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COMPREHENSIVE OVERVIEW OF THE CLONE RRISL 2001

K K Liyanage

INTRODUCTION

With the introduction of hybridization techniques into the rubber breeding programme in the year 1932 by Dr. C.E. Ford, a large-scale hand pollination programme was initiated to cross high yielding genotypes with disease-resistant characters to achieve high growth vigour in the population **(**Murray, 1940). From 1957, onwards, attempts have been made to combine the high yielding clones in the past such as; PB 86, PB 28/59 and RRIC 7 with the vigour and leaf disease resistance of RRIC 52. As a result, vigorous and high yielding clones, for instance, RRIC 100, 101, 102, 103 and the germplasm materials were added to widen the genetic diversity of *Hevea* breeding pool (Baptist, 1966; Fernando, 1966). Later, those high yielding clones were combined with each other to develop some exceptional clones. The hybridization and clonal selection process have resulted in the release of numerous outstanding *Hevea* clones (Liyanage, 2007; Liyanage, 2016a). With that objective in mind, the heterogeneous seedling population produced by the hybridization programme in the year 1976 (76 HP) was evaluated at the nursery level. The selected hybrids are cloned and evaluated in a phased manner in Small Scale Clone Trials (SSCT), large-scale in Estate Collaborative Trials (ECT) and in different agro-climatic regions to observe their adaptability to that particular environment. During this evaluation process, RRISL 2001 (HP 76-52) was recognized as a very promising clone with good raw rubber and timber properties for both estate and smallholder sectors (Jayasekara & Fernando, 1977).

Clone selection process

In the 1976 HP program, a total of 8198 pollinations were made within the 25 different crosses, and 248 seedlings were obtained. The total number of seedlings obtained was planted in a fully randomized design (Fernando, 1976) and screened for their yield potential and vigour. The tree diameter, petiole latex content and micro tapping yield were used as selection criteria. Fifty two (52) promising seedlings were selected from the total population. The selections were multiplied in bud wood nurseries prior to the establishment of small-scale clone trials (Fernando, 1980; Jayasekara, 1981; Jayasekara, 1982).

Parentage and the characters of the parents

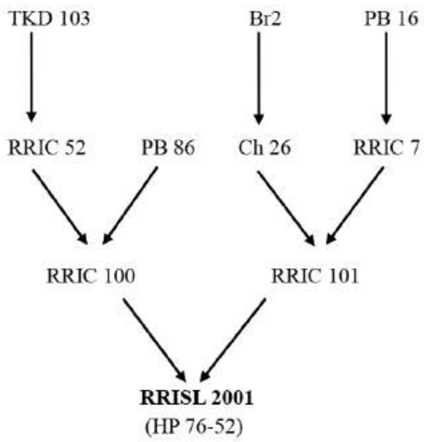

Fig. 01. Pedigree of the clone RRISL 2001

Clone RRISL 2001 was an outcome of a cross between two promising clones RRIC 100 and RRIC 101 as the female parent and male parent, respectively. Parents possess good latex and timber properties as well as improved disease-resistant characteristics. The clone RRIC 7, RRIC 52, PB 86 and Ch 26 are the grand parentage, and they are the most promising clones in very early selection stages. Therefore, clone RRISL 2001 possesses high yield, vigourous growth and some important disease-resistant features transmitted from both parentages and grand parentages (Liyanage, 2008; Liyanage, 2016a).

Yield data of Small Scale Clone Trial (SSCT)

Twenty-nine (29) selections from 1976 HP seedling progeny were established in 1985 in small-scale clone trials at the Tempo division of Hill-stream State Plantation. The selections were planted in a randomized complete block design with four replicates to evaluate their yield, vigour and disease resistant performances. The clone RRIC 100, RRIC 102, RRIC 103 and RRIC 121 were used as control clones (Jayasekara, 1985). Within five years *i.e.* in 1990, more than 60% of plants attained the tappable girth with an average of 54.3cm. However, tapping commenced in 1992 and panel A was tapped until 1996 and then panel B was open for tapping and continued till the year 2001. Average yield and girth data recorded for the HP 76-52 (RRISL 2001) and the control clone RRIC 121 in the trial during the first ten years period were in Table 1. Girth measurements recorded in this trial showed that HP 76-52 had almost similar growth as in the better performing control clone RRIC 121 (Jayasekara, 1989).

Table 1. *Average yield and the girth of the clone HP 76-52 (RRISL 2001) and control clone RRIC 121 during the immature stage and over ten years of tapping*

Year	HP 76-52 (RRISL 2001)		RRIC 121 (Control clone)	
	Girth (cm)	Yield (g/t/t)	Girth (cm)	Yield (g/t/t)
1992	58.2	48.3	59.5	48.7
1993	67.5	38.3	68.2	34.4
1994	74.8	65.2	77.7	52.8
1995	77.5	63.4	80.7	57.5
1996	82.3	58.0	84.1	59.9
1997	83.0	75.8	87.2	70.8
1998	86.5	63.7	90.0	72.0
1999	86.7	75.6	91.0	80.0
2000	88.4	73.7	94.5	70.7
2001	90.6	49.8	96.7	51.5

* TPD: Tapping Panel Dryness

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

ECT trials were established in Pallegoda Estate (1994), Nivitigalakele (2001) and Dorset Division of Clyde Estate (2004) to evaluate the performance of the selection HP 76-52. Data have shown that HP 76-52 is a promising clone for large-scale testing, and therefore, it has been registered as the clone RRISL 2001(Attanayake, 2000). The commercial yields obtained from ECT trials are given in Table 02. Incidences of Tapping Panel Dryness (TPD) in each location were comparatively low and was around 15%.

Table 02. *Average girth and the commercial yield of the clone RRISL 2001 in ECT at Pallegoda Estate (1995)*

Year	Girth (cm)	Yield (g/t/t)
1996	11.5	-
1997	21.6	-
1998	34.8	-
1999	46.3	-
2000	51.5	-
2001	53.2	36.9
2002	54.4	30.7
2003	56.5	41.5
2004	58.7	31.9
2005	61.0	29.8
2006	63.1	36.2
2007	65.3	32.5
2008	66.3	32.6
2009	66.8	35.5
2010	67.3	36.5
2011	68.1	29.4

No. of trees planted: 272
No. of trees tapped: 250

The yield data of SSCT indicated the average experimental yield of the clone which was around 61.2g per tree per tapping (g/t/t), and it is a high value when compared to the other clones in the same trial. However, the average commercial yield at ECT level was 34.0g per tree per tapping, and it was almost half of the value that we could obtain from the clone with proper management practices. Figure 02 depicts the relationship between the experimental yield and the commercial yield of the clone during first ten-years. It is observed that a considerable yield drops in the second year of tapping and is common for both experimental and commercial yield in two locations. Therefore, we can consider that, it is a clonal characteristic and planters were able to manage this yield drop to maintain the clone RRISL 2001 in healthy. In Figure 02, the differences in the yield at the experimental and commercial level are an eye-opener to the planters to re-consider their management practices adopted to maintain plantations in a cost-effective manner.

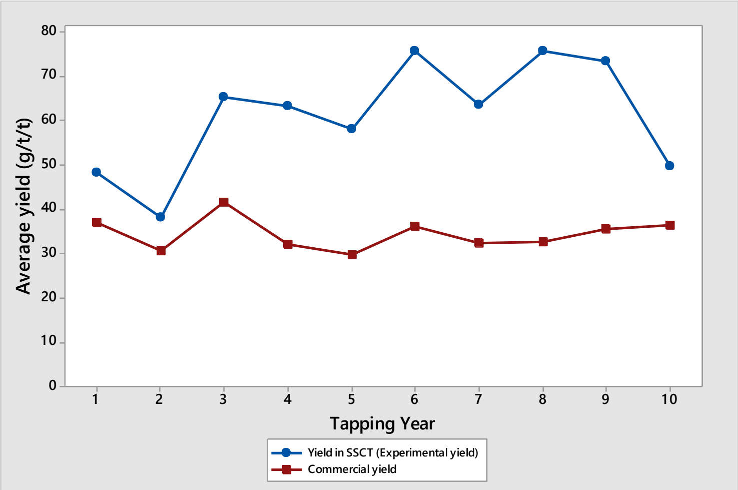

Fig. 02. Average commercial and the experimental yield of the clone RRISL 2001 over 10 years of tapping

The monthly variation in yield of clone RRISL 2001 and the control clone RRIC 121 over a ten year period in SSCT (Fig. 03) showed that February to May was the lean period with a sharp drop in yield below the average in the month of April. 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). The yield was found to peak in the month of July and later attained a higher peak in the month of November with varying yield increases within this period. Both clones showed a more or less similar variation in yield over the months indicated that it constitutes clonal characteristics. Therefore, the monthly variation in yield is very important in the establishment of any sampling procedure to estimate annual yields.

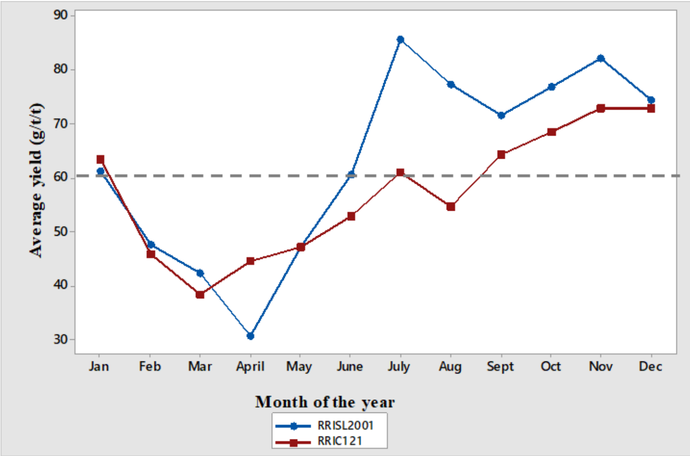

Fig. 03. Monthly yield variation of clone RRISL 2001 and control clone RRIC 121 over a ten year period of tapping in SSCT

Girthing properties

Clone RRISL 2001 showed a very high girth increment at pre-tapping stage and is around 9.2-9.5 cm/year in traditional rubber growing areas while 7.0-7.5 cm/year in non-traditional areas. The post-tapping girth increment was not yet calculated for non-traditional areas as most of the trials are either in immature or at the initial tapping stage. However, post-tapping girth increments in traditional rubber growing areas are comparatively high and are around 4.5-5.0 cm/year.

Use of RRISL 2001 in Clone Recommendation

The advisory circular on clone recommendation was revised in the year 2000, and clone RRISL 2001 was first introduced as a latex-timber clone to the new recommendation as a Group III clone (Estate/RRI collaborative clone trial) and recommended to plant 2ha of extent (Attanayake, 2000). In the next revision of the clone recommendation in August 2004, clone RRISL 2001 was upgraded from group III to group II and promoted as a promising clone. In the same recommendation, RRISL 2001 was recommended for smallholder lands and private estates, where the holdings have more than 5ha with the restriction of not exceeding more than 10% of the total extent (Attanayake, 2004).

Evaluation of clone RRISL 2001 under different environments

In order to monitor the performance of the clone RRISL 2001 in different agro-climatic regions and to carry out further studies on the environmental effect on the clone and their adaptability to that particular environment, several field trials were established (Table 03). However, most of the trials are still in either the immature stage or the early stage of harvesting. Therefore, it is too early to comment on the performance of the clone under different environments.

Table 03. *Locations of the trials of clone RRISL 2001, under different agro-climatic environments.*

Agro Climatic Zone	District	Estate	Year of planting
Low Country Wet zone (WL)	Kalutara (WL1)	Lagos Division of Payagala Estate Kalutara	2011
	Rathnapura (WL1)	Kuruwita Substation	2009
	Galle (WL4)	Katandola Estate Elpitiya	2011
		University of Ruhuna, Kamburupitiya farm	2010
Low Country Intermediate zone (IL)	Kurunegala (IL1)	Muwankanda Estate	2009
	Monaragala (IL1-IL2)	Kumarawatta Estate	2010
Mid Country Intermediate zone (IM)	Badulla (IM2)	Dameria B Estate - Passara	2010
	Badulla (IM1)	Wewassa Estate - Badulla	2011
Low Country Dry Zone (DL)	Vavuniya (DL1)	Smallholders in Vavuniya	2012

Smallholder Rubber Research Collaborative trials (SRT)

Smallholder Rubber Research Collaborative trials (SRT) were also established to evaluate the performance of RRISL 2001 in several locations. Most of them are still in the immature stage. However, their girthing performances are also in a good condition (Table 04).

Table 04. *Performance of the clone RRISL 2001 under smallholders' level*

Smallholder	District	Agro-climatic Zone	Year of planting	Av. Girth at the year 2019 (cm)
Mr. SM Weerawardana Padiyathalawa	Ampara	IL2	Nov. 2012	48.0
Mrs. Indrani Kusumalatha, Padiyathalawa	Ampara	IL2	Nov. 2012	55.6
Mr. RanjithThambawita Bandaragama	Kalutara	WL1b	Aug. 2012	58.2
Mr. M Seneviratne Mahaoya	Ampara	IL2	Nov. 2014	26.7
Mrs. AM Karunawathi Ilukpathana	Monaragala	IL1c	Oct. 2015	16.5
Mr. HM Punthibanda Ilukpathana	Monaragala	IL1c	Oct. 2015	22.0

Mr. GK Chaminda Sella Kataragama	Monaragala	DL5	Oct. 2016	31.6
Army Camp Kandakaduwa	Polonnaruwa	DL 1c	Nov. 2016	13.5

Identification of clone

Proper identification of this clone is vital to ensure the procurement of the right clone for planting. Knowledge of relatively consistent characters of a clone is used to identify the clone (Liyanage *et al*., 2013; Liyanage and Baddewithana, 2015). Characters of clone RRISL 2001, which can be used for identification, are listed and illustrated in Table 05, Figures 04 and 05.

Table 05. *Morphological characters of the clone RRISL 2001*

At immature stage (<2 years)	
Descriptor	**In clone RRISL 2001**
1) Leaf (Middle leaflet)	
Shape	Elliptical to obovate
Colour	Dark green (7.5 GY 3/4)
Luster	Glossy
Texture	Smooth
Leaf base	Cuneate
Leaf Apex	Acuminate to Apiculate
Leaf Margin	Smooth
Longitudinal Section	Strait or Flat
Cross Section	V-shaped
Degree of leaflet separation	Well separated
2) Petiolule	
Length	Medium (1.2 – 1.8 cm)
Orientation	Horizontal
Angle between Petiolule	Narrow (45 - 50°)
3) Petiole	
Shape	Convex
Length	Medium (26 – 32 cm)
Orientation	Horizontal
Pulvinus	Swollen
Nectar Gland	Normal
4) Leaf Storey	
Shape	Hemispherical
Separation	Well separated
Appearance	Dense or Closed canopy

5) Stem

Appearance	Straight
Surface	Smooth
Leaf Scar Size	Small
Leaf Scar Shape	Heart shape to round
Axillary bud appearance	Normal
Axillary bud distance from petiole	Close
Latex Colour	White

At mature stage (>5 years)

1) Trunk

Vigour	Good
Continuity	Persistent
Height	Tall
Shape	Round
Surface	Smooth
Colour	Light brown
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
Surface	Smooth
Density	Average

3) Crown

Shape	Oval
Size	Narrow
Density	Medium
Height	Moderate
Position	Balanced
Colour	Green

4) Seeds

Size	Medium
Shape	Square cuboid
Length	Medium
Width	Medium
Thickness	Medium
Seed coat colour	Light brown

Seed coat luster	Dull
Seed coat variegation	Shaded
Seed coat variegation colour	Light brown
Dorsal prominent ridge	Present
Dorsal shape	Flat
Ventral groove	Slightly
Ventral lateral cheek	Normal
Ventral anterior	Flat
Ventral posterior	Normal
Weight	Medium
Microphyle	Normal

a: Leaf Storey- It is the leaf-bearing part of the stem. It is hemispherical in shape (leaf stories look like half of the sphere), and the leaf story of a plant is well separated from each other by the bare stem. The density of leaves in the storey is high and indicates as a close 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 are elliptical to obovate in shape (leaf blade has its maximum width in between the middle of the leaflet and apex). The leaf margin is smooth. Veins are prominent and light green in colour. The luster of the leaf is glossy and smooth in texture.

d & e: Leaf apex and leaf base - Usually, the mature middle leaflet is used to observe the character. Leaf apex is acuminate to apiculate, and leaf base is cuneate. Acuminate tip refers to an acute apex, sides of which are somewhat concave and tapers somewhat into an elongated tip. The cuneate leaf base appears triangular, with the narrow end at the point of attachment.

f: Leaf scar - The leaf scar is the mark that is left after the leaf shedding. In this clone, they normally heart shape to round with protruded margin and the axillary bud (the bud found at the axil of leaves in which the branches and flowers arise from) are normal (not sunken or protruded) and visible.

g: The Longitudinal sectional appearance of a leaf - It is judged by viewing the leaflets from the side, and it is straight or flat

h: Petiole and orientation of petiole - To describe the petiole, its shape, length and orientation are considered. Lower leaves of the story are the best to observe the petiole characters. The orientation is horizontal to upward, and it describes the arrangement of the petiole in relation to the stem. All the leaves of the storey may not show the same orientation, but the orientation exhibited by a majority of leaves is taken as the clonal character. The shape of the petiole is convex (there is no bending or curving of the petiole) straight.

i: Petiolule – It is the short stalk connecting the leaf lamina to the petiole. It also displays variability in size, orientation and inter petiolule angle. The orientation of petiolule is horizontal to downward with respect to the plane of the petiole and narrow 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 "V" shaped.

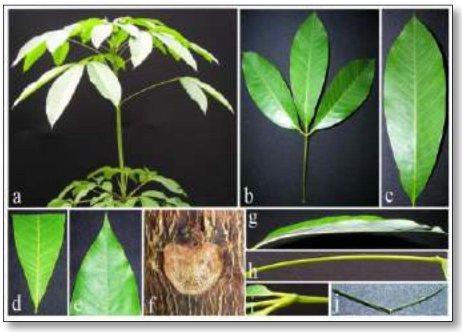

Fig. 04. Leaf and leaflet characters of clone RRISL 2001

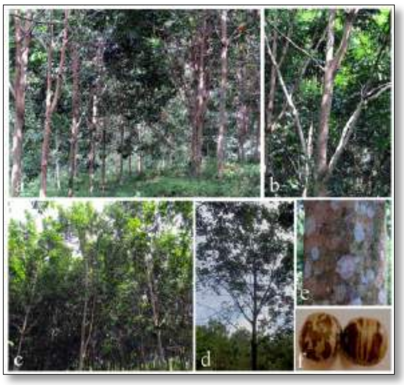

Fig. 05. Canopy, stem, branches and seed characters of clone RRISL 2001

a: Mature plantation – The tree trunk is more or less rounded and no nodule appearance in the main trunk.

b & c: Branching habit of the tree at its tappable stage – Low branching with clustered habit. They are spreading closely with a narrow-angle to the main trunk, strait in appearance and dissolve in the continuity. The density of branching is average.

d: Canopy- Oval shape medium density canopy

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

f: Features of seeds - Seeds are square cuboid in shape and dorso ventrally flat and medium in size. The dorsal side is light brown in colour with the prominent central ridge. Lateral depression is prominent. The seed coat is dull with large light brown patches well distributed in both sides.

Assessment on disease resistance:

***a) Corynespora* leaf fall disease (CLFD)**

Based on the clonal screening techniques followed by the Plant Pathology and Microbiology Department of RRISL during the past 15 years, the average disease severity index is zero (0) and the clone has been categorized as resistant to CLFD (Jayasinghe, 2004;2005;2006;2007;2008;2009; Silva, 2010; Fernando, 2011;2012; 2013; 2014; 2015; 2016; 2017; 2018;).

***b) Phytophthora* leaf disease**

Annual screening of clones for Phytophthora leaf fall disease shows that RRISL 2001 is a susceptible clone, under favourable weather conditions. Therefore, it is necessary to take precautionary measures to protect the clone from Phytophthora bark rot conditions in mature fields (Jayasinghe, 2009).

c) **Powdery mildew disease**

Clone RRISL 2001 shows a mild disease severity score and defoliation is 0-25% for the powdery mildew disease (Jayasinghe, 2002; Jayasinghe, 2003). However, RRISL 2001 is prone to secondary leaf fall disease under conducing weather conditions to the pathogen *Erysiphe quercicola* (earlier *Oidium hevea*) (Liyanage *et al*., 2016b; Liyanage *et al*., 2017).

Latex and raw rubber properties

Table 7 shows some important chemical and physical properties of fractioned bleached latex crape samples generally used in assessing the quality of raw material and its suitability in rubber product industries. According to that, RRISL 2001 shows more attractive latex and raw rubber properties compared with other clones (Rodrigo, 2011; Kudaligama *et al*., 2010).

Table 07. *Raw Rubber properties of clone RRISL 2001*

Properties	**Standard Values for crepe rubber**	**RRISL 2001**
Raw rubber properties		
Initial Wallace Plasticity of Rubber (P_o)	30 (min)	43
Plasticity Retention Index (PRI)	60 (min)	72
Mooney Viscosity (V_R)	75 -85	81
Ash Content % (w/w)	0.2 (max)	0.14
LovibondColour	1.5 units (max)	1.7
Nitrogen Content %	0.35 (max)	0.41
Latex property		
Acetone extractable non-rubber percentage (AEN%)	-	3.1
Percentage dry rubber content (DRC%)	-	35.56
Percentage of total solid content (TSC%)	-	38.19

(Source: Kudaligama *et al*., (2010) and Annual Review 2011, Biochemistry and Physiology Dept.)

The P_o test is a measure of the original plasticity (before aging). The clone RRISL 2001 has P_0 value of 43, and it is in the range of average and therefore does not influence the processability of rubber in the factory. The latex grades usually have PRI values above 60%, and PRI of RRISL 2001 is above 72 and grouped in the moderate category. Therefore it provides high quality latex for the rubber product industry. The Mooney Viscosity (V_R) is commonly used as the test to characterize and monitor the quality of rubber. The clone RRISL 2001 was groped in moderate category of Mooney Viscosity value and suitable for raw rubber production. The ash content % indicates the amount of inorganic chemical substances (metals) present in the rubber. If the ash content of a rubber sample is high, it indicates higher deterioration of the manufactured product due to the oxidation of the metal contaminant. In clone RRISL 2001, ash content is low and meets the specification requirement. The nitrogen content is the measure of non-rubber components, usually the proteinaceous matter present in the rubber phase and the minor content of non-protein nitrogen-containing substances. It is an important determinant as higher nitrogen contents increase the storage hardening and reduce the dynamic and aging properties. The clone RRISL 2001 was grouped at a moderate level in nitrogen content (Kudaligama *et.al*., 2010).

Other important characteristics

When RRISL 2001 is in tappable stage (*i.e.* in 6^{th} year of growth, average girth is 53.7cm) they have a bark thickness of 8-10mm ($\bar{x}$=8.7mm, n=30) at 120cm above from the ground. In the maturity stage (*i.e.* in the 15^{th}year of growth, average girth is 68.5cm), the virgin bark thickness was 11-17mm ($\bar{x}$=13.0mm, n=30) and the re-juanate bark thickness was 6-12mm ($\bar{x}$=8.6mm, n=30) at the same height. Those figures are greater than the clone RRIC 121 and therefore, it should be tapped somewhat deeper to get its maximum potential yield when compared to clone RRIC 121. After this long-term clonal evaluation process, the clone RRISL 2001 is recommended as a d2 clone, and therefore, it should be tapped on every other day.

RRISL 2001 is a fertilizer sensitive clone. Therefore, it is essential to add the recommended dosage of fertilizer at recommended intervals to get its maximum potential yield.

The measurable timber volume of the RRISL 2001 is around 0.326 m^3/tree and it is a high value when compared with RRIC 100 (*i.e.* 0.271 m^3/tree) and low with compared to RRIC 121(*i.e.* 0.406 m^3/tree) (Advisory circular of RRISL-Yield profiles of outstanding clones). Therefore, RRISL 2001 is considered a good timber clone.

Based on all these factors, the clone RRISL 2001 is considered a promising clone with good raw rubber properties and a higher timber value for both estate and smallholder sectors. Therefore, clone RRISL 2001 is recommended for planting to maintain the correct clone balance in the rubber plantations of Sri Lanka.

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COMPARISON OF BLACK AND TRANSPARENT POLYBAGS FOR GROWTH AND BUD GRAFTING PERFORMANCES OF RUBBER *(HEVEA BRASILIENSIS)* SEEDLINGS UNDER SUB-OPTIMAL CLIMATIC CONDITIONS

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ABSTRACT

Drought and heat stress are the major impediments limiting growth and bud grafting performance in rubber (*Hevea brasiliensis*) seedlings in nurseries in the Intermediate Zone of Sri Lanka. Polybag color is known to absorb solar radiation and subsequent increase in substrate temperature. Studies were conducted in a nursery in Moneragala to evaluate the effect of polybag colour on the growth of rubber seedlings. Black polybags of gauge 500, and 18 cm × 46 cm size were used as the control whilst transparent polybags of 500 gauge and 18 cm × 46 cm size were used as the treatment. Seedlings were grown in polybags and their growth data were recorded after 3 and 5 months of transplanting. No significant differences were recorded for diameter and height values of seedlings raised in black polybags when compared to transparent polybags at both growth stages. Root and shoot attributes *viz.*,the number of leaves, leaf area, and dry weight of shoots and roots after five months of transplanting did not differ significantly between the treatment and control. As the cost of a transparent polybag is higher than a black polybag and no significant differences in seedling parameters were observed between the two types of bags, black polybags may be continued to raise seedlings in nurseries established in the Intermediate Zone.

INTRODUCTION

Rubber (*Hevea brasiliensis*) is propagated by grafting buds of selected clones onto unselected seedling rootstocks raised in polybags using the young budding technique. In the nurseries in the Wet Zone, germinated seeds are placed directly in polybags and the plants that emerge are allowed to grow until the diameter of the stem becomes 6-7 mm. The plants are then bud grafted and successfully grafted seedlings are cut-back to promote the growth of the scion (Nayanakantha *et al.,* 2014). Seedlings in nurseries in the Wet Zone attain buddable size after about 3-4 months of transplanting. However, drought and heat stresses are the major impediments limiting crop performances in the Intermediate Zone and therefore, seedlings in nurseries in the Intermediate Zone require 5-6 months to attain buddable size.

Currently, two polybag sizes are recommended to use in rubber nurseries, 15 cm x 38 cm size and 300 gauge for the traditional Wet Zone and 18 cm × 46 cm size and 500 gauge for the Intermediate Zone in Sri Lanka. Black polythene bags are used in rubber nurseries in both Wet and Intermediate Zones. It is well known that darker substrates absorb more heat than lighter substrates and hence it is possible that the temperature in the soils in black polybags may increase during the daytime when compared to that in lighter polybags. As a result rubber seedlings could be subjected to heat stress which may negatively affect the growth of seedlings. According to Dharmakeerthi *et al.* (2008), temperatures within the polybags could rise to very high levels (more than 40 °C) in the nurseries in the Wet Zone. Accordingly, temperatures within polybags in nurseries in the Intermediate Zone could rise even more. In some woody species, root growth stops completely at soil temperatures above 39 °C (Mathers, 2003) which may affect plants deleteriously.

Growing rubber seedlings in polybags made of colours lighter than standard black may improve growth and bud grafting performances. Lighter-colored containers have greater albedo than dark containers and thus reflect more solar radiation away from the container *i.e.*, less solar energy absorbed by the container (Ham *et al.*, 1993). Consequently, lighter-coloured containers may be a means to mitigate heat stress in a nursery. According to Whitcomb (2003), substrate temperatures were reduced by 3 to 6 °C when standard black containers were covered with white laminated fabric sleeves. Similarly, substrate temperatures were decreased by 1 to 7 °C in containers made of an insulating black fabric that was coated on the outside with white polyethylene (Whitcomb and Whitcomb, 2006).

Therefore, this study was conducted to evaluate the effect of transparent polybags on the growth and bud grafting performance of *Hevea* seedlings under sub-optimal climatic conditions in Moneragala.

MATERIALS AND METHODS

This experiment was conducted in a nursery at Moneragala sub-station of Rubber Research Institute of Sri Lanka belongs to the Intermediate Zone. The experiment was conducted from January 2017 to February 2018. Transparent polybags of gauge 500 and having the dimension of 18 cm × 46 cm size were used as the treatment whilst black polybags of gauge 500 and having the dimension of 18 cm × 46 cm size were used as the control.

Fresh rubber seeds were collected and sown in a germination bed filled with sand. Topsoil without coarse particles was used for filling the polybags. An amount of 100 g of compost and 50 g of imported rock phosphate were added to each bag and mixed with the topsoil. After 14 days, uniformly germinated seedlings were selected and transplanted at the rate of one in each polythene bag. There were 200 polybags; 100 from each color so that each treatment had five blocks (20 plants per block) arranged in a nursery according to a randomized complete block design (RCBD). Two weeks after transplanting, application of chemical fertilizers was started and continued at two-week intervals. All other management practices were the same as recommended by the Rubber Research Institute of Sri Lanka (Anon., 2016).

Shoot diameter and height were recorded in all seedlings after 3 and 5 months of transplanting. At each growth stage, 10 plants from each treatment were selected randomly. The root system from each plant was washed gently under running water over a 0.5 mm sieve and the adhering soil and dust particles were carefully removed. Shoots and roots were dried in an oven at 70 ˚C for 24 hours and were weighted using an electronic balance.

Plants were bud grafted with RRISL 203 scions after 5 months of transplanting. Bud grafting success was observed and scion growth was monitored up to one leaf whorl stage.

The significance of the observed treatment differences was tested by analysis of variance using PROC ANOVA procedure of the SAS software package (version 9.1) and mean separation was done using the least significant difference (LSD).

RESULTS AND DISCUSSION

Results of the present study revealed no significant differences in diameter and height values of seedlings between the treatment and the control (Table 1). However, variation in the growth of seedlings of different species raised in polybags of different colors has been reported in other countries. Ahmad *et al.* (2009) reported that the differences between tea (*Camellia sinensis*) seedlings grown in the black and transparent polythene tubes as well as the interaction between the environments x polythene tubes color were non-significant for the growth parameters. Nevertheless, container opacity caused important changes in seedling morphology (Khurram *et al.*, 2017). Black containers had greater daily maximum temperatures compared to the other two colors (green and transparent). Black containers promoted root development of Afghan pine (*Pinus eldarica*) and Arizona walnut (*Juglans major*), and transparent containers resulted in an increase in shoot volume and shoot biomass compared to the black containers (Khurram *et al.*, 2017).

Table 1. *Mean stem diameter and height values of the plants grown in black and transparent polybags after three and five months of transplanting.*

Treatment	3 Months		5 Months	
	Stem Diameter (cm)	**Shoot Height (cm)**	**Stem Diameter (cm)**	**Shoot Height (cm)**
Black polybags	5.0 ± 0.10^{a}	45.1 ± 0.86^{a}	6.4 ± 0.18^{a}	62.6 ± 1.14^{a}
Transparent polybags	5.9 ± 0.64^{a}	46.3 ± 0.93^{a}	6.6 ± 0.17^{a}	66.9 ± 2.01^{a}

Means followed by the same letter within a column are not significantly different (P = 0.05)

No significant differences ($p<0.05$) were recorded for the shoot and root attributes *viz.*, the number of leaves, leaf area, dry weight of shoots, and roots in seedlings raised in transparent polybags when compared to those in black polybags (Table 2). Nevertheless, tea plants raised in black polythene tubes recorded a high shoot dry weight value when compared to those in transparent polythene tubes (Ahmad *et al.,* 2009). No significant differences were recorded for the bud grafting success in seedlings raised in black polybags when compared to those in transparent polybags (Table 3).

Table 2. *Shoot and root growth parameters of the plants grown in black and transparent polybags after five months of transplanting.*

Treatment	No.of leaves	Leaf area	Dry weight of shoots (g)	Dry weight of roots (g)
Black polybags	11.3 ± 1.01 [a]	642.3 ± 113.7[a]	7.6 ± 0.91[a]	2.2 ± 0.26 [a]
Transparent polybags	16.2 ± 1.44 [a]	1020.3 ± 197.7[a]	10.5 ± 2.28[a]	3.1 ± 0.48[a]

Means followed by the same letter within a column are not significantly different (P = 0.05)

Table 3. *Bud grafting success of the plants grown in black and transparent poly bags*

Treatment	% Bud grafting success
Black polybags	81.16 ± 3.6[a]
Transparent polybags	82.96 ± 2.8[a]

Means followed by the same letter within a column are not significantly different (P = 0.05)

One method of dealing with heat stress in container production is to use containers with alternative colors or compositions instead of black plastic. Contrary to the studies conducted for other crops in other countries, no significant differences were recorded for the growth and bud grafting performance of rubber seedlings raised in transparent polybags when compared to those in black polybags. Moreover, the cost of transparent polybags is higher than that of black polybags and therefore, black color polybags may be continued to raise seedlings in nurseries established in the Intermediate Zone.

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EFFECT OF DIFFERENT BIOCHEMICAL CONSTITUENTS OF LATEX ON DISCOLORATION OF NATURAL RUBBER : AN OVERVIEW

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Natural rubber (NR) is one of the most often used raw materials in a vast number of industries such as automotive, pharmaceutical, household, construction etc. due to its significant and strategic inherent properties (Ferreira *et al*, 2005). Anas (2000) states that information on the quality and properties of raw rubber is important in determining the type of products that will be produced from raw rubber. Also, they play a significant role in grading and deciding the specifications of rubber in the process of exporting. Those properties of NR are determined by several factors which are clonal characteristics of field latex, weather, tapping method, use of a stimulant, rubber processing method etc. As clonal characteristics are inherent, it is significant to identify suitable clones for the expected latex and rubber properties to meet the consumer needs (Eng *et al.*, 2001).

Darkening of rubber/ changes in the color is one of the major issues prevailing in both the processing and storage of rubber (Yapa, 1976). Discoloration leads to huge marketing problems in industries that require light color rubber materials for the manufacturing of rubber products (Sakdapipanich *et al.*, 2007). Thus the discoloration is still a disadvantage to most natural rubber latex-based industries (Cheewasedtham and Madsa-ih, 2012).

There are several factors that cause the discoloration of rubber latex (Nadarajah and Karunaratne, 1964). Enzymatic and non-enzymatic darkening are considered to be the major reasons for rubber latex discoloration (Yapa, 1976).

Enzymatic discoloration of NR

The reason behind the enzymatic discoloration is the oxidation of phenolic compounds (Adams and Brown, 2007). Phenolic compounds are a type of plant secondary metabolites (Rocha and Morais, 2001). These are also found to be responsible for the browning of many fruits and vegetables (Kapoor and Kaur, 2000). Wititsuwannakul *et al.*, (2002) reported that the color of wet rubber sheets is changed from white to brown color due to the browning process during the time of open-air drying. The amount of phenolic compounds vary among different genotypes widely in terms of quality and quantity. Polyphenol oxidase (PPO, EC 1.10.3.1) is considered to be the key enzyme that is responsible for the oxidation of phenolic compounds in rubber (Yapa, 1976). In plant cells, phenolic compounds can be found in vacuoles whereas polyphenol oxidase is located in plastids. Wititsuwannakul *et al.*, (2002) has mentioned that natural rubber latex contains polyphenol oxidase enzyme in Frey-Wyssling particles and lutoids. Damaged areas in cells allow the contact between PPO and phenolic compounds resulting the oxidation of phenolic compounds, and thus discoloration of rubber (Holderbaum *et al.*, 2010).

Phenolic compounds are oxidized to o-quinones by PPO in presence of oxygen (Shao and Zhang, 2015). The resultant quinones react with amino acids, other phenolic compounds present in latex in order to produce dark brown, red or black melanin type pigments (Ozdemir, 1997). Tyrosine is one of the most common substance related with the enzymatic discoloration by oxidizing into melanin type pigments. Many researchers have detected tyrosine in NR latex and at high concentrations, it had an impact on latex browning (Yapa, 1976). Furthermore, phenolic discoloration has been influenced by temperature. Several studies have shown an optimum temperature of 30ºC for PPO activity and it may range from 15–50 ºC (Shao and Zhang, 2015).

Cheewasedtham and Madsa-ih (2012) reported that polyphenols were found in concentration of about 2 x 10^{-2} % wt/wt in latex whereas, of the total absorptivity in the yellow-brown region, polyphenols contributed for about 2.3% of absorbance. Nadarajah and Karunaratne (1964) indicated that a considerable variation was observed in phenol content of different clones.

Non- enzymatic discoloration of NR

Non- enzymatic browning can be resulted from several chemical processes *viz.* degradation of ascorbic acid, lipid peroxidation, sugar-sugar caramelization and Maillard reaction (Davies and Wedzicha, 1992). Of them, Maillard reaction is the key reason for the non- enzymatic discoloration (Fogliano *et al*., 1999). The reaction of proteins with reducing sugars to form brown color polymeric compounds is called as Maillard reaction (Fogliano *et al*., 1999; Tessier *et al*., 2003). Cheewasedtham and Madsa-ih (2012) reported that latex of *Hevea* had about 1% wt/wt protein content and it showed a proportion of about 0.1% from total absorbance in the yellow-brown region.

Other reasons for discoloration of NR

In addition to the enzymatic and non- enzymatic discoloration, compounds such as carotenoids play a role in latex discoloration (Felt *et al*., 1999). Carotenoids are one of the natural pigments found in plants and responsible for red, orange and yellow colors (To and Wang, 2006). Structurally most carotenoids are consisted of a 40-carbon chain as the basal structure with conjugated double bonds (Stahl and Sies, 2003). Cheewasedtham and Madsa-ih (2012) found that natural rubber latex consisted about 3 x 10^{-5} % wt/wt carotenoids and it contributed for about 0.01% of the total absorptivity related to the yellow- brown region. According to Sakdapipanich *et al*., (2007), other than the carotenoids, tocotrienols, tocotrienol esters, monoglycerides, diglycerides, fatty alcohols, fatty alcohol esters and unsaturated fatty acids have been also responsible for discoloration of natural rubber.

Apart from the above-mentioned coloring compounds, around 90% of the total absorptivity was found to be caused by rubber molecules. The reason for that is high concentration and high absorptivity value resulted by double bonds in polyisoprene molecule structure (Cheewasedtham and Madsa-ih, 2012; Sakdapipanich *et al*., 2007).

Cases reported in Sri Lanka

According to the recent research conducted at the Department of Biochemistry and Physiology, RRISL, it was found that RRISL 203 clone had higher amount of polyphenol content compared to several other abundant *Hevea* genotypes (Centennial 3, RRISL 2006, Centennial 4 and RRISL 2001) in Sri Lanka which led to higher color index. Further varying amounts of coloring substances were found in latex amongst different *Hevea* genotypes grown in Sri Lanka. Among tested coloring constituents which are polyphenols, carotenoids and proteins, proteins were found at the highest concentration in most of the tested *Hevea* genotypes (0.04 - 0.14 w/w%). Carotenoid showed the lowest concentration amongst the tested genotypes ($3.0x10^{-5}$ - $11.5x10^{-5}$ w/w%) whilst polyphenols were present at the concentration of 0.03 - 0.06 w/w% in tested genotypes. Furthermore, polyphenol content in latex showed the strongest positive correlation with 'Lovibond' color index of rubber. The second strongest positive correlation was observed between carotenoid content in latex and color index. However, the strength of the relationship of color index with protein content was not significant.

It has been observed that stimulation with ethephon had an impact on increasing polyphenols in latex by reducing polyphenol oxidase enzyme activity (Attanayake *et al*., 2015). There had been incidents reported that high carotenoids content found in latex of rubber trees stimulated with ethylene gas or overdoses of ethephon.

Rather than using bleaching agents as a solution to discoloration, researches are being conducted in order to find alternatives that are less toxic or non-toxic.

Thiols (glutathione and cysteine) can inhibit discoloration by reacting with oxidized phenolic compounds to form colorless products (Yapa, 1976; Kapoor and Kaur, 2000). Thiol compounds contain the sulfhydryl group (-SH) attached to a carbon atom (Winther & Thorpe, 2015). Thiols are a type of antioxidant with the role of protecting cells against damages caused by free radicals (De Costa *et al*., 2006). Thiols protect cell compartmentation of latex and the function of laticifers by trapping oxygen- toxic forms. And also it acts as an activator for the key enzymes such as pyruvate kinase and invertase, thus influences the metabolic intensity and latex regeneration (D'Auzac, J *et al*., 1989). Therefore, thiols can be used as a solution for enzymatic discoloration of natural rubber.

Thus, identification and characterization of coloring substances in natural rubber latex is important in order to develop methodologies to reduce or eliminate those substances from latex.

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WHAT TO BE LEARNT FROM PAST STUDIES ON NUTRIENT MANAGEMENT IN RUBBER

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INTRODUCTION

In rubber cultivated areas, the land is being degraded gradually mainly due to soil erosion and continuous cultivation. Heavy rainfall conditions cause surface runoff and leaching soil nutrients down the profile resulting in infertile soils. Most of the currently existing rubber cultivations in the wet zone are in the third or fourth generation of planting. Lands have become less productive with the continuous cultivation of rubber (Dharmakeerthi, 2009). Therefore, the fertilizer application to rubber cultivations has become compulsory in order to sustain the vegetative growth and latex yield. It has been reported that the immature period of rubber plant can be shortened by optimum fertilizer management (Yogarathnum *et al*., 1984 and Sihotang, 1993). Proper fertilizer management during the mature phase has also shown improvements in latex yield (Samarappuli, 2000a; Purkwiwat *et al*., 2003; Pothiwatthutham *et al*., 2003). On the other hand, fertilizers are costly inputs in rubber cultivation. There is a huge demand for labour for the handling and application of fertilizers. The benefits of investment in fertilizer application can be assured only if the fertilizers are used efficiently and effectively. This can be based on the cost of fertilizers, the efficiency of uptake by the rubber plant and the return on investment. Necessarily, the appropriate fertilizer at the correct rate must be applied at the proper time and the resultant benefits are of economic advantage (Samarappuli, 2000b). Now, the concept has been shifted from fertilizer to integrated nutrient management to sustain yield and maintain soil quality and prevent deterioration (FAO, 2006). Information on the nutrient status in the soil and plants, the ability of plants for nutrient uptake and also the nutrient release by fertilizer source is required to practice in integrated nutrient management (Suchartgul *et al*., 2012). A modified approach is needed for plant nutrition in order to reduce labor cost for application of fertilizer and minimize land degradation and also sustain with labour shortage. This article describes some areas to be concerned about when modifying the conventional approach for plant nutrition in rubber.

Fertilizer for different rubber clones

The amounts of nutrients that are removed with the harvest have been increased with the introduction of new high-yielding rubber clones. This enhanced demand for nutrients has to be fulfilled by modification of plant nutrition approach in cost-effective manner. Previous experiments have proved that different clones show different uptake patterns of different nutrients that can also be varied with different soil moisture conditions. It was reported that clones varied in their ability to use P and it was related to the source of fertilizer and other soil characteristics (Dissanayake *et al*., 1992). Furthermore, there was a significant difference between clones in bark Nitrogen (N) and leaf Potassium (K) contents although they were uniformly fertilized according to Rubber Research Institute of Sri Lanka recommendation. For example, RRIC 121 had significantly higher bark N and leaf K contents. Some clones grown with low soil moisture conditions showed greater leaf P contents (RRIC 121, RRIC 102) while some clones (RRIC 110, RRIC 100) showed high leaf P contents when they were grown in high moisture conditions (Dissanayake *et al*., 1992). It has also been reported that the clone RRIC 102 is a Magnesium (Mg) loving clone and application of 25% of Mg would be more effective for RRIC 102 (Anon, 2013). Studies have been conducted at RRISL sub station Kuruwita to test the response of three clones RRISL 201, RRISL 202 and RRISL 217 to fertilizer during the mature phase. Three levels of applications, the current recommendation, 200% of current recommendation and no fertilizer application were tested as treatments. Based on the girth and girth increment, there were significant differences among clones but there were no significant differences among fertilizer treatments and no significant interaction effect was observed (Dharmakeerthi *et al*., 2007). However, the same fertilizer treatments were tested on fertilizer response in immature plants of RRISL 203 and RRIC 121 grown at Monaragala and it showed significant differences among clones as well as among fertilizer levels (Dharmakeerthi *et al*., 2007).

Therefore, the efficiency of nutrient uptake by the new high yielding clones under different soil series should be studied, so that recommendations can be made for specific clones grown in a particular soil. Screening of clones to maximize nutrient uptake by different clones can be used for the reduction of the labor cost for fertilizer application while improving the yield potential of rubber trees.

Site specific fertilizer recommendations

Fertilizer recommendation service based on soil and foliar analysis and information generated from soil classification was started by RRISL in 1973 (Dharmakeerthi, 2009). An experiment has been conducted to develop a simulation model based on site-specific fertilizer recommendation programme for immature rubber. Regression models were developed to estimate the nutrient uptake pattern by the immature rubber plants using the girth of the plants (Dharmakeerthi *et al*., 2010). However, this service is currently applied only for mature rubber fields followed by a foliar survey. Leaf diagnosis shows the nutrient status of the plant at a particular time of sampling. Since the results of the leaf analysis vary according to the facts such as the age of the leaf, its position on the tree, there is a standard protocol established by the RRISL to select trees and leaves for sampling. Leaf diagnosis alone may not give an accurate picture of fertilizer requirement. Because of the complexity of factors affecting the results, leaf analysis has to be integrated with soil analysis (Anon, 2017).

Soil testing has the advantage of measuring the level of nutrients present in the soil as well as the availability of those nutrients for plants' uptake. The fertilizer recommendations that have been developed is based on soil data of particular fields, were reported as more effective on the growth and yield of rubber plants compared to traditional blanket fertilizer recommendation (Boonyamanee *et al*., 2013). It was found that the girth and biomass of untapped rubber trees supplied with fertilizer according to the recommendations based on soil test, were higher than those of blanket fertilizer recommendation. Latex yield after fertilizer application based on soil analysis was higher than those of traditional fertilizer application (Kangpisadarn, 2010). Soil nutrient status is one of the many factors which determines a crop's nutritional status. There are some other important factors that influence nutrient uptake by plants, such as soil pH, cation exchange capacity, temperature and soil moisture conditions. In addition, the presence or absence of one nutrient element in soil may affect the uptake of another. There is a special technology for recommending fertilizer called the precision application of fertilizer (Anon, 2014). This technology considers factors such as; nutrient supply capacities of different types of soil, the relationships between soil water & fertilizer use efficiency, nutrient demand of rubber leaves and desired yield of rubber trees when deciding fertilizer recommendations (Anon, 2014). The precision application of fertilizer technology is more precise in fertilizer application than the traditional one as it is more accurate in fertilizer application rate, location and time, and more rapid in decision making of fertilizer application (Anon, 2014). Therefore, it is important to combine the details of soil parameters, other agroecological parameters and the potential yield of new clones for the models developed for recommending fertilizer.

Furthermore, continuous field trials are important to assess the correlation of each fertilizer recommendation based on the collected data with plant growth and yield parameters. The presence of any nutrient deficiency symptoms and agronomic practices should also be considered while assessing such correlation.

Inorganic versus organic fertilizer application

Inorganic fertilizers have become the major source for maintaining soil fertility of degraded soil. However, there is a potential for marked economic loss of N, P, K and Mg through losses by leaching, runoff, volatilization and denitrification. The issues related to the cost of fertilizers and the low fertilizer use efficiency have caused for seeking of alternatives for plant nutrition. Poor characteristics of tropical soil such as rapid decomposition of organic matter, low cation exchange capacity and low pH can be remedied by adding organic residue or organic fertilizer to the soil (Ogundare *et al*., 2012). Therefore, scientists are focusing on research to omit or reduce the recommended amounts of inorganic fertilizer application by combining organic sources of manure to get a sustainable production.

RRISL has given recommendations to apply: compost to poly bagged nurseries and straw, green manure, compost, poultry manure to immature and mature field plants. Not only that, investigations have been carried out using different organic sources as manure by different scientists and have come up with promising results. It has been reported that 23 MT of rice straw application during the first 6 years contribute to approximately 43% of N and more than 100% of K of the recommended chemical fertilizer amounts (Samarappuli *et al*., 1998) In addition, Samarappuli *et al*., (2003) revealed that about 50% of urea can be cut down during the immature phase of rubber with the use of *Mucuna bracteata* as a cover crop. Further, biofertilizers are reported to be highly beneficial in the enrichment of soil fertility and fulfilling the plant nutrient requirements by supplying the nutrients through microorganisms and their byproducts. Biofertilizers are organic and eco-friendly and more cost-effective than chemical fertilizers. It has been reported that the leaching loss of dissolved organic matter, exchangeable Mg, K and nitrate nutrients can be reduced to a significant level by the combined use of chemical fertilizer with biofilm biofertilizer in rubber nursery media (Hettiarachchi *et al*., 2014). Biofilm biofertilizers with 50% of recommended fertilizers could improve rubber plant growth at the nursery stage (Hettiarachchi *et al*., 2012). The application of biofertilizers has improved soil fertility and plant growth of immature stage of rubber as well (Hettiarachchi, 2015). It is reported that the use of organic fertilizer for rubber in Thailand increased chemical fertilizer use efficiency or even partial substitution of chemical fertilizer (Damrongrak *et al*., 2015). In comparison with inorganic fertilizers, organic fertilizers have advantages such as enhancing chemical, physical and biological properties of soil, no harm on the environment and no wastage due to leaching, volatilization *etc*. On the other hand, there are a few problems related to organic manure in case of availability, bulkiness, cost of application and slow response by plants to the applied organic fertilizer. Moreover, the question is that whether the optimum production can be achieved with the use of only organic manure. Therefore, the most effective approach seems to be the combination of both inorganic and organic fertilizers for plant nutrition in rubber.

Supplement of micronutrients together with macronutrients for rubber

The role of micronutrients in rubber trees gets less attention. Fertilizer recommendation is generally based mainly on N, P, K and Mg while micronutrient requirement is very small and can be satisfied with the available levels in the soil (Adiwiganda *et al*., 1994). If only the fertilizers that contain major nutrient elements are used, plants have to obtain the microelement from soil. When the concentrations of those microelements in the soil do not meet the demand of plants, the use of major nutrient elements alone will not give benefits anymore (Suchartgul *et al*., 2012). It is reported that correction of micronutrient imbalance is not a simple task since very small amounts are involved (Samarappuli, 2000b). Therefore, it is important to diagnose the requirement and availability of micronutrients and use the data for modification of the fertilizer recommendations.

A study has been carried out to assess the distribution profile of Mn, Cu, Zn and B in rubber growing soils in Sri Lanka. Analytical data indicated that exchangeable Mn, Cu, Zn in Boralu, Parambe and Homagama soil series were low while B content was not in the detectable range. It was suggested that those low levels might be due to leaching loss of nutrients from the soils. Also, it was suggested that low soil pH would make micronutrients more available to plants and therefore deficiency symptoms had not been reported. The data suggested that micronutrients should be applied as fertilizer to maintain the optimum micronutrient contents in rubber growing soils (Hettiarachchi *et al*., 2013). Damrongrak *et al*., (2015) suggested that organic fertilizers like compost should be considered for application to gain microelements to plants. However, further studies should be conducted before making recommendations for micronutrients.

Slow releasing fertilizers

Few studies reported the potentials of slow-releasing fertilizers as a substitute to straight fertilizers. In Indonesia, a tablet form fertilizer containing N, P, K, Mg and kaolinite as a slow-release agent was used for mature rubber and it was revealed that the slow release agent was more efficient in terms of nutrient uptake compared with the recommended straight fertilizers (Wijaya *et al*., 2014). In nursery trials at Millewa, Panawatta and Dartonfield, it has been reported that the optimum growth rate of nursery plants was achieved with a single application of slow-release fertilizer for the whole nursery period. In addition, the application of fertilizers encapsulated with rubber latex and coir dust as a slow-releasing technique was effective for releasing N, K and Mg at their optimum levels over an extended period (Hettiarachchi *et al*., 2016). This coir block technique is currently being tested for immature rubber at field conditions. Slow releasing fertilizer would be an effective approach for minimizing fertilizer wastage and also for the labor cost associated with split applications. Further investigations should be carried out on slow-releasing fertilizers.

CONCLUSIONS

Proper modification in fertilizer recommendations would be useful to increase fertilizer use efficiency while reducing the cost of production and environmental hazards. However, such modification should be done in a scientific manner considering many factors *i.e.* nutrient status of soil and leaves, agroecological data and yield data. Novel trends of fertilizer applications such as slow-release fertilizer, biofertilizers, organic acids and micronutrient formulations should be further tested before coming up with recommendations.

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GROWTH AND BUD GRAFTING PERFORMANCE OF SELECTED CLONAL SEEDLING ROOTSTOCKS OF RUBBER *(HEVEA BRASILIENSIS)*

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ABSTRACT

Rubber (*Hevea brasiliensis* Muell. Arg.) is propagated by grafting buds of selected clones onto unselected seedling rootstocks raised in polybags using the young budding technique. Currently, seeds of clones recommended for rootstocks in the early 1970s and & 1980s are being used to raise rootstock nurseries. Since there is a dearth of information on the performance of seedlings of newer clones recommended for rootstocks in the mid-1990s, this study examined the germination, growth and budding performance of the seedlings of five new clones *viz* RRISL 201, 206, 220, 221, and 226 compared to an old clone RRIC 100. More than 50% of seeds of all six clones germinated after 14 days and showed 80-95% germination within 21 days after sowing. There were no significant differences in shoot and root attributes *viz.*, plant height, stem diameter, number of leaves, leaf area, chlorophyll content, dry weight of tap root, dry weight of lateral roots and the dry weight of total roots of new clones compared to those of RRIC 100. However, shoot dry weights of seedlings of RRISL 206 and RRISL 220 differed significantly from RRIC 100. The seedlings were bud grafted with RRISL 203 scions. Rootstocks of RRISL 226 exhibited 100% bud grafting success with 67% of sprouting whereas RRIC 100 showed 89% only with 61% of sprouting one month after the cut back of stocks, respectively. Therefore, all the five new clones may be used as rootstocks for effective bud grafting with RRISL 203 scions to produce quality rubber plants.

Keywords: Bud grafting, clones, growth, rubber, seedlings

INTRODUCTION

Rubber (*Hevea brasiliensis* Muell. Arg.) is an economically important crop primarily because of its latex which is used in the production of natural rubber. Quality of planting material is of utmost importance to achieve potential yields of *Hevea* clones with maintaining recommended stand of vigorous plants. During the initial stages of rubber cultivation, the rubber tree was propagated exclusively by seeds. However, currently, rubber seeds are not used as a planting material merely because of variation among seedlings with regard to growth, vigour and yield, resulting in low productivity (Seneviratne, 2001). Therefore, high-yielding *Hevea* clones are commonly propagated through grafting buds of selected clones onto unselected seedling rootstocks raised in polybags using the young budding technique (Nayanakantha *et al.*, 2014). Therefore, seedlings are indispensable as stock plants for bud grafting of *Hevea*.

In young budding, germinated seeds are placed directly in polybags and the seedlings that emerge are allowed to grow for up to 3-4 months until the diameter of the stem becomes 6-7mm. The plants are then bud grafted and successfully grafted rootstocks are cut-back to promote the growth of the scion (Seneviratne, 2001). The quality of a young-budded plant depends on the quality of the rootstock and the bud patch (scion). Therefore, rootstocks play an important role in influencing the performance of scion after bud grafting.

Until 1975, there were recommended clones such as Tjir 1, AVROS 163 and BD 10 to collect seeds for rootstock nurseries. However, as the clones recommended for plantations changed, the older ones recommended to collect seeds gradually disappeared from rubber plantations and therefore seeds of all clones such as RRIC 45, PB 86, RRIC 36, RRIC 52, etc., were recommended to establish rootstock nurseries (Samaranayake, 1975). Nevertheless, some clones such as Wagga 6278 were restricted to use in stock nurseries due to low success in bud grafting (Samaranayake, 1975).

Currently, the clones recommended in the early 1970s and 1980s such as PB 86 and RRIC 100 are being used to establish rootstock nurseries. Nevertheless, the cultivation of PB 86 was stopped in the mid-1990s and the cultivation of RRIC 100 has been restricted (Nayanakantha, 2009). Older clones are being replaced with newer clones with high yielding potential under the current scenario. However, the currently popular clone RRIC 121, which has covered more than 50% of the total rubber cultivation of Sri Lanka, and other clones *viz.*, RRISL 203 and RRISL 2001 recommended for smallholders have recorded a low seed yield (Anon, 2015). Nevertheless, some newer clones (RRISL 200 series) *viz.* RRISL 201, 206, 217, 220 and 226 recommended in the mid-1990s have shown satisfactory seed production (Anon, 2015). Therefore, evaluation of the seedling population from new clones is important.

Since the rootstocks are of seedling origin and heterozygous, their variability could influence the intra-clonal variability of the budded rubber plants. Attempts had been made to identify *Hevea* clones whose seedlings were comparatively better stocks for certain scions (Ng *et al.,* 1981; Cardinal *et al.,* 2007; Gireesh *et al.,*2011; Daud, *et al*., 2012). Monoclonal rootstocks such as GT 1, RRIM 623 and PB 5/51 have been known to have a beneficial effect on tree growth and productivity whilst rootstocks of RRIM 600 and PB 260 were reported to have poor growth potential (Ng *et al.,* 1981; Ahmad, 1999). Therefore, the selection of good rootstock is of utmost importance to obtain the maximum yield of the scion.

Currently, rubber cultivation is being expanded into dry and marginally dry areas of Sri Lanka and abiotic stresses such as drought and heat would be major impediments limiting the growth and development of rubber plants (Nayanakantha *et al.,* 2014). Since the root system is vital to the water and nutrient uptake of all plants, it is envisaged that the use of suitable rootstock with a better root architecture would be beneficial in improving water uptake from the soil for better growth under stress. The rootstock of the clone RRIM 600 has been shown to possess a deep rooting characteristic which is essential for drought tolerance in budded rubber plants (Clermont-Dauphin *et al.*, 2013; Khotcharat *et al.*, 2016). Therefore, the present study was conducted to evaluate the germination dynamics, growth and bud grafting performance of seedlings raised from seeds of selected newer clones and bud grafted with the RRISL 203 scion.

MATERIALS AND METHODS

Planting Material

This study was conducted in a nursery at the Rubber Research Institute of Sri Lanka (RRISL), Dartonfield, Agalawatta, from August 2016 to March 2017. Open-pollinated rubber seeds of six *Hevea* clones *viz* RRIC 100, RRISL 201, 206, 220, 221and 226, planted in 1999, were collected at the early seed fall from Salawa Estate, Avissawella and brought to RRISL.

The experiment consisted of newer clones *viz.*, RRISL 201, 206, 220, 221 and 226 which were considered as treatments whilst the clone RRIC 100 was considered as the control. Seeds of these clones were sown in a germination bed filled with sand according to a Randomized Complete Block Design (RCBD) with four blocks. Each block contained 6 plots with 20 seeds from each clone and therefore, the total number of seeds used for the experiment was 480. Germination beds were watered once daily. Cumulative germination percentage was recorded at 14 and 21 days after sowing. Seeds were considered as germinated when the radicle had protruded about 2 mm through the seed coat.

Germinated seedlings were transplanted in black polythene bags, gauge 300 and having lay-flat dimensions of 15 cm diameter and 37 cm height, filled with soil. Polybags were arranged in a nursery according to a Randomized Complete Block Design (RCBD) with three blocks. Each block contained 42 plants, 7 from each treatment and therefore, the total number of replicates for each treatment was twenty-one. Two weeks after transplanting, application of young budding fertilizer mixture in liquid form into seedlings was started and carried out at two-week intervals. All other management practices were the same as recommended by the Rubber Research Institute of Sri Lanka (Anon., 2013).

Measurement of Growth Parameters of Seedlings

Growth attributes of rubber seedlings were assessed after five months of transplanting. Ten plants from each treatment were removed and the root system was washed gently under running water over a 0.5 mm sieve and the adhering soil and dust particles were carefully removed. Morphological attributes *viz.*, the diameter of the stem, plant height and number of leaves were recorded. Leaf area was determined by leaf area meter (Model L1-3100, LI-COR, USA). Chlorophyll content was measured using SPAD 502 Plus Chlorophyll meter. Dry weights (DW) of shoots and roots were obtained by oven-drying the samples at 70^{o}C for 48 hours.

Bud grafting

Seedlings were bud grafted with scions of RRISL 203 clone, which is one of the major clones recommended for both plantation companies and smallholders at present, using the green budding technique after five months from transplanting. Three weeks after bud grafting, polythene strip was removed from each plant, the green buds were counted and the percent bud grafting success was calculated by using the following formula:

$$\text{Bud grafting success (\%)} = \frac{\text{Total green buds}}{\text{Total buds inserted}} \times 100$$

Successfully grafted plants were pollarded at 15 cm above the bud patch one week after the removal of the polythene strip. The sprouted buds in each clonal seedling stock were counted one month after the cut back of stock plants and the sprouting percentage of bud was calculated using the following formula:

$$\text{Sprouting \%} = \frac{\text{Sprouted buds}}{\text{Total bud take}} \times 100$$

Manuring and all other agro-management practices were done as recommended by the Rubber Research Institute of Sri Lanka (Anon., 2013).

Data Analysis

The significance of the observed treatment (clonal) differences was tested by analysis of variance using the PROC ANOVA procedure of the SAS software package (version 9.1). Dunnett's t-tests were done to test the significant difference between the control (RRIC 100) and each newer clone at the 5% probability level.

RESULTS AND DISCUSSION

Seed Germination

Vegetative propagation through bud grafting is the current practice in the production of planting material in *Hevea* which involves rootstock and scion. Rootstocks are mainly raised from healthy seeds and the scion belongs to an elite genotype. Results of the present study revealed that the genotype did not influence germination of rubber seeds as the germination was satisfactory from all newer clones as compared to the old clone RRIC 100. Seeds from all clones recorded more than 50% germination within 14 days and completed 80%-90% germination after 21 days of sowing (Fig. 1). However, in contrast to the present study, Daud *et al.*, (2012) reported that, out of six *Hevea* clones, seeds from the clone PB 260 (old clone as the control) recorded the highest germination percentage (72%) whilst those from newer clones *viz.,* RRIM 2005 and RRIM 2006 recorded the lowest (below 50%) after 14 days of sowing. Apart from rubber, variation in seed characteristics for germination has been reported in other crops such as *Dalbergia sissoo* (Singh and Sofi, 2011). There were a lot of variations in seed size, seed weight, seed germination and growth parameters of different clones of *Dalbergia sissoo* (Singh and Sofi, 2011).

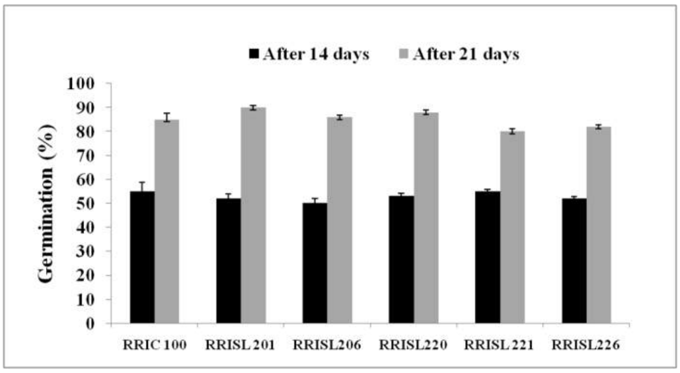

Fig. 1. Effect of clone on germination percentage of rubber seeds after 14 and 21 days of sowing

Seedling Attributes

Analysis of variance showed no significant differences (P<0.05) among clonal rootstocks for shoot attributes *viz.*, stem diameter, plant height, number of leaves, leaf area and chlorophyll content at 5 months of age (Table 1). Interestingly, the tallest plants with the highest stem diameter and chlorophyll content were recorded from seedlings of RRISL 226 although this clone exhibited the lowest values for the number of leaves and leaf area. The shortest plants were recorded from seedlings of RRISL 221 and the lowest stem diameter value was recorded from seedlings of RRISL 220 (Table 1). The maximum number of leaves, leaf area and chlorophyll content were recorded from seedlings of RRISL 201, 221 and 226 respectively (Table 1). The lowest values for mean shoot dry weight were recorded from seedlings of RRISL 220 and RRISL 206 and the values differed significantly (P<0.05) with that of RRIC 100 (Table 2).

There were no significant differences (P<0.05) between the old clone RRIC 100 and newer clones for root attributes *viz.*, dry weight of tap root, dry weight of lateral roots and dry weight of total roots (Table 2). Nevertheless, the maximum dry weight value for taproot and the total roots were recorded from the seedlings of RRISL 226 (Table 2). Moreover, the highest value for shoot dry weight was recorded from seedlings of RRIC 100 although the highest value for the total roots was recorded from the seedlings of RRISL 226. These data suggest that maternal origin is an important determinant of the early seedling growth of *Hevea.*

Table 1. *Effect of clone on growth attributes of rubber seedlings*

Treatments (Clones)	Stem height (cm/plant)	Stem diameter (mm/plant)	No.of leaves (per plant)	Leaf area (cm^2 /plant)	Chlorophyll content (SPAD value)
RRIC 100	112.47± 5.02	12.17± 0.49	15.00± 0.12	2041.20± 322.27	54.26±2.49
RRISL 201	106.33± 7.69	11.07± 0.23	17.50± 0.31	1523.00 ±48.89	57.51±1.80
RRISL 206	103.70± 3.75	11.07± 0.75	13.33 ±0.45	1615.70 ± 63.71	56.68±1.84
RRISL 220	108.73± 12.14	10.17± 0.68	14.16± 0.46	1892.20 ± 111.86	55.46±2.39
RRISL 221	94.53± 5.17	11.60 ± 0.35	14.83 ±0.52	1972.80 ± 129.44	56.84±2.52
RRISL 226	132.80± 4.60	12.30±0.74	11.66± 0.43	1352.20± 175.69	58.12±1.23
$LSD_{0.05}$	30.22	2.24	4.66	747.29	9.3
	NS	NS	NS	NS	NS

The values are the means and standard error (SE) of 10 seedlings (n=10). NS: Dunnett's t-test not significant at p≤0.05.

Variation in seedling populations raised from seeds of different clones has been reported in other countries as well. According to Wattanasilakorn *et al.* (2015) seedlings of the clone, RRIM 600 showed significantly higher shoot growth when compared to EIRpsu 1 and EIRpsu 2. Ahmad (1999) reported that rootstocks of GT 1 and RRIM 623 had a greater allocation of dry matter that went to the root than to shoot thus resulting in a higher root: shoot ratio. In contrast, budded plants raised from seedlings of RRIM 600 had a significantly lower root: shoot ratio since the dry matter was preferentially allocated to shoot rather than to root growth. Nevertheless, in contrast to the studies referred to above, the seedlings of the clone RRIM 600 have been shown to possess a deep rooting characteristic and hence perform well under drought conditions (Clermont-Dauphin *et al.*, 2013; Khotcharat *et al.*, 2016). Annapurna *et al.* (2005) studied the impact of clones in clonal seed orchards on the variation of seed traits, germination and seedling growth in *Santalum album* and found vast variation in seed size, weight, germination, vigor and seedling growth of the seed of different clones over the years.

Bud grafting

Bud grafting success was satisfactory for seedlings of all newer clones except RRISL 220 when compared to seedlings of RRIC 100. Interestingly seedlings of RRISL 226 recorded 100% bud grafting success followed by those of RRIC 100 (88.9%), RRISL 221 (77.8%) and RRISL 201 (73.3%) after one month from bud grafting (Fig 2A). Nevertheless, the seedlings of RRISL 226 recorded the highest sprouting percentage (67.2%) whilst those of RRISL 221 showed the lowest sprouting percentage (37.3%) after one month from the cut back of the stock plants. Seedlings of other newer clones recorded an average sprouting percentage as compared to those of RRIC 100 (61.1%) (Fig. 2B).

Table 2. *Effect of clone on the shoot and root attributes of rubber seedlings*

Treatments (Clones)	DW of tap root (g/plant)	DW of lateral (SR & ESR) roots (g/plant)	DW of total roots (g/plant)	DW of shoot (g/plant)	Root/shoot ratio (g/g)
RRIC 100	6.74±2.46	4.40± 2.33	11.16±0.14	29.16±2.75	0.39±0.03
RRISL 201	7.37±1.14	2.23± 0.59	9.58±1.58	21.30±0.23	0.45±0.07
RRISL 206	6.4±0.73	2.63± 0.81	9.02±1.52	18.90±2.70*	0.47±0.01
RRISL 220	6.0±1.52	2.13± 0.35	8.13±1.83	17.60±3.00*	0.51±0.16
RRISL 221	6.5±0.52	2.37± 0.76	8.87±1.17	28.86±1.30	0.30±0.02
RRISL 226	7.84±0.36	3.13± 0.36	11.74±0.47	21.40±0.87	0.54±0.01
$LSD_{0.05}$	5.86 NS	4.37 NS	5.77 NS	7.89	0.33 NS

DW: Dry weight; SR: Secondary roots, ESR: Early secondary roots. The values are the means and standard error (SE) of 10 seedlings (n=10). Asterisks indicate a significant difference between the control (RRIC 100) and each treatment according to Dunnett's t-test at p≤0.05. NS: Dunnett's t-test is non-significant at p≤0.05.

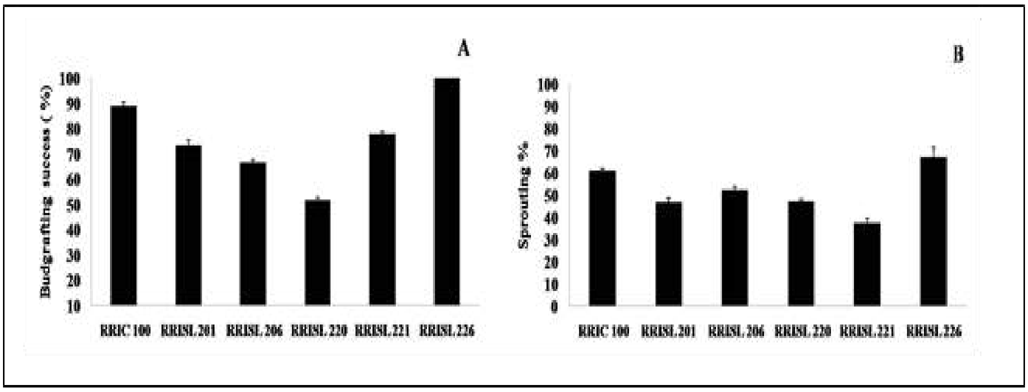

Fig. 2. Effect of clonal seedling rootstock on percentage bud grafting success with the RRISL 203 scion (A) after one month and percentage sprouting (B) after one month from cut back of the stock plants.

The growth of many plants in cultivated systems is profoundly affected by the selection of an appropriate rootstock. Rootstock selection offers a powerful tool for the sustainable intensification of crop production because while the scion genotype can be used to select crop properties, adaptation to abiotic and biotic stresses can all be influenced by the choice of rootstock (Tamura, 2012). A scion grafted onto a rootstock with a limited capacity for water uptake would operate under a continual mild water deficit that may limit shoot growth (Cohen and Naor, 2002). Therefore, it can be presumed that the budded plants of RRISL 203 carrying the seedling stocks of RRISL 226 and RRIC 100 would perform well under abiotic stress conditions and be more suitable to cultivate in nontraditional drier areas of Sri Lanka.

According to the general consensuses of the budders, the bud grafting success with the RRISL 203 scion is low as compared to a popularly clone RRIC 121. Nevertheless, the low bud grafting success of RRISL 203 on different rootstocks in the present study could be attributed to high incompatibility and/ or the unfavorable weather conditions (high temperature and drought) that prevailed during the budgrafting period. In the present study, seedling families raised from RRISL 203 were not used as the seed production of RRISL 203 was very low when compared to other clones used in the present study. Donald (1973) reported that 91% of the grafts were compatible when seedling families were grafted upon rootstocks that were compatible with both parents. Ng *et al.* (1981) showed that rootstocks could significantly influence the growth and yield of the scions of *Hevea.* Gonçalves and Martins (2002) reported that the scion of RRIM 600 showed high compatibility with various rootstock clones. Nevertheless, the seeds of RRISL 203 showed average compatibility with rootstock clones used in the present study. Santos *et al.* (2004) examined rootstock mediated dwarfing in sweet cherry and found that trunk cross-sectional area (TCSA), final shoot length and final node number were significantly affected by different rootstocks. Therefore, the growth performance of budded plants should be evaluated under nursery and field conditions to study the influence of stock on the growth of scion of rubber. However, mechanisms underlying interspecific graft incompatibilities are as yet insufficiently understood (Goldschmidt, 2014).

Incomplete and convoluted vascular connections impede the vital upward and downward whole plant transfer routes. Long-distance protein, mRNA and small RNA graft-transmissible signals currently emerge as novel mechanisms which regulate nutritional and developmental root/top relations and may play a pivotal role in grafting physiology (Goldschmidt, 2014). The upward supply of water and mineral nutrients, as well as the downward flow of photosynthates, could be modified due to the interchange of hormonal signals through the graft union zone (Goldschmidt, 2014). Sorce *et al.* (2002) demonstrated that scion levels of zeatin riboside and indole acetic acid (IAA) amounts were significantly controlled by the rootstock in the peach variety 'Armking' on three interspecific rootstocks.

The time taken for sprouting could be a few days to three months or more depending on the scion genotype and stock scion interaction of *Hevea* (Seneviratne *et al.,* 1996). Therefore, the reason for the high bud grafting success percentage but with low sprouting success in the RRISL 203 scion on the stock of RRISL 221 could be due to the requirement of a long time for the onset of sprouting. Therefore, all five newer clones may be utilized to raise stock nurseries for bud grafting with RRISL 203 scions. Rootstock-scion interactions persist throughout the life of the budded plants, even where satisfactory graft compatibility has been achieved (Goldschmidt, 2014). Therefore, further research is needed to investigate the response and growth performance of selected scions bud grafted onto newer clonal rootstocks of *Hevea* under field conditions.

Conclusion

Seedlings raised from seeds of newer clones *viz.*, RRISL 201, 206, 220, 221 and 226 may be used as rootstocks for bud grafting with RRISL 203 scion to produce young-budded plants of rubber.

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OPTIMIZING THE UTILIZATION OF RUBBER LANDS WITH INTERCROPS: A FINANCIAL ASSESSMENT

P G N Ishani, V H L Rodrigo, J K S Sankalpa and A M R W S D Rathnayaka

Introduction

In productivity improvements, yield per tree and productive trees per unit area have been the major concerns in rubber plantations throughout (Wibawa *et al.*, 2006; Rodrigo, 2007; Gohet *et al.*, 2016). Limitation in lands for agriculture, escalating management costs, high level of life expectations and competition from other remunerative crops under low price situations for rubber are not in favour of sole cropping of rubber (Rodrigo, 2007; Iqbal *et al.*, 2006; Jongrungrot and Thungwa, 2014; Hougni *et al.*, 2018). With that, the potential of cultivating intercrops in rubber lands for extra income generation is under the consideration (Iqbal *et al.*, 2006). Intercropping rubber with another remunerative crop is a popular term with regards to spatial and temporal optimization in land use (Rodrigo, 2001; Iqbal *et al.*, 2006; Jongrungrot and Thungwa, 2014; Hougni *et al.*, 2018; Sankalpa *et al.*, 2020).

The question is which crops are to be suitable for rubber-based intercropping. There is no single answer; all crops have both advantages and disadvantages. Obviously, in crop selection, agronomic, social, financial, marketing and management aspects are to be looked into with given consideration to strengths available and possibilities of avoiding weaknesses. Due to the nature of complexity, this study does not intend to discuss all these aspects; but to guide in selecting crops on a financial basis.

Methodology

Financial analyses were conducted with nine intercrops including three annual crops (maize, groundnut, cowpea), three semi perennials (passionfruit, banana and pineapple) and three perennial crops (pepper, cinnamon and cocoa). We gathered information from the intercropping survey conducted in Monaragala District and published data (2019) by the Ministry of Agriculture, Sri Lanka. The annual crops and semi perennials can be cultivated in the first four years of rubber cultivation. Perennials like cinnamon, pepper and cocoa could be intercropped throughout the economic life span of rubber plantations (Rodrigo, 2001; Sankalpa, 2020).

We gathered the quantities of labour and material inputs together with their market rates from the farmers involved in intercropping for farm-level cost estimations. Also, crop yields and farm gate prices of harvests were collected from the same to value the income. All values were standardized in consultation with the experts in the relevant fields (Department of Export Agriculture (DEA), Fruit Crop Research and Development Institute (FCRDI)). A summary of the monetary values of planting materials and yield components is given in Table 1. In each case, the value of a labour day was considered as LKR 1,200.

Table 1. *Monetary values of planting materials and yield components*

	Intercrop	Planting materials (Units/ha)	The unit cost of planting material (LKR)	Yield (kg/ha)*	Farmgate price of yield (LKR/kg)
Annual	Maize	Seeds - 3.6 kg	Seed – 1245/kg	2156	44
	Groundnut	Seed - 42.16 kg	Seed – 195/kg	1021	180
	Cowpea	Seed -7.89kg	Seed – 268/kg	356	173
	Pineapple	Suckers -12500	15/Sucker	12500	90
Semi Perennial	Banana (“Kolikuttu”)	Plants - 600	125/Plant	4913	115
	Passionfruit	Plants - 530	75/Plant	7455	60
	Pepper	Plants -1000	23/Plant	982	800
Perennial	Cinnamon	Plants – 6500	9/Plant	533	2000
	Cocoa	Plants – 400	12/Plant	630	300

*For annual crops – kg/ha/season; For other crops – kg/ha/yr

Being the most common method employed in project analysis, indices of Benefit-Cost Analysis (BCA) are used to compare the financial profitability of the intercropping systems. Hence, three metrics namely; Benefit-Cost Ratio (BCR), Net Present Value (NPV) and Internal Rate of Return (IRR) which are incorporated in the BCA approach are used to evaluate the different intercropping systems. When a particular project continues for several years, worthiness of the project cannot be done simply by comparing the cumulative values of costs and benefits occurring at different points in time. The flow of funds (costs and revenues or benefits) over time need to be taken to present values by a process called discounting. Hence the cash flows generated from the different intercropping systems were discounted at a 10% discount rate.

NPV refers to the difference between the discounted present values of future benefits and the discounted present values of future costs. If NPV is positive that means the project benefits are greater than its costs, and *vice versa*. BCR of a project can be calculated by dividing the discounted present value of future benefits by the discounted present value of future costs. BC ratio is greater than one when the discounted benefits exceed the discounted costs. Investments with higher BC ratios are preferred over investments with lower BC ratios. IRR is the discounted rate at which the NPV of a project becomes zero. If the internal rate of return of a particular project is higher than the rate of return produced by an average similar investment, the investment is considered worthwhile. Moreover, a higher internal rate of return of a project indicates the higher desirability of the project (Gittinger, 1982; Campbell and Brown, 2003; Munasinghe and Rodrigo, 2017). Being limited to a single year, no discounting approach was adopted for annual crops, hence no analysis of IRR. In addition to the above-mentioned indicators, the initial investment required, average monthly income and payback periods were reviewed in assessing the utilities of the selected intercrops. The payback period refers to the time required to recover the initial investment made on crop establishment. Having several years involved, the payback period was calculated only for semi-perennial and perennial crops.

Better to show how BCR etc. are calculated.

Results

Initial investment

Initial investment plays a major role in selecting an intercrop except for the agronomic suitability and grower's intention on the short and long-term return. This has been subjected to a high level of variation as shown in Table 2. Among the annual crops, the highest level of initial investment has been required for maize cultivation followed by groundnut and cowpea. The initial investment for groundnut was about twofold higher than what is required for cowpea. In semi perennials, the initial investment in pineapple cultivation was 39% and 66% higher than that of passionfruit and banana cultivations, respectively. In three perennial crops selected for this study, the highest level of initial investment has been required for cinnamon cultivation followed by pepper and cocoa. The initial investment required for cocoa cultivation was five to six folds lower than that of pepper and cinnamon cultivations.

Table 2. *Initial investments required for intercrops*

Type	Intercrop	Initial investment (LKR/ha)
Annual	Maize	75,828
	Groundnut	63,418
	Cowpea	31,029
Semi Perennial	Pineapple	533,887
	Banana	184,055
	Passionfruit	320,611
Perennial	Pepper	441,425
	Cinnamon	530,039
	Cocoa	89,089

Average Monthly Income

The farmer received the highest average monthly income when he opted for pineapple cultivation in the rubber land (Table 6). Having only a specific time for harvests, monthly income distribution was assessed only in semi-perennials and perennials. In perennials, the highest monthly average income was recorded from pepper followed by cinnamon and cocoa.

Table 6. *Average Monthly income generated from the selected intercrops*

	Intercrop	Average monthly income (LKR/ha)
Semi Perennial	Pineapple	77,813
	Banana	37,734
	Passionfruit	43,651
Perennial	Pepper	61,075
	Cinnamon	45,460
	Cocoa	14,697

Net Present Value (NPV)

Discounted net profit (NPV) of the selected intercrops are depicted in Table 3. Among the annual crops, groundnut has dominated over the other two. In semi perennials, NPV of pineapple exceeded LKR 2 million with a gap of LKR 1.1 million to passionfruit whilst NPV of banana remained at LKR 0.5 million. Among perennial crops, the highest NPV of LKR 2.65 million was recorded from cinnamon followed by pepper (LKR 0.97 million) and cocoa (LKR 0.84 million).

Table 3. *NPV of the selected intercrops*

Type	Intercrop	NPV (LKR)
Annual	Maize	66,316
	Groundnut	419,909
	Cowpea	106,749
Semi Perennial	Pineapple	2,211,609
	Banana	511,699
	Passionfruit	1,094,932
Perennial	Pepper	966,639
	Cinnamon	2,652,082
	Cocoa	839,937

Internal Rate of Return (IRR)

Having several years involved in cultivation, IRR values were calculated only for semi perennial and perennial intercrops (Table 4). In semi-perennials, the highest IRR was exhibited from passionfruit cultivation followed by pineapple and banana cultivations. From the three perennial crops selected the IRR values of cocoa and cinnamon were quite comparable and higher than the IRR value of pepper.

Table 4. *IRR values of selected intercrops*

	Crop	IRR (%)
Semi Perennial	Pineapple	63
	Banana	55
	Passion Fruit	78
Perennial	Cinnamon	37
	Pepper	19
	Cocoa	39

Benefit-Cost Ratio (BCR)

Groundnut system reported the highest value for BCR and, maize became the lowest among annual intercrops (Table 5). In semi perennials and perennials, pineapple and cocoa recorded the highest BCRs, 3.46 and 2.62, respectively. The BCR value of pineapple was the highest among all crops. Although pepper had the lowest BCR, the value recorded was greater than one showing the financial profitability.

Table 5. *Benefit Cost Ratio (BCR) of selected intercrops*

Type	Intercrop	BCR
Annual	Maize	1.25
	Groundnut	2.90
	Cowpea	1.99
Semi Perennial	Pineapple	3.46
	Banana	1.52
	Passionfruit	2.55
Perennial	Pepper	1.22
	Cinnamon	2.48
	Cocoa	2.62

Payback period

The initial investment on all semi-perennial crops could be recovered within two years. While it took 5 years to recover the initial capital allocated on pepper and cocoa systems, cinnamon has had only 3 years to recover the initial capital (Table 7).

Table 7. *Payback period of the selected intercrops*

	Crop	Payback Period (Year)
Semi Perennial	Pineapple	2
	Banana	2
	Passion Fruit	2
Perennial	Cinnamon	3
	Pepper	5
	Cocoa	5

Discussion

Annual crops considered in the present study are mainly grown in drier climates, hence used as intercrops of rubber only in non-traditional rubber growing areas. Therefore, above mentioned intercrops can be found in the areas of Moneragala and Ampara districts under non-traditional cultivation. Also, there is a potential to grow annual crops under rubber in the other non-traditional areas (North Central and North province). Among the annual intercrops, cowpea has become the low input crop in terms of labour and materials and therefore a low level of the initial investment was required for the establishment. This is mainly due to higher family labour and the use of their own resources in cowpea cultivation compared to other annual crops. However, cowpea has had a reasonable level of farmgate price for the produce (LKR 173/kg) and hence, a high level of profit margin could be gained as shown by NPV and BCR. The benefit received by the groundnut ground cultivation in rubber lands is three times higher than their cost of investments and it is 2 and 1.25 for cowpea and maize, respectively. Similarly, BCRs for other crops are given in Table 5. Farmers tend to use imported seeds in maize cultivation with a high level of investment; however, ultimate harvest varies with the prevalence of pest infestation and thus, the average return for investment remains at a low level. Groundnut cultivation has had a moderate level of initial investment with the highest level of profit margin as shown by NPV and BCR. Therefore, it could be considered as the best annual crop for intercropping on financial aspects.

Semi-perennials are limited to the first four years of rubber cultivation. Among the crops investigated, pineapple has become the most profitable crop though it required a high level of initial investment particularly for land preparation and planting materials. The next in line was the passionfruit. However, both these crops need to have proper marketing arrangements to gain such profits according to the authors' own experiences on the marketing channels of intercrops. Banana seems to be the most companion crop grow with the rubber though it generates a lower return compared to other intercrops. The higher adoption of banana in rubber lands was reported in many areas of the traditional region (Rodrigo *et al.*, 2001) and the non-traditional region in Sri Lanka (Sankalpa *et al.*, 2020) since the banana has been reported as the most companion crop for smallholder farmers which requires minimum inputs compared to other crops.

The initial investment required for cinnamon was the highest among the three selected perennial crops for the study; however, its overall profit seemed to be the highest among the perennials tested. In general, pepper and cocoa are rather shade-tolerant; hence, long-term cultivation with rubber is feasible. Cinnamon is a sun-loving crop and in the case of intercropping, the planting density of rubber has to be compromised. Therefore, its preferability as an intercrop becomes limited with the maturity of rubber plants.

As shown by all indicators, all crops tested here as intercrops are financially worthwhile. However, the selection of a particular intercrop should be done according to the socio-economic characteristics of the farmer where social, human, physical, natural and financial assets are considered. However, if a particular crop is promoted at a high scale based on the present level of profitability, the market for its products could be affected by reversing the profitability through an oversupply of the produce. Therefore, crop diversity is required and proper guidance by the extension personnel is essential to identify the most suitable intercrop by the respective farmer.

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IMPROVED ROOT MORPHOLOGY IN YOUNG BUDDED RUBBER PLANTS

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Introduction

Budded plant production for rubber cultivation was started with the introduction of the grafting technique by Dutch horticulturist Van Helton in 1917. Since then, all rubber growing countries gradually moved away from using seedlings in new planting and replanting programmes. The use of budded plants not only improved the productivity of rubber clearings but also the yields were predictable to a greater extent. However, nursery management is necessary to guarantee the quality of budded plants and also to produce the quantity required. The rootstock nurseries were maintained as ground nurseries until 2003 and the disadvantages of ground rootstock nurseries were mainly the long period required to produce a bare root budded plant and secondly the damages occurred at the time of uprooting them after bud grafting. Ground root stock plants are bud grafted when they are about 1½ years old and with same aged bud wood. The green budding technique was to improve the quality of planting material through reducing the age of the budded plant, but the majority ended up in producing brown buddings. However, from the 1980's onwards, these bare root budded pants were first planted in large size poly bags, 9′x18′ and grew up to 2-3 leaf whorl stage. The use of these poly bag plants increased field establishment rate at field planting and allowed to identify the clone at the age of 2-3 whorls.

However, when bare root budded plants produced in ground rootstock nurseries were planted in polybags, the main disadvantage was the extended time taken to produce a plant for field planting and the coiling of the taproot in the bag which affected the growth of the root system. Also though large size bags were used, there were only a few lateral roots developed on the taproot du (Plate 1).

Since 2003, in Sri Lanka, the total rubber plant production was through young budding technique, where the germinated seeds are directly planted in small size polythene bags filled with topsoil.

In young budding technique, it is recommended to sow fresh rubber seeds collected from the early seed fall in germination beds and to harvest only early germinated 50% or less to generate rootstocks. When the proper seed selection was done for vigorous rootstocks, the taproot generally reach the base of the bag within the first month of transplanting of the germinated seeds into the bags. Once the tap root touches the bag it grows horizontally, within the bag at the base generally termed as coiling. In some cases, the taproot penetrates the base of the bag and grow into the soil after 2-3 rounds of coiling. In rare cases, especially with weak seedlings, the coiled tap root remains in the bag without penetrating the base. Restricting the growth of root system creates a "bonsai effect". When the growth of the roots is restricted, the growth of the aerial parts is restricted and this affects the bud grafting success. At least 6 mm diameter is required to undertake bud grafting which is expected after about 4 months of planting of germinated seeds in bags. The roots should be allowed to grow freely in order to improve girthing. The objective of this study was to observe the effect of having a central hole in the polybag for the growth of the plants and the root morphology.

Materials and Methods

Seeds were collected in the early seed fall and sown in germination beds. Early germinated seedlings were transplanted into 6’x15’ black polythene bags of gauge 300, the bottom half perforated. Filing of bags was done with top soil mixed with rock phosphate (50g/bag) and compost at 50g per bag as recommended (Advisory leaflet, 2006/04, ‘Fertilizer to rubber’)

Nursery management and aftercare were as per the Advisory Leaflet 2016/09, ‘Production of budded plants’.

Two treatments tested were poly bags with ½’ and ¾’ hole at the center of the base of the bag with the control. Replication was 50 and rootstocks were bud grafted with budwood of clone RRIC 100. The diameter of rootstock and budded plants were measured with a caliper and the height was measured with a meter ruler.

Polybags were supplied from local suppliers and the two different sizes of central holes were tested. Square shape hole at the base of the bag was prepared by folding the bag lengthwise in to two and then making with a diagonal cut with a pair of scissors, measured to be 1/2’ and 3/4’ in length.

The diameter and the height of the seedlings and budded plants were measured. Coiling of the tap root was monitored and presented as a percentage and the length of the roots was measured.

Results

Mean diameter and the mean height of the seedlings 10 weeks after transplanting in to bags are shown in Figures 1a and 1b.

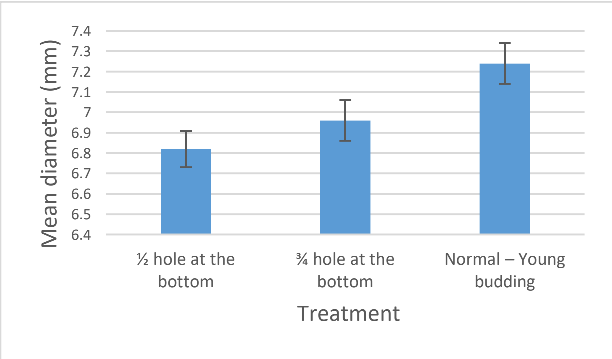

Fig.1a. Mean diameter (mm) of the seedlings grown in 3 types of bags, i.e. 10 weeks after transplanting into bags with ½’ hole, ¾’ hole and the control. SEM values are given on the bars.

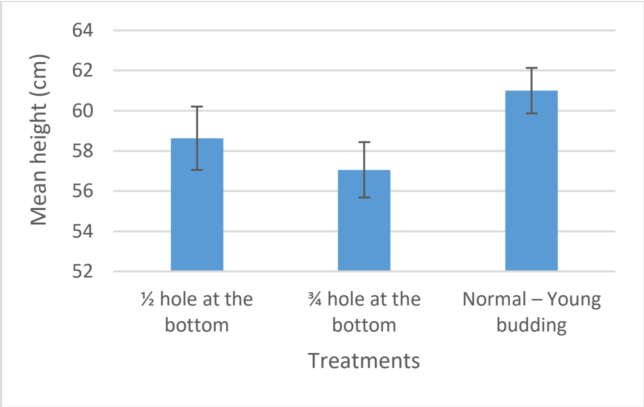

Fig. 1.b Mean height (cm) of the seedlings grown in 3 types of bags, i.e. 10 weeks after transplanting into bags with ½' hole, ¾' hole and without a hole. SEM values are given on the bars.

As it is clear from Figure 1a, diameter values of more than 6mm have been achieved in plants grown in all three types of bags. Low SEM values indicate the uniformity within the treatment.

The diameter or the seedlings grown in normal polybags is slightly higher than the growth of seedlings grown in the other two types with central holes at the base. Mean heights also show the same pattern and the SEM values are low for the height of the seedlings, though the differences are very small.

One month after bud grafting the seedlings with bud wood of RRIC 100, rootstocks were cut back and the mean diameter and the mean height of the scion shoots after 5 weeks of cut back are shown in Figures 2a and 2b.

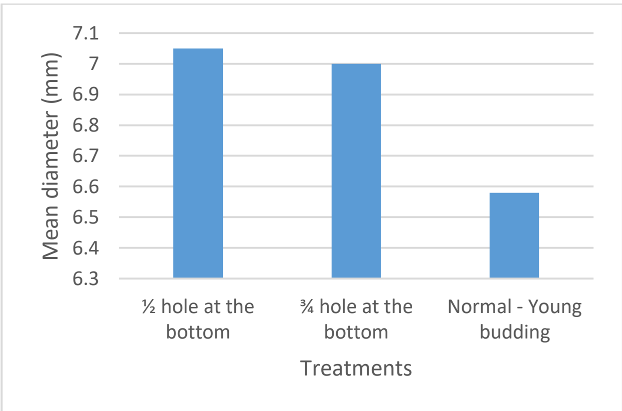

Fig. 2a . Mean diameter (mm) of the scion shoot of clone RRIC 100, five weeks after cut back of the rootstock in plants grown in three types of bags, ½' hole at the base of the bag, ¾' hole at the base and without hole at the base.

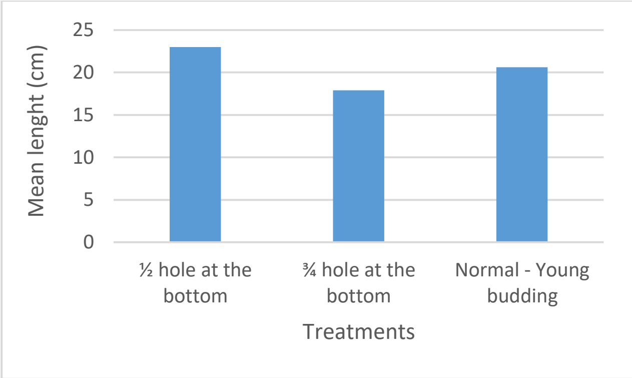

Fig. 2b. Mean height (cm) of the scion shoot of clone RRIC 100, five weeks after cut back of the rootstock in plants grown in three types of bags, ½ʹ hole at the base of the bag, ¾ʹ hole at the base and without a hole at the base

As it can be seen from Figure 2a, the mean diameter of the grafted scion shoot of the plants grown in all three types of bags are comparable at 5 weeks of cut back. However, those grown in bags with central holes show slightly higher diameters than those grown in bags with no central hole. For the height also the values are a little lower when the bags had a ¾ʹ central hole, possibly due to flush growth and some shoots are in the stationary phase at the time of measuring.

Root morphology

It was observed from the data that tap root coiling was lower when the bag has a central hole at the base and morphological differences are shown in Plate 2.

Plate 1. Tap root coiling at the base of the bag in polybags before penetrating to the ground.

(a). ½′ hole at the base

(b).¾ ′ hole at the base

(c) without a hole at the base

Plate 2. Differences in root morphology in budded plants grown in three types of bags, (a) ½′ hole at the base of the bag, (b). ¾′ hole at the base and (c) without a hole at the base.

Percentage values of tap root coiling at the base of the bag and mean root length of the taproot penetrated below the bag of unbudded plants are given in Table 1.

Table 1. *Percentage of coiling of tap root at the base of the bag and mean length of the tap root penetrated below the bag of the unbudded plants grown in three types of bags, ½′ hole at the base of the bag, ¾′ hole at the base and without hole at the base, at four months.*

Treatment	**Taproot Coiling %**				**Mean root length below the bag (cm)**
	Fully coiled	**Half coiled**	**Slightly coiled**	**Not coiled at all**	
½′ hole at the base of the bag	21.4	14.3	10.7	53.6	189.8
¾′ hole at the base of the bag	7.8	16.8	26.5	48.9	168.8
Control- without a central hole	50	36.7	10.1	3.2	174.4

As it is clear from the data, there is a marked difference between the central hole and the absence of the hole at the base of the bag for root coiling. The mean length of the tap root is more or less the same, varying from 1.6m to 1.8m.

Discussion

The results of the present study reveal that the tap root can be allowed to grow without coiling if a hole is made at the center of the base of the bag. It also reveals that though not significant, the growth of the scion is improved when the bag has a central hole. As the growth of rubber seedlings and budded plants occur in flushes, the height of the plant sometimes masks the effect of a treatment. The diameter is a more reliable measurement at any given time. Though some tend to worry about root coiling, at the base of the bag, the tap root is anyway cut at the base of the bag at field planting of young buddings. The tap root also grown thicker than the size of the trunk and at uprooting the root bowl looks like a huge mass of tapering to a depth of about one meter. Thick lateral roots also emerge and the number varies to a greater extent. A good root system is compulsory for the satisfactory growth of the trunk. In rocky lands and areas with shallow bedrock, the growth of the trees are severely affected.

At planting, one may cut the tap root at the beginning of the root coiling in order to allow the tap root to grow in the field without a loop. however, polybag planting was practiced in Sri Lanka since the 1980's and 100% of young budding planting was adopted since 2003.

Good growth is seen in the field and the factors that continue to the growth of the trees are the clone, the soil condition, especially whether the land is very rocky and very sloppy and the climate and weather conditions. As young budding plants are transferred to the field when they are about 10 months they grow faster than bare root budded stumps which are about two years or some times more.

Root trainers are popular in India (Soman, 1999) and the main advantage being no root coiling as seen in poly bag plants. But, as reported earlier. If the same size hole is prepared with a smaller size bag then there is hardly any room at the base of the bag for the tap root to coil but grow straightaway down without coiling. Also, the effect of the container seems minimum as the tap root penetrates the bag even when there is no hole. The advantage of having a hole at the base is that then the tap root grows without coiling. However, as reported by Dharmakeerthi, *et al.*, (2008), once the rootstock is cut after bud grafting, the root system especially the lateral roots gets naturally pruned to a greater extent within the bag. Though the tap root grows outside without coiling at the base, that portion of the tap root or the lateral will be removed at field planting. As the bag is removed at planting the part of the coiled tap root can also be removed. So that the tap root will continue to grow from the cut point. The reason why the planting is recommended with the onset of the monsoon rains is the disturbances happen to the root system at field planting, which are unavoidable.

The most important factor in rubber planting material production is to take all possible steps to produce high quality plants, which has the long-term effect which determines the productivity of the rubber tree in the field.

Main factor for the vigorous root system is to collect seeds from the early seed fall and then harvesting only 50% of early germinating seedlings from germination beds. For the bud wood, they should be juvenile in order to have a faster growth rate. Provided the selection of vigorous root system and maintenance of juvenility in bud wood is properly looked after then the quality is plants are good. If immature upkeep is done as per the recommendations of the RRISL especially during the growth phase of the first 4-5 years of field planting, then the trees will grow satisfactorily and guarantee the potential yield of the clone.

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APPROPRIATE USE OF STATISTICAL METHODS IN RAINFALL ANALYSIS:DETECTING MONOTONIC AND SEQUENTIAL TRENDS IN RAINFALL DATA AT DARTONFIELD

A M R W S D Rathnayaka, N D Wijesuriya, B W Wijesuriya

ABSTRACT

This article introduces the statistical methods available for detecting monotonic and sequential trends in rainfall series. The illustrations are focused on methods available in Excel add-ins (MAKESENS 1.0) and R open-source software. Out of the monthly series, only February has a significantly increasing monotonic trend and also exhibited a sequential trend change (change point) in 1987. None of the other months or seasonal rainfall series did not show either significant monotonic or sequential trends.

INTRODUCTION

Trend analysis is one of the most popular statistical approaches which has been extensively used in meteorological sciences for analysis of the variation in hydro-meteorological variables in recent decades. Broadly speaking, trends occur in two ways: a gradual change over time that is consistent in direction is called a monotonic trend and an abrupt shift at a specific point in time is called a step trend or a sequential trend.

The Mann-Kendall (MK) statistical test proposed by Mann (1945) and Kendall (1975), to test the monotonic trends is a rank-based non-parametric method. This method has been widely used for detecting trends in hydro-meteorological time series including groundwater, water quality, stream flow, lake level, temperature, and precipitation. Compared to parametric tests such as regression coefficient test, non-parametric tests such as the MK test has no requirements on the distribution of the data sample and is less sensitive to outliers. As the MK test statistic is determined by the ranks and sequences of time series rather than the original values, it is robust when dealing with non-normally distributed data, censored data, and time series with missing values (Hirsch and Slack, 1984) which are commonly found in hydro-meteorological time series. The MK test is available in statistical software packages and also available in Excel as add-ins. It is also possible to use R Studio through packages; “Trend” and especially when there exist serial dependence in time series data, it is suggested to use the package “modifiedmk” available in R.

The step trends or abrupt changes in time series or sequential trends of rainfall are also important to detect the change point in trend change. Since the MK method does not provide any information about the fluctuation points or changes in the trend location, the sequential MK test is proposed by the World Meteorological

Organization (WMO) (Sneyers, 1990). Here the MK test is sequentially applied for each point in the time series as suggested by Sneyers (1990) to produce sequential values u(t) starting from the first value through last (pro-grade series) and u'(t) (retrograde series) from the same method applied to the series from the last point to the first point.

The objective of this article is to introduce the above methods for the rainfall records of the Dartonfield Meteorological Station to analyze the trends for monthly and seasonal series of rainfall. While introducing the MK approach, it is expected to investigate the monotonic and sequential trends of rainfall series for different months at Dartonfield to see whether they exhibit trends which is an indication of the shifts in rainfall pattern.

METHODOLOGY

Data:

The monthly series for the 12 months and the 04 seasonal series for the period 1980 to 2020 recorded at the Meteorological station at Dartonfield, Agalawatta in the Agro-ecological Region, WL_{1a} were used in this study.

Statistical Method:

The MAKESENS package (MAKESENS 1.0) in Excel is used for computing the MK statistic for simplicity in illustration 1. This user-friendly package was developed by the Finnish Meteorological Institute in 2002. Before doing the trend analysis, the serial dependency of the time series data was checked using the auto-correlations. Illustration 2 subsequently uses the open-source software R with packages 'Trend' and if autocorrelations are present the 'ModifiedMK' method is used. R package 'trend change' and sequential Mann Kendall test 'sqmk' were used for the analysis of sequential trends.

ILLUSTRATIONS

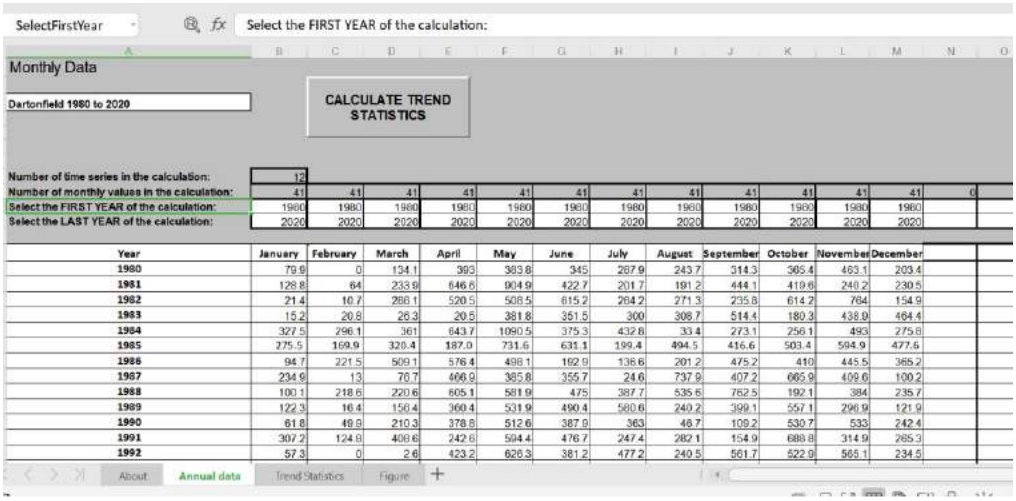
1. Use of MAKESENS package for detecting monotonic trends for the 12 months

The Excel template 'MAKESENS' is developed for detecting and estimating trends in time series. The procedure is based on the non-parametric Mann-Kendall test for the trend and the non-parametric Sen's method for testing the magnitude of the trend. The Mann-Kendall test is applicable to the detection of a monotonic trend of a time series with no seasonal or other cycles and Sen's method uses a linear model for the trend.

As the first step, the series of all months were analyzed to see whether there is a serial dependence between the values employing the Durbin-Watson (DW) statistic. The DW values obtained for all the months were in the range of 1.79 to 2.49, which is within the range of 1.5 to 2.5, and therefore there is no serial dependence of the data concerned which suggests that there is no necessity to use the modified Mann Kendall procedure.

The template used in MAKESENS to input monthly rainfall data is given in Figure 1. In this window, we can observe the number of time series in the analysis, the number of monthly values in the calculation, the first and the last year of calculation together with the tab for calculation of trend statistics. Once the tab is pressed, it gives an output of different statistics (Fig. 2).

Using MAKESENS, we want to test the null hypothesis of no trend, H_0, *viz*. the observations are randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. In the computation of this statistical test, MAKESENS exploits both the so-called S-statistics given in Gilbert (1987) and the normal approximation (Z statistics). For time series with less than 10 data points the S test is used, and for time series with 10 or more data points the normal approximation is used. In Figure 2, we can observe that 'Z' is computed since that the data series consisted of 41 values. To estimate the true slope of an existing trend (as a change per year) the Sen's non-parametric method is used (Gilbert, 1987). Sen's method can be used in cases where the trend can be assumed to be linear, where Q is the slope and B is the constant.



Number of time series in the calculation:	12												
Number of monthly values in the calculation:	41	41	41	41	41	41	41	41	41	41	41	41	0
Select the FIRST YEAR of the calculation:	1980	1980	1980	1980	1980	1980	1980	1980	1980	1980	1980	1980	
Select the LAST YEAR of the calculation:	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	

Year	January	February	March	April	May	June	July	August	September	October	November	December
1980	79.9	0	134.1	393	383.8	345	287.9	243.7	314.3	365.4	463.1	203.4
1981	128.8	64	233.9	646.6	904.9	422.7	201.7	191.2	444.1	419.6	240.2	230.5
1982	21.4	10.7	286.1	520.5	508.5	615.2	284.2	271.3	235.8	614.2	784	154.9
1983	15.2	20.8	26.3	20.5	381.8	351.5	300	308.7	514.4	180.3	438.9	464.4
1984	327.5	296.1	361	643.7	1090.5	375.3	432.8	33.4	273.1	256.1	493	275.8
1985	275.5	169.9	320.4	187.0	731.6	631.1	199.4	494.5	416.6	503.4	594.9	477.6
1986	94.7	221.5	509.1	576.4	498.1	192.9	136.6	201.2	475.2	410	445.5	365.2
1987	234.9	13	76.7	466.9	385.8	355.7	24.6	737.9	407.2	665.9	409.6	100.2
1988	100.1	218.6	220.6	605.1	581.9	475	387.7	535.6	762.5	192.1	384	235.7
1989	122.3	16.4	156.4	360.4	531.9	490.4	580.6	240.2	399.1	557.1	296.9	121.9
1990	61.8	49.9	210.3	378.8	512.6	387.9	363	46.7	109.2	530.7	533	242.4
1991	307.2	124.8	408.6	242.6	594.4	476.7	247.4	282.1	154.9	688.8	314.9	265.3
1992	57.3	0	2.6	423.2	626.3	381.2	477.2	240.5	561.7	522.9	565.1	234.5

Fig. 1. The template for data input in MAKESENS template

In this analysis, only the time series 'February' exhibited a significant trend at 0.05 probability level and the relevant slope and the constant are; 2.129 and 61.87, respectively (Fig. 2). Figure. 3 (A) depicts the temporal variation in the 'February' series which exhibits a monotonic trend. Figure 3 (B) depicts the variation in May, which does not exhibit a monotonic trend.

			Sen's slope estimate					
Time series	Test Z	Signific.	Q	Qmin95	Qmax95	B	Bmin95	Bmax95
January	0.71		0.950	-1.772	3.272	113.75	187.74	75.07
February	1.91	+	2.129	-0.090	4.503	61.87	110.75	4.87
March	-0.28		-0.221	-3.298	2.951	211.28	271.05	152.32
April	-1.07		-1.973	-6.582	2.169	420.09	526.09	340.88
May	-0.17		-0.565	-7.020	6.491	575.12	717.13	459.15
June	-0.37		-0.698	-4.726	2.773	395.14	492.92	336.29
July	-1.31		-2.038	-5.495	1.736	286.62	360.32	210.93
August	0.80		1.833	-2.608	5.290	223.70	310.79	177.02
September	0.80		2.152	-3.820	7.545	392.14	503.85	273.50
October	0.78		2.561	-3.949	7.290	490.59	592.64	366.261
November	-0.33		-0.623	-4.148	3.065	413.96	482.74	350.053
December	0.21		0.382	-2.938	4.224	232.65	297.62	200.159

Fig. 2. The output on the analysis from MAKESENS

2. Detecting monotonic trends in seasonal rainfall at Dartonfield using R

The usual bimodal pattern caused by the monsoonal influence exists in most rubber growing areas with peaks coinciding with May and October. North-East rains are usually experienced during the period from December to February. In general, the first inter-monsoon period (IM1) commences during March and April. South-West rains begin during May and extend to September followed by the second inter-monsoonal period (IM2) during October and November.

(A) (B)

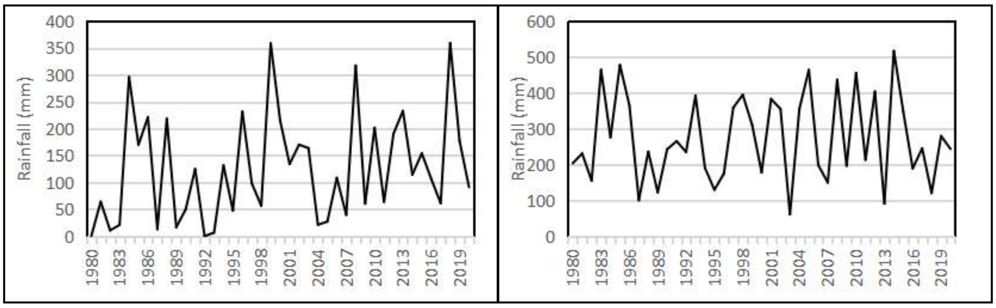


Fig. 3. The time series plot for the months of February (A) and December (B) for the Dartonfield Meteorological station

The temporal change in seasonal rainfall at Dartonfield is depicted in Figure 4. For the naked eye, the temporal series did not show any kind of trend. However, it is necessary to confirm this observation. This illustration uses seasonal rainfall data for the period 1980 to 2020 and the analysis is done using R software with the package 'Trends'. As for the monthly rainfall series, the serial dependency does not exist in seasonal rainfall time series. The Durbin-Watson statistic for the time series lied between 1.98 to 2.40, which suggests that there is no serial dependency in data.

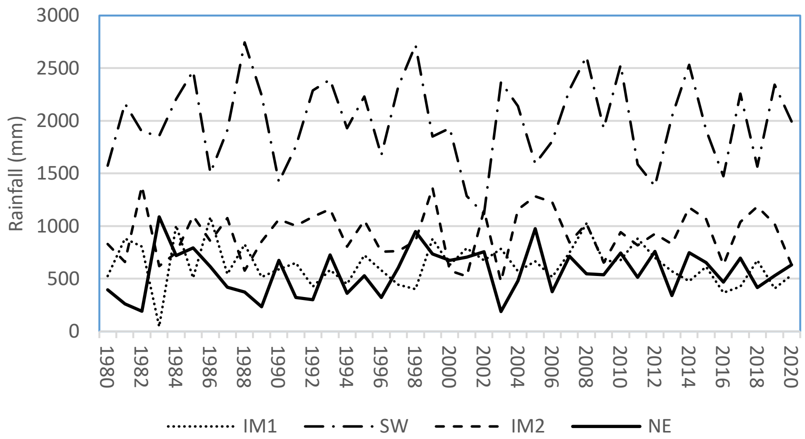


Fig. 4. Temporal variation in seasonal rainfall at Dartonfield (IM1-First inter monsoon, SW-South-West Monsoon, IM2-Second inter monsoon, NE-North-East monsoon)

The output by running the R code; *>mk.test(x, ci=0.95)* (x=time series considered) for the rainfall yielded the information in Table 1. None of the seasonal rainfall series showed any significant trend at 0.05 probability level. Sen's slope, which is an estimate of the true slope of an existing trend (as change per year) is also estimated and Kendall's Tau is the non-parametric correlation between the independent and dependant variables. Accordingly, as per Table 1, none of the seasonal series exhibited significant monotonic trends.

Table 1. *Z values, their significance, estimates of Sen's slope and Kendall's Tau for the seasonal series of rainfall*

Time series	Z value	Probability	Sen's slope (S)	Kendall's Tau (τ)
IM1	- 0.91	0.36	- 2.23	- 0.100
SW	0.37	0.71	1.29	0.040
IM2	0.02	0.98	0.11	0.002
NE	1.02	0.31	0.23	0.110

(IM1-First inter monsoon, SW-Southwest Monsoon, IM2-Second intrmonsoon, NE-Northeast monsoon)

3. Detecting sequential trends in monthly and seasonal rainfall at Dartonfield using R

Mann–Kendall method does not provide information about the complete structure of the trend (trend picture) for the whole time series. The fluctuation points or changes in the trend location are also important over the time period considered, which can be identified by applying the test sequentially for every individual period (Sneyers, 1990).

In this method, Sequential values u(t) (prograde series *viz*. starting from the first through the last value of the series) and u'(t) (retrograde series *viz*. starting from the last through the first value of the series) from the progressive analysis of the MK test was done to identify any change of trend with time (Sneyers, 1990).

The Sequential Mann-Kendall test is computed using ranked values, y_i of the original values in analysis (x_1, x_2, x_3, …, x_n). The sequential Mann-Kendall test statistic allows detection of the approximate beginning of a developing trend. When u(t)and u'(t) curves are plotted against time, the intersection of the curves locates an approximate potential trend turning point. If the intersection of the curves occurs beyond 1.96 (5% level) of the standardized statistic, a detectable change at that point in the time series can be reasoned out.

This illustration uses seasonal rainfall data for the period 1980 to 2020 and the analysis is done using R software with the 'Trendchange' package. The output by running the R code; >sqmk(x,1980) (x=time series considered and followed by the start year) gives a plot of prograde and retrograde series against time. The analysis suggests that none of the monthly series have intersections beyond the cut-off points ($\mp$1.96 *viz.* P=0.05). The only month that had an intersection point beyond $\mp$1.96 is February for Dartonfield (Z= 1.85, P=0.06) (Fig. 5). Accordingly, the change in trend for February happened during 1987 and it can be regarded as a change point. The analysis for the seasonal series also found that there were no significant intersection points for the four seasons suggesting that there is no significant sequential trends (Fig. 6).

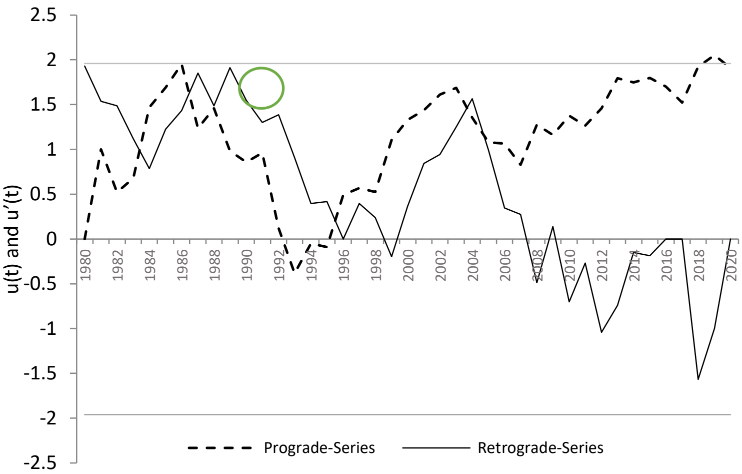


Fig. 5. Graphical representation of monthly sequential values of the statistics prograde series u(t) (dashed line) and retrograde series u(t) (solid line) obtained by SQ–MK test for February (main intersection point is indicated inside the circle)

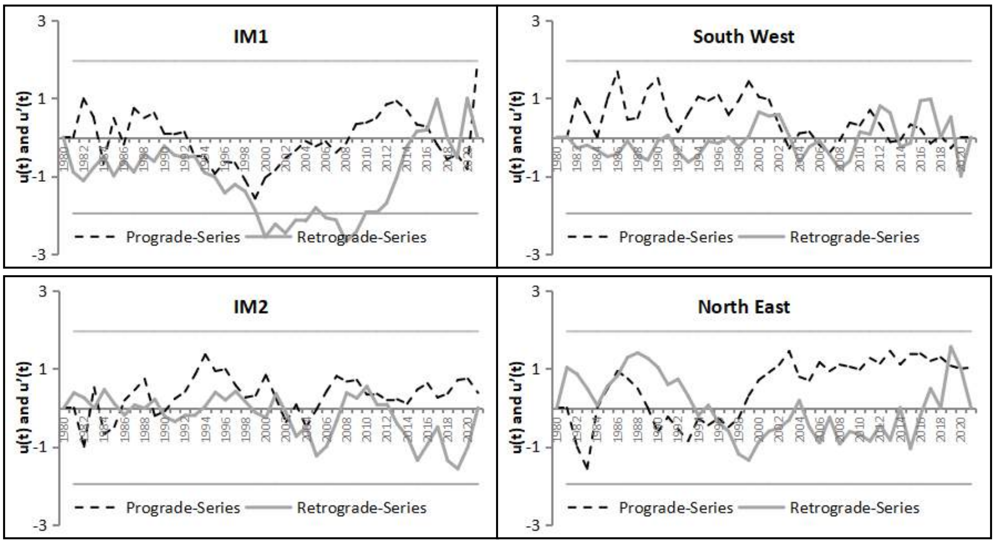


Fig. 6. Graphical representation of monthly sequential values of the statistics prograde series u (t) (dashed line) and retrograde series u (t) (solid line) obtained by SQ–MK test for seasonal series.

CONCLUSION

This article is based on an analysis of monthly and seasonal rainfall series at Dartonfield to investigate any monotonic or sequential trends (step trends) to identify any shifts in rainfall series. Except for February, none of the months exhibited monotonic trends, and the seasonal rainfall series also did not show any trends. Sequential trends which is an indication of abrupt changes was observed only for the February series at the point of 1987 and also no indication in seasonal rainfall series.

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