shows the girth of plants of two clones at 120 cm height during the immature period from 2014 to 2019. Accordingly, the trees of clone RRIC 100 reached the tappable girth of 50 cm early, in six years when compared to PB 86 which reached its tapping stage one year after.

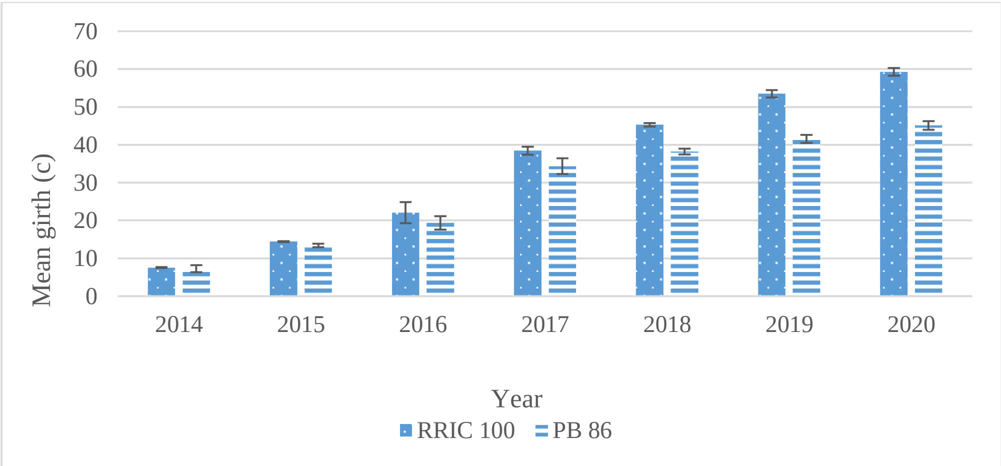

Fig. 1. Mean girth of PB 86 and RRIC 100 from 2014 to 2020

Figure 2 shows the number of trees of two clones in different girth classes. The clone RRIC 100 recorded the highest number of trees in higher girth classes which reached the tappable girth of more than 50 cm at the height of 120 cm from the bud union, earlier. It is also revealed in Fig.1 that the clone PB 86 reached the tappable growth condition at the end of the seven years after planting.

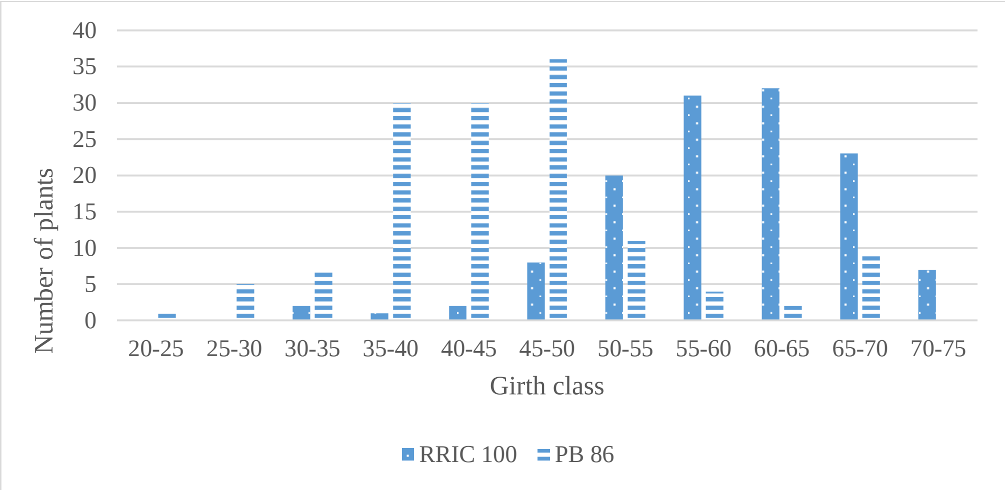

Fig. 2. Number of plants in each girth class of RRIC 100 and PB 86 after seven years of planting

Tapping was commenced in 2021 in both clones after the trees from PB 86 clone reached the tappable girth in 2020 (Fig. 2). Latex was collected according to two tapping systems (*ie;* S/2d2 and S/2 d3) of two clones and tabulated in Table 1. The results in Table 1 indicated that RRIC 100 recorded the highest g/t/t values under both tapping systems when compared to PB 86. The maximum yield per tree per tapping (g/t/t) was received through S/2d3 tapping frequency for both clones. An estimation of the crop was done with 500 trees per hectare and tapping days as 160 and 107 for d2 and d3 tapping systems, respectively to calculate yield per hectare (YPH). The yield of both clones gives the highest values with the d2 tapping system when compared to d3 system (Table 1). However, when comparing the yield variation pattern during the study period, clone PB 86 showed considerably lower YPH than that of RRIC even under the same tapping system and climatic condition (Table 1).

Table 1. *Actual g/t/t and calculated YPH for the clones PB 86 and RRIC 100 under S/2 d2 and S/2 d3 tapping systems*

Clone	Tapping system	Yield (g/t/t)	Yield (YPH)
RRIC 100	S/2 d2	25.4	2028.3
	S/2 d3	28.6	1531.7
PB 86	S/2 d2	11.6	923.5
	S/2 d3	16.3	870.4

According to the results, clones RRIC 100 and PB 86 showed a marked variation in growth and latex yield, especially g/t/t values. The calculated YPH is based on the theoretically possible number of tapping days. But the actual response of a tree is different especially for the frequency of tapping in the long run. Multiplying test tapping data therefore may not indicate the true performance. A long-term evaluation of tapping is required including d1 tapping for both clones for proper understanding of the performance on the yield and the incidence of TPD. Annex 1 attached to this show the morphological differences of the two clones evaluated.

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Annex. 1. *Main Characteristics of clones PB and RRIC 100*

RRIC 100

PB 86

Characteristic feature	RRIC 100	PB 86
1. Tree architecture	Comparatively large trees, medium to tall height. Average girth is 50-55 cm and height is 20-25 m after 5 years of planting.	Comparatively short trees with short to medium height. Average girth is 45 cm and height is 15-20 m after 5 years of planting.
2. Leaf & leaflet characters	Normal elliptical medium sized green-colored leaflets touching each other. Leaves are thick, dull and with an irregular wavy margin	Obovate shaped leaflets are well-separated dark green in color and thick. Dull in luster and with irregular wavy margins.

		
3. Leaf story	Closed canopy with hemispherical shape well-separated leaf whorls	Open canopy with conical-shaped and stories s are well-separated
4. Petiole and petiolule characters	Medium-sized up word orientated petiole with down word petiolule.	Long characterized horizontally oriented petiole with horizontally orientated petiolule.
		
5. Stem	Dark brown colored rough surface (irritated cork layers) develops especially on mature stem	Dark-colored patches are available on the entire stem
6. Growth performance	Vigorous clone in the leading position for yield, growth rate, vigor and resistance to most foliar diseases (Seneviratne, 2020).	Clone shows a low growth rate and comparatively low initial yield, the high thickness of virgin and renewed bark would relate to minimum incidence of tapping panel dryness with considerable latex yield and higher timber volume in the latter part.

7.Yield performance	During the first ten years of tapping, this white latex clone gives about 1624 kg/ha//y dry rubber yield and require proper usage of fertilizer for optimum growth and yield (Attanayeka, 2001).	The average annual yield of the clone is about 1200 kg/ha/y by the end of the third year of tapping (Jayasekara, 1989). It yields white latex with low Mooney Viscosity value (Yapa, 1989).

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ROLE OF SLOW-RELEASE FERTILIZER FOR IMMATURE RUBBER (*HEVEA BRASILIENSIS*)

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Nitrogen (N), Phosphorus (P), potassium (K), and magnesium (Mg) are the major nutrients deficient in most rubber-growing soils and their sufficient availability is necessary to attain maximum growth, especially during the immature phase and sustain high yields throughout the mature phase of rubber. Hence, several fertilizer mixtures were formulated and recommended for ease of their application (Silva, 1971; Yogaratnam *et al*., 1984b; Yogaratnam and Weerasuriya, 1984a). Fertilizer use efficiencies are identified as 30% -60% for N, 15%-20% for P, and 60%-80% for K. Low nutrient use efficiencies not only increase the cost of production but also cause environmental pollution (Bhattacharya, 2019). There is a potential for marked loss of nitrogen, phosphorus, potassium, and magnesium that could occur through leaching and runoff. Moreover, nitrogen could get lost also through volatilization and denitrification (Vrignon-Brenas *et al*., 2019). Other than that, P fixation varies in rubber-growing soils due to the high availability of Fe and Al contents under the low soil pH of rubber plantations (Pushparaj *et al.,* 1975). Therefore, nutrient management of rubber-growing soils has to be done systemically. With the global fuel crisis, prices of inorganic fertilizers have risen sharply. Besides the high cost of inorganic fertilizers, low fertilizer use efficiency, continuous use of inorganic fertilizers, and their consequent negative repercussions have drawn attention to the search for alternative approaches to fertilizer use. There is a variety of strategies available to increase fertilizer use efficiency. All fertilizer recommendations included split application as one of the methods to enhance fertilizer use efficiency. This practice is laborious and labour scarcity and high cost of labour badly affect the proper establishment of these activities.

The use of slow-release fertilizers (SRFs) have been designed to release their nutrient contents gradually to match the nutrient requirement of the plants and are available for plants over an extended period (Sempeho, 2014). This has been widely tried in the recent past as an effective method to enhance crop productivity with fewer environmental concerns. Slow Release Fertilizers (SRFs) can be generally classified into several groups such as low solubility organic fertilizer, low solubility inorganic fertilizer, coated fertilizer, matrix-based fertilizer, etc.

Natural SRFs include organic manures, such as green manure or cover crops, all animal manures (poultry and cow dung), and compost. Owing to their organic nature, they must be broken down by microbes before releasing nutrients to the environment. In general, organic fertilizers may take a long time to release nutrients, and these nutrients may not be available at the time when the plant needs them. The duration of nutrient release of this type of organic fertilizer mainly depends on the soil microbial population which is driven by the soil moisture content, pH, and temperature.

Organic SRFs contain both macro-nutrients (nitrogen, phosphorus, potassium, *etc.*) and micro-nutrients (iron, manganese, copper, *etc.*). The nutrient concentrations of organic SRFs are relatively lower compared to synthetic SRFs. For example, poultry manure contains only 3-2-2 % N, P_2O_5, and K_2O, respectively.

However, slow-release fertilizer research has mainly focused on coated fertilizers. These fertilizers can be physically prepared by coating granules of conventional fertilizers with various materials that reduce their dissolution rates (Shavit *et al*., 2002).

Various materials have been utilized as a coating to slow down nutrient releases and boost fertilizer use efficiency. Most often, slow-release fertilizers coated with plastic resin or sulfur-based polymers slowly break down from water, heat, sunlight, and/or soil microbes. To develop environmentally friendly fertilizers, an effort has been put to utilize eco-friendly coating materials which are naturally available. These natural materials display multiple advantages over synthetic polymers due to their eco-friendly source, low cost, and easily available and biodegradability (Wezel *et al*., 2014; Schneider *et al*., 2016). Chitosan, extracted from crustaceans, sodium alginate extracted from brown seaweed, starch, and its derivatives, cellulose and their derivatives, agricultural residues, biochar, and polydopamine are the materials commonly used in present day context for making environmentally friendly coated slow-release fertilizer types (Chen *et al*., 2018).

Although, SRFs could have more benefits in nutrient use, to date these products are exceedingly expensive. Therefore, the application of SRFs for crops spread over a large area is an expensive operation and will not be practicable. It will be more favorable for a crop with a high market value. Considering above mentioned difficulties and constrains associated with different fertilizer application practices, attempts were made to introduce slow release techniques i.e. Encapsulated Coir Brick (ECB), Reusable Fertilizer Porous Tube (RFPT), and Reusable Fertilizer Porous Bag (RFPB) for rubber plantations.

Encapsulated Coir Brick (ECB)

It is beneficial to use coir dust to produce slow-release type high-value products. The material corncob is also a byproduct of corn production. Recently, it has been utilized for the production of slow-release type fertilizers (Wen *et al*., 2017). Encapsulated Coir Bricks (ECB) have been developed using rubber latex and coir dust as the coating material (Fig. 1a & 1b).

Half of the recommended quantity of inorganic fertilizers were encapsulated with coir dust

Fig. 1a. Encapsulated Coir Brick (ECB)

Fig. 1b. Field establishment of ECB

Further, the high cost of rubber latex increases the production cost of ECB, currently, this preparation is done only with compressed coir dust. Except for advantages with ECB, it automatically applies organic carbon rich coir dust and helps to enhance depleted organic carbon contents in rubber-growing soils. Moreover, ECB is not advisable to use in soils infected with White Root Disease & Cockchafer Grub or it could be used under the condition of disease control.

Reusable Fertilizer Porous Tube (RFPT)

The prepared porous polythene profile with fertilizer and other compounds closed at both ends was named as Reusable Fertilizer Porous Tube (RFPT) (Fig. 2a & 2b).

Filled RFPT with a mixture of half of the recommended quantity of inorganic fertilizer

Fig. 2a. Reusable Fertilizer Porous Tube

Fig. 2b. Field establishment of RFPT

This RFPT can be reused for several years is a special advantage and these porous tubes were prepared by using a mixture of used and discarded rubber products. Due to the price increase of rubber-based porous tubes, the perforated polythene bags were introduced. Comparatively Reusable Fertilizer Porous Bag (RFPB) is very cheap and there is a possibility to cut down the initial cost associated with the purchase of RFPT or ECB.

Reusable Fertilizer Porous Bag (RFPB)

A prepared porous polythene bag with fertilizer and other compounds closed at both ends was named Reusable Fertilizer Porous Bag (RFPB) (Fig. 3a & 3b).

Filled RFPB with a mixture of half of the recommended quantity of inorganic fertilizer

Fig. 3a. Reusable Fertilizer Porous Bag

Fig. 3b. Field establishment of RFPB

Any of these materials were buried in the soil around the base of the rubber plant. The distance should be increased with the age, up to about 100-120 cm at the end of the 5th year to facilitate more nutrient availability for the absorptive zone of the rubber plants.

According to the conventional fertilizer application during the immature phase of rubber, it is recommended 3/4 split applications per year. These fertilizers should be applied around the base of the rubber plant, in a circle, or at 2 to 4 points with light forking. Further, weed control is an accepted practice before fertilizer application. These practices are laborious, and the high cost of labour and labour scarcity badly affect the implementation of this type of essential practices. Further, the unavailability of weedicides and laborious manual weeding practices before fertilizer application indirectly affect the use efficiency of fertilizers. Although ECB, RFPT, or RFPB could be applied only once a year, about 05 applications are sufficient for the total immature phase of rubber (5 years) compared to 20 – 23 applications recommended according to the conventional fertilizer application for the same phase of rubber. Further, this technology helps to reduce fertilizer usage by 50% compared to the conventional fertilizer application which was recommended by the Rubber Research Institute of Sri Lanka (RRISL). It is noted that the establishment of cover crop *Mucuna bracteata* or *Pueraria phaseoloides* with one of these methods: ECB or RFPT or RFPB helps further enhancement of nutrient availability over an extended period which is more beneficial than the conventional form of fertilizer application. Further, the controlled release mechanism associated with these methods releases nutrients slowly equal to the rate required by the plants minimizing the chance of nutrient loss and environmental pollution. In a summary, the benefits associated with the slow-release fertilizer concepts adopted by ECB, RFPT, and RFPB are: (i) one fertilizer application per year leading to reduce labour cost by 75% and (ii) the amount of fertilizer application reduced by 50% minimizing fertilizer wastage and environmental pollution while maximizing fertilizer use efficiency.

Experiments were laid down at several estates to study the effectiveness of these methods on growth and the mineral composition of leaves of immature rubber plants. ECB/RFPT/RFPB were applied once a year and fertilizers for control treatment were applied at three month intervals throughout the experimental period. The below mentioned information is related to the experimental sites in different areas, established with three distinct methodologies: ECB, RFPT, and RFPB.

An experiment was laid down at Elston estate to study the effectiveness of RFPT on the growth of rubber plants. The filling medium was the difference between RFPT type 1 and RFPT type 2 and they contained only 50% of the recommended fertilizer rate. Thirty months after the field establishment of young budding plants, the girth measured at 120 cm above the ground level showed a significant difference between treatments. The RFPT treatments (T2 & T3) gave significantly higher girth compared to the control treatment (T1) and RFPT type 2 gave significantly the highest girth compared to the other treatments (Table 1). Leaf nutrients showed significant differences between treatments. However, RFPT showed a better or comparable performance compared to conventional fertilizer applications. It means plants performed either better or equal to the conventional practice (Table 2).

Table. 1. *Effect of different fertilizer applications on plant girth at 30 months after planting*

Treatments	Girth (cm)
T1 (Control)	15.0^{c}
T2 (RFPT type1)	17.29^{b}
T3 (RFPT type2)	17.88^{a}

Values in the same column followed by the same letter are not significantly different at p=0.05

Table 2. *Effect of different fertilizer application techniques on leaf nutrients at 30 months afterplanting*

Treatments	N%	P%	K%	Mg%
T1 (Control)	2.6^{c}	0.16^{b}	0.805^{b}	0.19^{a}
T2 (RFPT type1)	2.9^{a}	0.18^{a}	0.77^{b}	0.19^{a}
T3 (RFPT type2)	2.8^{b}	0.16^{b}	0.88^{a}	0.21^{a}

An experiment was laid down at Rhigama estate, Horana to study the effectiveness of ECB's on the growth of immature rubber plants. The ECB type 1 and ECB type 2 were prepared by using 50% and 75% of the recommended quantity of fertilizers, respectively. The assessment of plant girth made at the end of 12 months (one year) and eighteen months (1 ½ year) after the commencement of the treatments did not show any significant differences between different forms of fertilizer application treatments (Table 3).

Table 3. *Effect of different fertilizer applications on the growth of immature rubber plants*

Treatments	Plant Girth (cm)	
	After 12 months	After 18 months
T1 (Control)	10.39^{a}	14.54^{a}
T2 (ECB type 1)	10.145^{a}	14.74^{a}
T3 (ECB type 2)	10.545^{a}	14.81^{a}

Values in the same column followed by the same letter are not significantly different at p=0.05.

The present crisis conditions badly affected the above activities as they needed raw materials for the preparation of RFPT and ECB. Hence, modification of the above method as a Reusable Fertilizer Porous Bag (RFPB) was introduced, and it reduced the initial preparation cost by 90% except for the reduction of fertilizer cost by 50%. The initial trial has been established in the Salawa estate and, it maintained the proper condition of plant growth.

Therefore, it can be strongly suggested that it is possible to use a single application of these methods as a substitute for 3 - 4 split applications of conventional fertilizers recommended for immature rubber plants. Reduction of fertilizer cost and labour costs associated with these methods is an important advantage under the condition of skyrocketed fertilizer cost and their unavailability, high labour cost, and their scarcity and hence can be practiced in most of the rubber plantations in Sri Lanka.

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MAMMALIAN PEST DAMAGES AND PROSPECTS OF APPLICATION OF REPELLENT FORMULATION IN SMALLHOLDER RUBBER FIELDS IN THE INTERMEDIATE ZONE: A CASE STUDY IN KURUNEGALA DISTRICT

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Mammalian pest attacks in agricultural lands in Sri Lanka

Incidences of mammalian pest attacks have increased in agricultural lands during the last two decades. This situation has occurred due to the destruction of their living habitats with deforestation. Moreover, the reduction of their food due to planting alien species in the available forest patches. In addition, the neglected agricultural lands act as breeding sites for mammalian pests. Apart from consuming the edible portion of the crops, some pests damage the vegetative parts too. Also, crop losses take place when some animals dig the soil where crops are cultivated. Wild boar, porcupine, monkey, rabbit, samba, deer, bandicoot and wild squirrels are mammalian pests that cause damages to crops.

Mammalian pest attacks in rubber cultivations

In rubber cultivation, economic harvest is not an edible portion of the tree; however, they damage small plants and bark of the immature and mature trees. At present, wild boars and porcupines are the most critical mammalian pests for rubber cultivation, while Samba (*Gona*), Deer (*Olu muwa*), Monkey, Rabbit and Bandicoot are the other possible threatening species (Silva and Thennakoon, 2014). Rubber lands, where tapping has been stopped for an extended period due to low rubber prices and tapper shortage, and uprooted lands, which have not been replanted due to the low rubber price existing for several years, act as breeding sites for the animals. Due to the mammalian pest attacks, farmers are facing problems in agricultural activities, not only with rubber but also with other crops.

Sustainable rubber plantation helps to achieve the optimum yield from the unit land area throughout the economic lifespan. Tree stand per unit land area is one of the critical factors that affect the productivity of rubber cultivation since the loss of trees cannot be recovered until the next replanting cycle. The mammalian pests cause total damages to rubber plants during the first two years. Though it can be recovered through in-filling vacancies during the first two years of planting, it increases the cost of cultivation. Therefore, farmers are reluctant to do replanting in the areas where this problem is prevailing. These animals consume or attack the bark creating wounds in the tree bark. The size of the damage varies from place to place as well as tree to tree. Since they attack the base of the tree, it affects the tapping process. Nevertheless, the removal of bark: (ring bark condition) can cause the death of trees even at the latter part of the immature stage (Silva and Thennakoon, 2016). Therefore, mammalian pest attacks affect the maintaining tree stand as well as healthy trees in the field. According to the farmer's point of view, these attacks increase just before the commencement of tapping i.e. fifth and sixth years after planting.

Different measures have been introduced by the Plant Pathology and Microbiology Department of the Rubber Research Institute of Sri Lanka (RRISL) to manage mammalian pest attacks. At the initial stage, it is recommended to build and maintain a good fence surrounding the land, especially targeting the creatures such as wild boar entering the land. However, this is not an effective measure against the porcupine attacks at which the animals live in the burrows dug within the land premises. Using a mesh covering the plant is also recommended to protect the plants at the initial stage. Though the farmers have to spend a high initial cost for materials and labour, the mesh can be used for several years. Cover the base of the plants (up to 3 feet from ground level) using polythene is the other method that can be used to protect the trees. This is a low-cost method compared to covering with mesh, but the effective duration is low. In addition, farmers also practice some techniques to control Mammalian pests using their indigenous knowledge and experience. Some farmers apply different material based on the availability as physical excluders for these pests. Smallholders use mixtures of clay, cow dung, chilli powder, wood ash and household ash to repel the pests. However, some of these mixtures may cause infections in trees and also these can be washed off easily with the rain.

Mammalian pest repellent formulation

Plant Pathology and Microbiology Department, RRISL has introduced a mammalian pest repellent to overcome mammalian pest attacks, especially for the wild boars and porcupines. The repellent was developed using Tetramethyl Thiurum Disulphide (TMTD), and several other chemical components (Jayasinghe *et al*, 2010). Application of repellent formulation is recommended for trees of more than two years of age or plants with brownish stems, as phytotoxicity is caused when the formulation is applied on the stems of younger plants. It helps to protect the field without damaging the tree bark by repelling mammalian pests. The repellent formulation should be applied on the bark in a two feet height at the base of the tree. This has been tested in rubber fields in the Wet Zone (WZ) and has shown successful results. However, repeated application is needed due to the degradation of chemicals with sunlight and washout due to heavy rains. According to the results in the WZ, the repellent should be applied at a three-month interval and the retention period has been identified as a feature to be further improved. Thus, the retention period is more or less related to the climatic conditions in the area, and the application frequency varies accordingly. Since the climatic conditions in the Intermediate Zone (IZ) are different from those of the WZ, it is necessary to identify the application frequency for the zone. Especially, it can be expected that a reduced application frequency would be viable, if it is carried out after the major rainy spell of the region. Moreover, it is a general observation in the WZ that the mammalian pest attacks are reduced with the commencement of tapping, however, it was needed to test to assess the reliability of that observation under the conditions in the IZ. Therefore, the study was carried out with the following two objectives.

Objectives of the study

The two main objectives of the study were to identify whether the timely application of the mammalian pest repellent could reduce application frequency in the IZ and to identify whether there is any reduction in mammalian pest attacks with the commencement of tapping in the IZ.

Study area

Alawwa and Polgahawela Rubber Development Officers' Divisions (RDO Divisions) of the Kurunegala district were selected for the study representing the IZ of the country. In the area, Mammalian pest attacks were very high on rubber cultivations and other crops as well. In rubber, farmers experience direct harvest losses and indirect yield losses due to damaged bark. The most common mammalian pests found in the area were wild squirrels, wild boars, porcupines and monkeys, while wild boars and porcupines were the pests that harm rubber plantations. Four fields were selected to carry out the experiment related to the first objective. Out of them, one field was within the Polgahawela RRISL Sub-station premises, while the other three were smallholder rubber fields (Table 01). Another three smallholder fields at the onset of tapping were selected to achieve the second objective (Table 02). All the smallholder fields were located around the Polgahawela Sub-station.

Details of the study sites

Table 1. *Details of the study sites used to identify the effective application frequency of the repellent formulation*

Field	Planting year	Clone
Smallholder field 1	2015	RRISL 203
Smallholder field 2	2014	RRIC 121
Smallholder field 3	2012	RRIC 121
Polgahawela Sub-station field	2012	RRIC 121

Table 2. *Details of the study sites used to assess the relationship between the incidence of mammalian pest attacks and commencement of tapping*

Field	Planting year	Clone
Smallholder field 1	2009	RRIC 121
Smallholder field 2	2010	RRIC 121
Smallholder field 3	2011	RRIC 121

Rainfall pattern in the area

Since all the selected rubber fields are located around the Polgahawela sub-station, the rainfall data of the Polgahawela Sub-station recorded using a non-recording type rain gauge, were used to identify the rainfall pattern. Monthly average rainfall values were calculated using ten-year-average data, and the graph was plotted using the monthly average values (Fig. 01). According to the graph, a bimodal rainfall distribution pattern was observed, with two peaks during the April - May and October - November monsoon periods. During January and July, two suppressions in rainfall were observed.

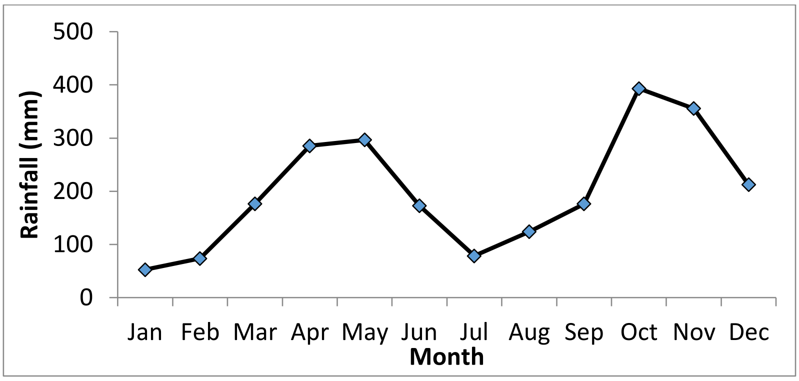

Fig. 1. Monthly rainfall pattern in the area (average of ten-year rainfall data)

a. Application of mammalian pest repellent

Sixty trees were selected for application of the mammalian pest repellent in each field, and the same number of trees were kept as the control (without applying the repellent). Application of repellent formulation was carried out during early January, where a suppression of rainfall was observed at the end of the major rain spell of the area ('*maha*' season). Damages were recorded in six-month intervals in treated and untreated plots. Before the application of repellent, a pre-damage assessment was carried out (table 03).

Table 3. *Pre-damage assessment of the study sites*

Field	Percentage of trees with mammalian pest attacks (%)
Smallholder field 1	12
Smallholder field 2	20
Smallholder field 3	39
Polgahawela Sub-station field	89

Damage assessment after the application of the repellent formulation

Data collection was carried out on the number of trees damaged by mammalian pests for the study period and the percentage of damaged trees was calculated using gathered data. The damaged tree percentage for the six months is given in table 4.

Table 4. *Damage assessment after the application of repellent by six-months interval*

Field	Trees damaged by mammalian pests (percentage)					
	Treated			Not treated		
	Application to 6 months period	6 -12 months after application	12-18 months after application	Application to 6 months period	6-12months after application	12-18 months after application
Smallholder field 1	0	8	5	5	10	4
Smallholder field 2	0	17	8	10	12	10
Smallholder field 3	0	33	15	13	35	18
Polgahawela Sub-station Field	0	8	10	5	8	10

No mammalian pest damages were reported in treated plots during the first six months after applying the repellent. However, trees in non-treated plots have been attacked during the period. Wilcoxon (Man-Whitney) Rank Sum Test was performed to investigate whether there is a significant difference in the percentage of damaged trees in treated and non-treated plots during the first six months after the application (Table 5). According to the results, there is a significant difference between treated and non-treated plots. The same test was used to assess the situation in two consecutive periods; during the second six months and the second year. Results revealed that there is no significant difference in treated and non-treated plots during the second six months and the second year after the application of repellent. Therefore, it can be concluded that the effective period of repellent application is six months for the IZ. According to the rainfall pattern, two peaks are observed with highest and second highest rainfall in the months of October and May, respectively. January and July show the depressions of rainfall in the area (Fig. 01). Hence, in order to attain a longer retention, these two months can be considered suitable for repellent application.

Table 5. *Results of the Wilcoxon (Man-Whitney) Rank Sum test*

Period	**z value**	**Probability > |z|**
During 1st six months after application	2.477	0.0132
During 2nd six months after application	0.296	0.7674
During the second year	0.296	0.7674

Tapping commencement and mammalian pest attacks

Damages due to mammalian pest attacks were recorded in the selected three fields, and an initial damage assessment was carried out in December, 2017. As in all three fields tapping was initiated in 2018, and damage assessments were carried out at the end of 2018 and 2019.

Table 4. *Percentage of damaged trees before and after the commencement of tapping*

Field	Percentage of damaged trees (%)		
	2017	**2018**	**2019**
Smallholder 1	95	1	0
Smallholder 2	87	6	0
Smallholder 3	75	0	0

With the commencement of tapping, mammalian pest attacks have reduced in the tested three fields. The most probable reason would be increased human activities associated in such fields. However, damages in tapping fields are also reported in some occasions.

Conclusions

The application frequency of the repellent formulation can be reduced to two times per year in the IZ if applied in the months of January and July. Further, with the commencement of tapping, a reduction of damages could be observed with the increasing human activities in the field.

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ETHEPHON (2-CHLOROETHYLPHOSPHONIC ACID) AS A YIELD STIMULANT IN *HEVEA*

K V V S Kudaligama

The first commercial plantation of rubber in Sri Lanka was established in 1883 and within a few years it rapidly expanded. Over the years many exploitation techniques have been introduced to enhance yield outputs. Low Intensity Harvesting (LIH) systems evolved with various combinations of cut lengths, frequency of tapping, and stimulation techniques become the driving force to investigate more cost-effective technologies in production. LIH systems are only possible with a suitable stimulant to achieve comparable yields to that of conventional tapping *i.e.* S/2 d2 system. A wide spectrum of chemical compounds including ethylene generating compounds, auxins, auxin analogues, herbicides, inorganic salts, *etc.* was tried as yield stimulants. Few of them were ethylene generators and other compounds are more or less phytotoxic and induce endogenous ethylene production. Ethephon (2-chloroethyl phosphonic acid) was found superior to all the chemicals tried out and even today ethephon is the only stimulant used in commercial application. Hence, nowadays ethephon has become an essential chemical component used in the exploitation of *Hevea* latex.

The physiological processes behind the yield enhancement due to stimulation are still not fully understood. Generally, stimulants are known to enhance yield by increasing the rate and duration of latex flow. Many researchers stressed that the objective of stimulation must not be to obtain a yield more or less equal to that of the control system (*i.e.* S/2 d2), without any baneful secondary effects. Judicious application of ethephon with correct harvesting systems may only give long-term sustainable yields.

Ethephon as a yield stimulant

Ethephon is widely used as a ripening accelerator in the pre and post-harvest of fruits, yield stimulant of *Hevea,* enhance female flowering of Cucurbitaceae, *etc.* Ethephon is a whitish solid that is readily soluble in aqueous solutions. It is found to be the most effective nongaseous ethylene-releasing chemical (Hunter *et al.*, 1978). The active ingredient is mixed with an inert material *i.e.* methylcellulose, starch, palm oil or a mixture of such materials, to make it more viscous and marketed under several brand names *i.e*. Ethrel, Ethephon, Ethephon plus and Livotex, *etc.* These mixtures are available in 2.5, 5 and 10% strength of the active ingredient and as water based and oil based formulations.

Method of application

Ethephon is applied either on the bark, panel, or groove of the tree. In bark application corky layer of the bark just below the cut is scraped carefully without damaging the latex bearing tissues. Peak yields have been reported within the first ten tapping days after application (Paardekooper, 1989). The main disadvantage of the bark application is the cost of scraping. In panel application, ethephon is applied on the renewing bark just above the tapping cut avoiding the tree lace. This method is more popular as it is less labour intensive. The groove method was introduced by P'ng *et al.* (1973) in which a thin layer of ethephon is applied with a small brush to the tapping cut after removing the tree lace. Response to stimulation is highest in panel application followed by bark and groove application (Gireesh *et al*., 2005). The reason for this may due to the effective absorption of ethephon when contact with growing tissues in the panel area (Abraham *et al.,* 1971). Sethuraj *et al.* (1977), found that stimulation of many separate patches up to the branches enhance yield by extending the drainage area. The application of long vertical bands was also reported to be very effective. But due to the practical difficulties, these methods were not popular among the growers.

Generally, low concentrations are recommended for the trees that are being tapped on virgin bark whilst the higher concentrations are recommended for trees tapped on renewed bark and during intensification. However, the application frequency and the concentration depend on the intensity of the tapping system used. Dilution of ethephon with warm water (*ca.* 50 °C) to get the desired concentration should be avoided every time as this could not be done correctly in the field. On the other hand, ethephon reacted readily once mixed with water evolving ethylene leading to reduction of active ingredient concentration in the mixture.

Biochemical and physiological status behind ethephon stimulation

Ethephon is a plant growth regulator with systemic properties, penetrates the plant tissues, and is translocated and progressively decomposed to ethylene (Anon, 1987), which is a kind of plant hormone that affects the biochemical and physiological status of the tree resulting high in yields. Sivakumaran (1982) showed the interval of about 12 hrs. between application and first tapping is sufficient for the absorption of the stimulant. However, highest yield will be given after 96 hrs. from the application (Kudaligama *et al*., 2014).

With the presence of water, ethephon decomposes in the tissues releasing ethylene (Equation 1), a plant hormone which acts as the yield stimulant.

$$Cl\text{-}CH_2\text{-}CH_2\text{-}PO(OH)_2 + H_2O \rightarrow CH_2{=}CH_2 + HCl + H_3PO_4$$ ----- Equation 1

Ethephon does not totally decompose in to by-products mentioned in the above equation, but a certain amount metabolizes in to volatile products in the tissues (Audley *et al*., 1976a). Over 20% of the ethephon applied is converted to β-D-glucopyranose-1-(2-chloroethylphosphonate) and later this compound releases a considerable amount of ethylene through an enzymatic reaction (Anon, 1977).

Ethylene is thought to enhance latex production by delaying the plugging of latex vessels (Abraham *et al*., 1971). Both initial flow rate (de Jonge, 1955) and duration of flow (Ho & Paardekooper, 1965) increased after stimulation. Researchers commonly accept that the increase of yield is mainly due to an extension in drainage area (Pakianathan, *et al*., 1976).

The massive outflow of latex induced by stimulations leads necessarily to an increase in the anabolic activities in the cells and specially biosynthesis of rubber and of proteins involved in this renewal (d'Auzac, 1989). Tupy, (1973) explained that a rise in latex pH after stimulation results in an increase in invertase activity which intensify mobilization and transportation of sucrose towards vessels where regeneration of latex and metabolism is activated.

Response to climatic condition

Rubber trees showed good response to stimulation in wet areas than in dry areas (Kudaligama *et al*., 2010; Rodrigo *et al*., 2010). Njukeng *et al*., (2011) showed that the number of insolation hours and the mean daily temperature were not directly correlated with yields in stimulated trees. Response to chemical yield stimulation was found to be influenced by the cumulative rainfall and soil moisture, especially during the months preceding stimulation (George and Jacob, 2000).

Long term effects of Ethephon stimulation

Latex production is closely dependent on climatic conditions and particularly on the availability of water in the soil, relative humidity and the temperature. During dry seasons and refoliation, negative response to stimulation has been observed. Under poor conditions of water, supply stimulation may not only be ineffective but harmful to the tree.

Response of yield to initial applications of ethephon is always greater than in subsequent applications and commonly lessens with time. Reduced sucrose levels in latex has also been observed in trees subjected to repeated stimulation and this has been described as one of the reasons for falling response to the stimulant (Tupy & Primot, 1976). Much greater discharge of minerals from the tree will result in a decrease in the volume of assimilatory roots and foliar surface (Haridas *et al*., 1976). Reduction of sucrose, quebrachitol, and other cyclitols in latex markedly reduced turgor pressure of laticiferous tissues in long term stimulation. Electron microscopic studies have revealed an increase of stone cells in the soft bark and partial emptiness of latex vessels of stimulated trees (Pakianathan *et al*., 1982).

The dry rubber content of latex in stimulated trees is lower than that of unstimulated trees even they are tapped under the same frequency. The incidence of dryness is generally higher in stimulated trees (Sivakumaran *et al*., 1981). Girth increment has been reported to be negatively affected by stimulation (Abraham *et al.*, 1975). Properties of raw rubber do not affect significantly when stimulation with recommended dosages of ethephon

Numerous external and internal factors play a role in the response of *Hevea* to stimulation and dangers are inherent in misuse of the stimulant. Optimum yields in ethephon based harvesting systems could be assured when the frequency and the concentration of stimulant applied modulated as a function of the clone, age of the tree, and tapping system (Sivakumaran, *et al*., 1982). For long-term sustainable yields stimulation protocols should be adopted about the clone, the prevalent eco-climatic conditions, and the intensity of exploitation of the tree.

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WAITING FOR 30 YEARS TO REPLANT RUBBER; IS IT JUSTIFIABLE UNDER SRI LANKAN SITUATION?

E S Munasinghe and V H L Rodrigo

If someone ask what the economic lifespan of rubber cultivation is; obviously the answer would be 30 years. This is based on the traditional expectation that we leave initial six years for the immature phase and then tapping for 24 years in four major based panels, usually six years in each panel. With the recommended bark consumption (1.25 mm per tapping), if the traditional half spiral alternate day tapping (S/2 d2) is practiced, both virgin and renewed barks would be consumed by 24 years. Due to any reason, if bark has been fully utilized before 30 years, that would end the tappable lifespan of the tree warranting replanting. In low frequency tapping, number of tappings per tree is greatly reduced; hence each panel can be tapped for more than six years extending the lifespan of the tree. For instance, should S/2 d4 tapping (tapping half spiral once in four days) be practiced throughout, rubber tree could be kept over 50 years (Rodrigo *et al.*, 2011). Forget the renewed bark tapping, even virgin bark tapping could be practiced over 30 years with S/4 d3 (Rodrigo *et al.*, 2012). Accordingly, lifespan can be extended, if bark could be left with whatever tapping system. In other words, the lifespan depends on the bark availability. Obviously, rubber has a bark-based lifespan and not really the economic/financial lifespan!

Economic lifespan should be decided in national perspective. However, commercial rubber growers are more concerned on financial profitability. Hence this paper discusses the financial lifespan of rubber. In deciding the financial lifespan, several factors need to be considered, *i.e.* variation in rubber price, gradual decline in yield potential with age and the cost of production (COP). High level of uncertainty exists in rubber price and also there is a temporal variation in tree stand. In addition to the cost involved in inputs, COP varies with the management system and productivity. For instance, there is a huge difference in COP between the large scale planation sector and the smallholder sector. Such complexity has also driven for the protocol of deciding bark based lifespan.

Nevertheless with entrepreneurship angle, one who expects to cultivate rubber would be interested in knowing whether it is financially viable to keep rubber trees for 30 years or what would be the corrective measures to be taken for an extended lifespan. With this objective in mind, we used the data available on variation of yields with age under average growing conditions together with associated factors (Munasinghe *et al.*, 2014) and the prevailing market prices of commodities relevant to rubber cultivation (Table 1).

Table 1. *Market prices of major commodities used for the financial analyses*

Item	Unit	Unit cost/value (LKR)
Rubber price	Kg	500.00
Timber biomass	Tree	At 30 years 3500.00 (2% year on decrease if lifespan is shortened)
Labour rate	Labour day	1000.00
Planting material	Rubber plant	120.00
Fertilizer	Kg	350.00

The financial tools such as Net Present Value (NPV), Benefit:Cost Ratio (BCR) and Internal Rate of Return (IRR) was used for evaluation. With high level of initial investment during the six year gestation period for yielding, a lifespan shorter than 18 years can never be expected and so, a series of stepwise year on analyses were performed for the lifespans of 18 to 30 years at a discount ratio of 10%. As presently practiced, there is a possibility to intensify the tapping for high yields at any stage with a view to shorten the lifespan below 30 years (Munasinghe *et al.*, 2018). Nevertheless, intensification during latter years of rubber cultivation was adopted in this analyses. Yield profile used for the analysis is shown in Figure 1. Values up to 24 years were obtained from estate level records (Munasinghe *et al.*, 2008) whilst yield records for the last six years were based on the schedule adopted in gradual intensification in Dartonfield Estate of the RRISL. Accordingly, at the intensification of a given lifecycle, it was assumed to have a 25% tree level yield increase from the last normal tapping year (*i.e.* 24th year in the case of baseline scenario of 30 years, 23rd year in 29 year lifecycle and so forth up to 12th year in the shortest lifecycle of 18 years) for three years, 15% increase from the 3rd year of intensification for the next two years and then additional 15% from the 5th year of intensification for the last year.

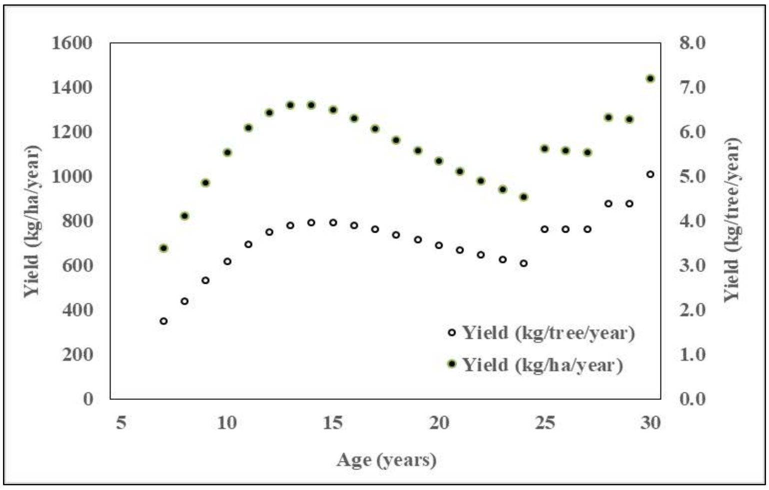

Fig.1. Yield profile of the rubber tree with the last six year intensification schedule under the baseline scenario.

Under the usual situation (*i.e.* the baseline scenario of 30 year lifespan with the intensification schedule for last six years), the NPV happened to be LKR 0.21 Mn/ha with the values for BCR and IRR 1.9 and 11.5%, respectively. However, with a reduction in lifespan up to the age of 18 years whilst keeping last six years for intensification, NPV increases at a rate of LKR 0.02 Mn/ha per year. Accordingly, the discounted highest profit of LKR 0.32 Mn/ha was recorded with 21 year lifespan. In addition to NPV, BCR and IRR also improve as 1.98 and 12.3%, respectively with the shortening of lifespan up to 21 years.

In the above analyses on existing situation in plantations, tree stand at 21 years was considered to be 305 trees per hectare taking into consideration of a gradual decline up to 285 trees per hectare in 30 years (Munasinghe *et al.*, 2014). Annual average decline of tree stand during this ten year period has been 0.75%. Maintenance of greater tree stand is feasible under good agro-management practices. However, there could be natural causes of deaths and about 1-2% annual loss of trees is expected in forestry related projects (UNFCCC, 2022).

In view of identifying the plausible factors for the reduced financial lifespan, the above analyses were repeated under scenario of the best management practices (expected situation) where 400 trees remain at 30 years of age. Although overall profit (i.e. NPV at 10% discount rate) of rubber cultivation increased up to LKR 1.17 Mn/ha at 30 years, it also showed a gradual increase up to a maximum of LKR 1.25 Mn/ha at 22 years of age (Fig. 2). Moreover, IRR appreciated from 16.7% at 30 year lifespan to the highest at 21 years *i.e.* of 17.2%. Further, BCR value of the best expected stand was 2.45 at 30 years which increased to its highest of 2.56 at 21 years. It means that correct tree stand improves the overall profitability, but still has not much effect on the best lifespan.

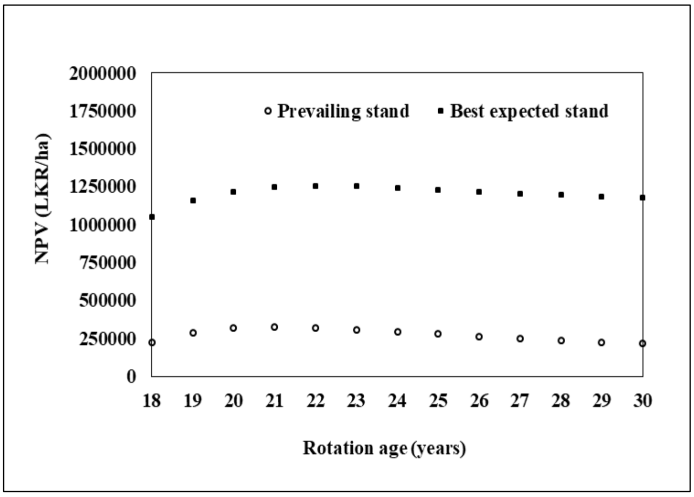

Fig. 2. Variation in the Net Present Value (NPV) along with the changes in the lifespan of rubber cultivation under the prevailing stand and the best expected stand. At any lifespan, intensification of tapping during the last six years has been adopted.

Fluctuation of rubber price over the time is found to be a common market phenomenon. In order to assess its effect on the lifespan, the analysis was repeated with the increase in rubber price by 10%, 15% and 25% and decrease of rubber price by 10% and 15% from the present price. Obviously, any increase in rubber price increases the NPV (at 10% discount rate) and *vice versa* at any given lifespan. Nevertheless, the highest NPV for any given price increase or decrease, was recorded as LKR 0.59 Mn, LKR 0.72 Mn and LKR 0.98 Mn for the increase in rubber price by 10%, 15% and 25%, respectively with a lifespan of 21 years (Fig. 3). Similarly, the highest levels of IRR and BCR were also recorded for 21 years i.e. 14%, 14.7% and 16.1% for IRR and 2.15, 2.23 and 2.4 for BCR with the increase in rubber price by 10%, 15% and 25%, respectively. Rubber cultivation was viable only up to 25 years if the price declines by 10%.

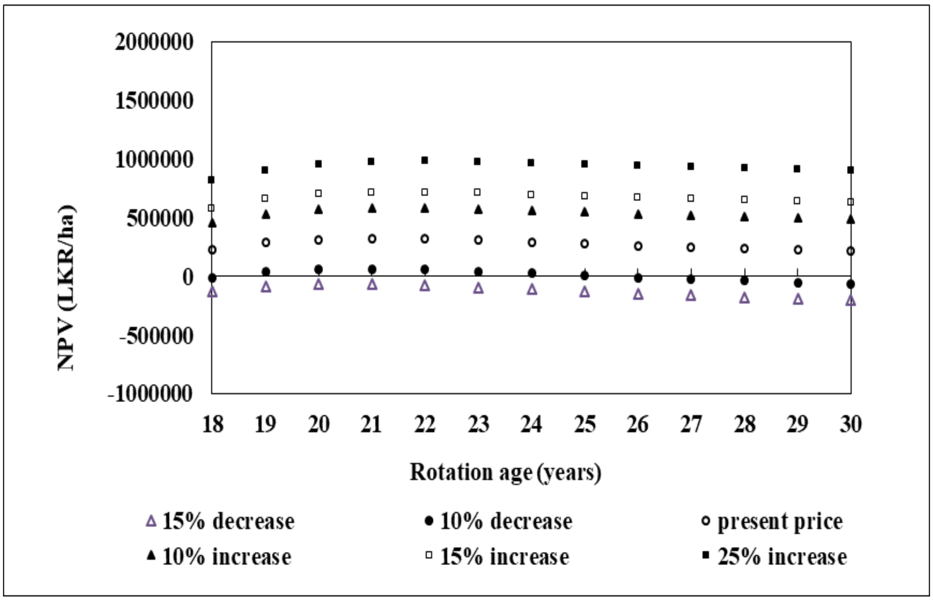

Fig. 3. Sensitivity of financial viability to variation of rubber price under different lifespans of rubber cultivation.

Frequent wage hikes have been experienced over the recent past affecting the cost of production (COP). Therefore, financial viability of rubber cultivation with the increase in daily wage by 10%, 20% and 30% from the present wage was also considered in identifying the best lifespan. The NPV (at 10% discount rate) of rubber cultivation at any lifespan remained positive in 10% wage increase with the highest value of LKR 0.22 Mn recorded with 20 year lifespan. With 20% wage increase, rubber cultivation was viable only at 19-21 year lifespans. If the wage rate increases above that level, rubber cultivation remains unprofitable (Fig.4).

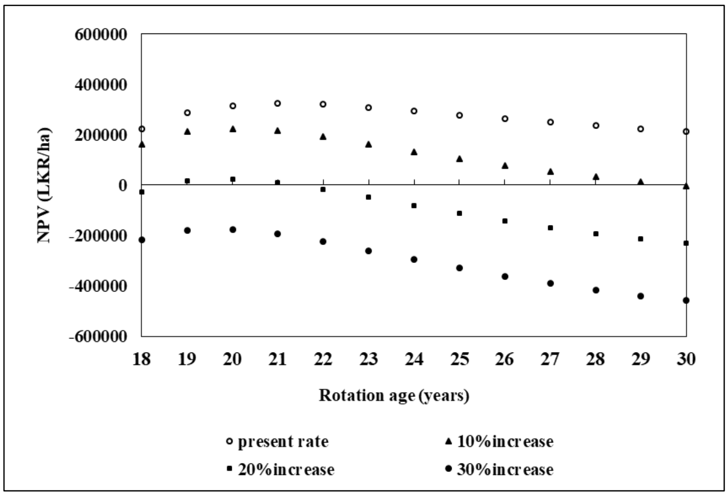

Fig. 4. Sensitivity of financial viability in rubber cultivation to wage rate increase under different lifespans.

The assessment of the impact of tree yield on the financial lifespan was the next attempt. In the yield profile used, yield per tree per year (YPT) tends to decline after 14 years. Under good management practices, this may not be the case; hence, analyses were done with two scenarios, *i.e.* 1) constant YPT after 14 years till the intensification and 2) YPT from 14 to 18 years remains constant and then declines by 13% till intensification as indicated by Nugawela (2002). Both scenarios are alike for the lifespans up to 24 years due to last 6 year intensification schedule and YPT decline matters only for the lifespans thereafter.

Under both scenarios, NPV (at 10% discount rate) increased with the increase in the lifespan (Fig. 5). Other financial profitability indicators (i.e. IRR & BCR) also behaved similarly. This shows the importance of yield pattern in deciding the most profitable lifespan and in particular, the need for preventing yield decline to achieve the agronomic lifespan of 30 years or more. Except the yield determining factors (*i.e.* tree stand and YPT), all other variables used in this analyses (rubber price and wage rate) remained constant throughout; hence had no influence on determining the financially best lifespan despite their effect on the profitability level. Among the yield determining factors, the tree stand declined with time; However, its effect has not been substantial to change the financially best lifespan. Therefore, the key factor for deciding the financially best lifespan happened to be the YPT.

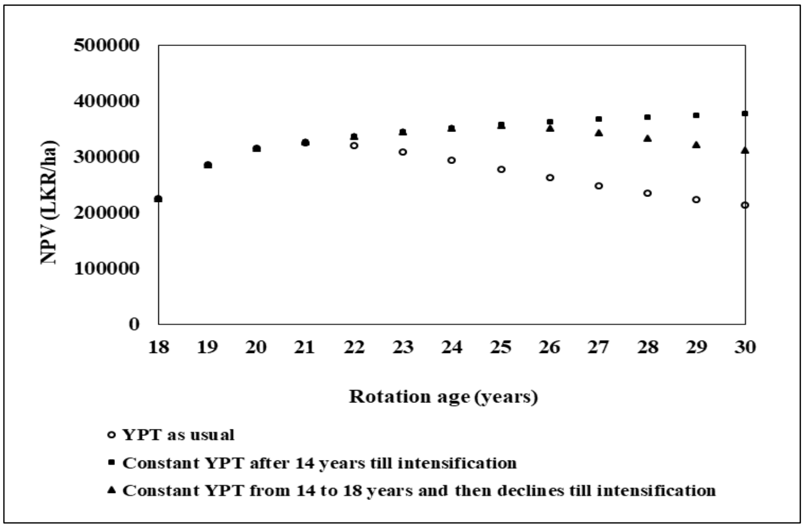

Fig. 5. Variation in the Net Present Value (NPV) along with the changes in the lifespan of rubber cultivation under different yield per tree per year (YPT), (*i.e.* YPT as usual, constant YPT after 14 years till the intensification and constant YPT from 14 to 18 years and then declines as usual till intensification.

The yield profile used for YPT initially would depict the common situation of rubber plantations where high level of bark consumption prevails as shown by Silva *et al.* (2012). This situation results in consuming the virgin bark earlier than expected and so, casual undertaking of tapping on renewed bark in early stages becomes unavoidable. This would be the principal reason for decline of YPT after 14 years. Under such a situation, early replanting at about 21-22 years becomes financially attractive. If YPT can be maintained without any drop, obviously the extended lifespans are financially worthwhile.

Despite the effect of key financial influences (i.e. rubber price and wage rate) and production parameter (*i.e.* tree stand) on the overall profitability of rubber cultivation, the most crucial determinant of the lifespan happened to be the tree yield. Therefore, maintenance of tapping quality which sustains the tree yield throughout is in high importance if expected 30 year lifecycle is achieved profitably. Nevertheless, the present analyses cannot be applied to the situations where a person possesses a rubber property and decides on whether tapping to be continued or land replanted since the investment up to the particular time point is ignored. Further, changing the harvesting policies with the change of rubber price is not implicated here. However, this indicates the practicality in intensified tapping during high price periods. Considering the boom bust cycle of rubber price which lapses for about 20 years with 8-14 years in each phase, replanting at early stages of low rubber price seems to the best approach to reap the maximum financial benefits.

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