Advances in Tree Seed Science and Silviculture

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Front cover : Germination studies in Calophyllum inophyllum
(Photo: R. Anandalakshmi)

Back cover : Windbreak agroforestry system with superior clones of IFGTB to protect Banana crop (Age of trees-4 years)
(Photo: C. Buvaneswaran)

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MODIFIED ROOT ARCHITECTURE FOR DEEP ROOTING IN RUBBER (*HEVEA BRASILIENSIS*)

Vinoth Thomas*, T.A. Soman[#] and James Jacob

Different planting materials and cultural operations are being practiced in rubber (*Hevea brasiliensis*) for its better establishment, but none of them gave a satisfactory result to the long pending desire of farming community - a planting material with a deep root system, which is characterized by a long and uncoiled geotropic root (tap root) from which lateral roots arise. This kind of a root system will be advantageous to the plant for better anchorage, deep mining of water and minerals from the soil, better survival and early establishment particularly in drought prone regions, and thereby an increase in latex yield, better adaptability, *etc.* In a preliminary study conducted recently, Rubber Research Institute of India have developed a new planting material of rubber designated as 'Modified root trainer plant' (MRTP) which is characterised by two whorls of leaves, and a long root core of length of about 90cm (contrary to the root length of 25cm in a normal root trainer cup) comprising 18-25 strong, straight and vertical geotropic adventitious roots and a large number of horizontal lateral roots throughout. This can be achieved with an additional period of nearly 2 ½ months. Hence, the plants will be ready for planting in the same season. The root core of the modified plant consists of two tiers of which the upper one is the original root system of the root trainer (RT) plant which is being used as the base material in the experiment, and the lower tier developed in a root elongation tube (RET) with a modified root architecture. Fine root production was abundant in the modified root core. The MRTP have many favourable and unique characteristics, advantageous to the rubber growers. Further studies are envisaged to develop it as a planting material of rubber. A pioneer attempt for developing the MRTP of rubber is described here.

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Key words : *Hevea brasiliensis*, Modified root trainer plants, Multiple roots, Root architecture

Running Title: Engineering of root architecture in *Hevea*

Introduction

Different planting materials *viz.*, direct seeding, budded stumps, polybag plants and recently the - Root trainer plants were adopted widely for establishing rubber plantations in the past decades and the successors have notable advantages over the earlier ones (Marattukalam *et* al., 1980; Abraham, 1986; Samarappuli *et al.,* 1996; Marattukalam and Saraswathyamma, 1997; Soman and Saraswathyamma, 2005; George *et al.*, 2012). The adoption of budded stumps in early 60's, polybag plants in early 80's and root trainer plants in the recent years have revolutionised Indian Rubber Plantation sector in terms of area expansion, reducing the immaturity period, yield improvement, tree uniformity, better acclimatization, easy transportation and planting operations, etc. (Gireesh *et al.*, 2012). In India, about 90 per cent of the existing rubber plantation is being established with polybag plants. Despite various advantages of polybag plants, coiled tap root development at the bottom of the bag is a major limitation in rubber too (Wilson, 1986; Ginwal *et al.*, 2001; Soman and Saraswathyamma, 1999). A coiled tap root can never attain its normal growth even years after transplanting and has been reported to affect adversely wind fastness and drought tolerance of plants in several crop species (Wilson, 1986; Sharma, 1987; Chadurvedi, 1994). This limitation of polybag plants is overcome by root trainer plants in which natural air pruning occurs to the tap root through the drainage holes at the bottom of the container (Soman *et al.*, 2002). The natural air pruning can cause a stress to the plant and after transplanting, the air pruned tap root was noticed to grow deep into the soil, which may help the plant to seek the much needed ground water during extreme soil moisture stress (Huang, 1997; Oliveira et al., 2005; Soman *et al.*, 2010). Following the recommendation by the Rubber Board India, root trainer plants are becoming popular among the rubber farmers, and some of the large scale rubber nurseries in the private sector have already been equipped for raising root trainer plants. They are producing on an average 10-12 lakhs of root trainer plants annually which is being used for raising plantations both in the traditional rubber growing tract as well as in the non-traditional areas where climatic conditions particularly, drought act as a limiting factor.

Hevea has a root system comprising of a geotropic tap root which is predominantly meant for anchorage and a number of horizontally running laterals arising from different levels in the tap root, meant for intake of water and minerals from the soil (Srinivasan *et al.,* 2004). Better root system can improve growth, adaptability and yield of plants (Lynch, 1995). Tree loss following wind damage is a common phenomenon in rubber plantations and the uprooting of trees is reported to be due to poor tap root development. Wind damage (uprooting/ trunk snap) can lead to substantial decline in the revenue from the rubber plantations by loss of yield and tree stand per unit area, which may ultimately lead to an increase in the frequency of replanting cycle. Since long a number of attempts were envisaged for improving the root system of the planting materials in rubber so as to develop a strong root system for the mature trees. The approaches made for better root system with more focus on tap root ramification are the use of large sized polybag, deep planting, seed at stake, twin stock plants, application of growth regulators etc. (Webster, 1989; Varghese *et al.,* 2005; Thomas *et al.,* 2007; Abraham *et al.,* 2012) but none of these efforts gave a satisfactory result for wide adoption.

In conjunction with the research on ways and means to improve the root system in *Hevea*, an attempt was made to develop modified root trainer plants with improved root architecture.

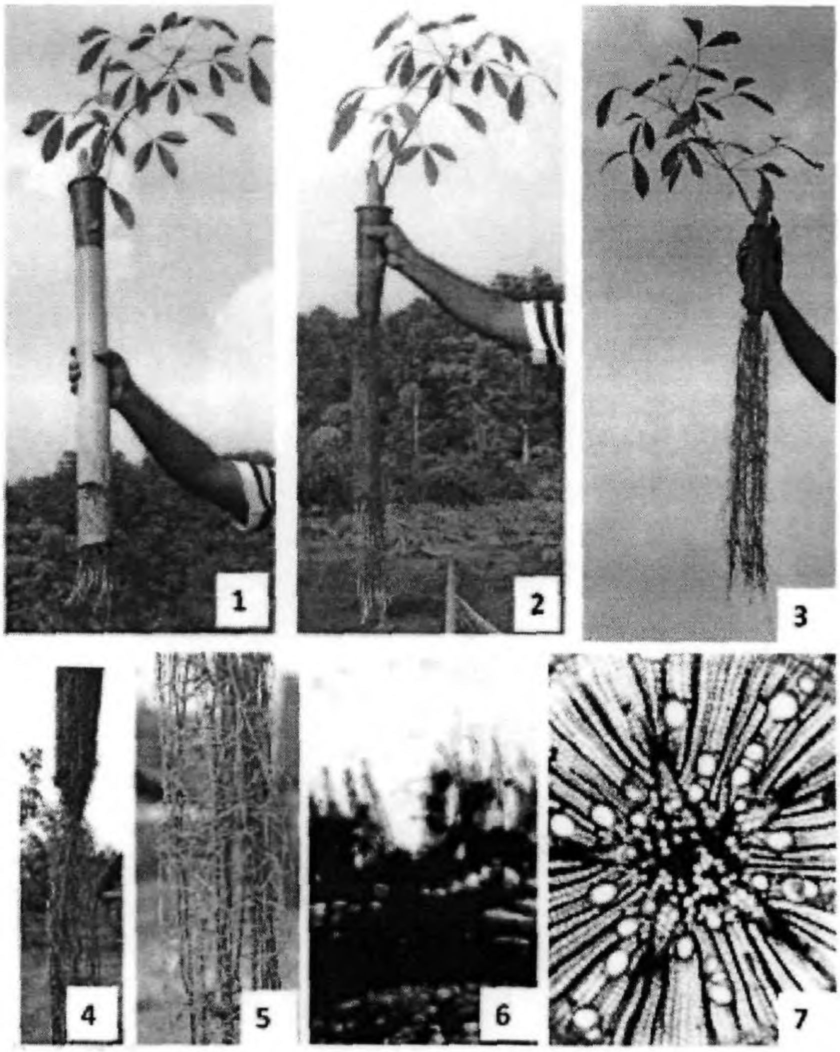
Materials and Methods

Forty hardened root trainer plants (Soman and Saraswathyamma, 2005) with two whorls of leaves raised in 800cc cups were used for the preliminary experiment initiated at HBSS, Paraliar, Tamil Nadu, India. Twenty plants were planted as control and the remaining plants were subjected to root elongation studies. The plants were taken out from the cup and transferred to another cup which is modified as follows. Empty root trainer cups of 800cc were split vertically into two equal halves and tied together into a cup with a thin metallic wire of about 24 gauges. The drainage hole at the bottom of the cup was widened to a diameter of about 3cms. To these modified cups, plants with intact root system were properly transferred. This system is placed tightly at the top of a Root Elongation Tube (RET) which is prepared from a PVC tube (length of 60 cm and a diameter of 7.5cm), by splitting vertically into two halves, tied together as the case with the modified RT cup. It is then filled with soil. The bottom of the vertically placed RET with RT plants were kept under direct sun in a trench of about 5cm and covered with soil. The control plants were planted as usual in pit size of 75cm^3. During the experimental period received only limited rain water hence, irrigation was provided to the plants lying in the modified system in alternate days. Extent of root elongation was studied 45, 75 and 105 days after the initiation of the experiment and recorded morphological and anatomical characteristics of the root system. Hand sections of the root was taken and stained with Toluidine blue O (O'Brien, and Mc Cully, 1964) for general histology and I_2KI (Johansen, 1940) for starch. Observations and photomicrographs were taken by using a Leitz Diaplan microscope equipped with Leica Qwin image analyser system.

Results and Discussion

One and half months after the initiation of the experiment, both the modified RT cup and RET were untied and root development was observed. Within the modified RT cup, original laterals i.e., developed earlier were found alive but no new ones were observed to be developed. In the RET, the air pruned roots (Soman and Saraswathyamma, 2005) at the drainage hole of the modified RT cup developed about 23 straight adventitious roots having an average length of 14.8cm and a diameter of about 1.5mm. The roots are pale brown in colour, devoid of lateral roots, growing geotropically into the fresh potting media of RET that contains certain amount of organic manure. The root apex possesses a calyptra. Further root development within the RT cup was observed to be poor which may be due to the scarcity of space and nourishments available within the cup, or the plant has got ample chance to grow into the RET where the potting media contains certain amount of organic manure. The fast growth of the root into the RET relieves the stress within the RT cup. In the control plants new sets of roots were developed geotropically to a length of 12.5cm.

Both modified RT cup and RET were tied together to study the extent of root development periodically. After 75 days, profuse development of both lateral and tap root was observed within the RET (Figs. 1-3). In the region where the modified RT cup and the RET attached, a constriction was noticed in the root system (Fig.4) that demarcates it into two distinct tiers in which the lower tier was developed within the RET. Within the entire length of the RET, 27 straight (more than 50% are stiff) geotropic tap roots were developed, and a number of horizontally running laterals arise throughout the length of tap root (Fig.5). The tap roots developed inside the RET are distributed along its inner walls. The root core is cylindrical in appearance constituted of tap root, laterals and remenance of the potting media. The plant possess two whorls of leaves with a root length of 90cm of which 25cm was developed in the RT cup and remaining 65cm in the RET. The length of geotropic roots developed in control plants is 19.8cm (Fig. 9b) .



Explanation to figures:

1. Figs. 1&2. Root trainer plants developed its root system in the root elongation tube (RET).
3. Large number of uncoiled geotropic roots developed within the RET.
4. Root system developed within the root trainer cup and RET is demarcated by a contriction.
5. Root core with large number of adventitious and lateral roots.
6. Fine roots.
7. Starch deposition in the pith, secondary xylem and cortical cells of the tap root.

The average root elongation within the RET is estimated to be 1.20 cm daily. For some of these plants the roots have come out from RET and started to develop in to the soil of the trench where the plants were kept. The roots of these plants were allowed to grow further in the soil and the plants were digging out after month i.e., 105 days after the initiation of the experiment for root elongation. The roots which came out from the RET penetrated geotropically into the soil and developed many laterals from it. The plant developed the third whorl of leaf and at this juncture the total length of the geotropic root system was measured to be 134.5cm (Fig. 8, 9a), and the approximate root elongation was found to be 1cm per day into the soil. For the control plants a total of 71cm length was noticed105 days after planting. The MRTP can establish a root system at a deeper stratum in the soil may be advantageous over normal root trainer plants particularly in arid zones, as the pits of larger dimensions have no definite advantage on root development and growth of plants (Joseph *et al.*, 2012)

Microscopic observation of both tap root and laterals showed the development of large number of unicellular fine roots (Fig.6) as an extension of the epidermal cells. The epidermis of the root is ensheathed by a thick cuticle and is intruded into the epidermal cells, and also noticed the development of cork cells. Starch grains were accumulated in the parenchyma cells of secondary xylem in a radial manner (Fig. 7). The pith cells possessed 3-5 large starch grains which are fully occupied while those in the cortical cells are smaller in size leaving large area in the cells. Accumulations of starch both in the cortical and pith cell denote the involvement of the new root system in the uptake from soil and enhanced photo assimilate allocation. The bud break for the formation of next whorl of leaf are stronger sinks for carbohydrates than roots (Thaler and Pages, 1996; 1997) for which the root system have to be established as soon as it comes in contact with the soil.

Among the different root parameters, root hairs and fine root density are most important for the uptake of water and nutrients from the soil. Fine roots, even though they are smaller in size, as extensions from the root epidermis, are the organs for water and nutrient acquisition by woody plants (Leuschner and Hertel, 2004). Jessy *et al.*, (2005) have reported that maximum fine root developments occur in the top soil, and its density was comparatively low during the summer period. According to Mc Cully (1999) fine roots play important role in drought resistance and recovery in many plants. The geotropic roots in the extended root system of MRTP possessed large number of lateral roots and fine

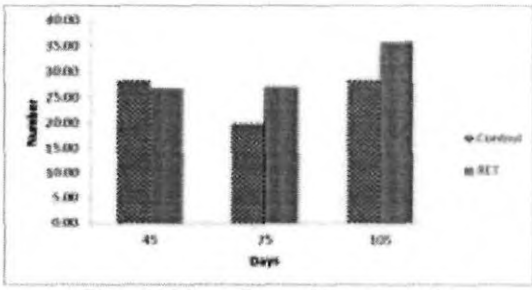


Fig. 9a Number of geotropic

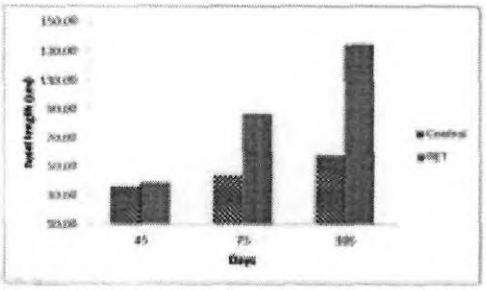


Fig. 9b Total length of root system of the plant

roots (Fig. 6) at a deeper strata and hence, may be advantageous to the plant for better uptake from the soil even during summer period.

From the original tap root of the stock plant planted in the RT cup, 1-3 geotropic tap roots were found to be developed. These roots were air pruned at the drainage hole of the RT cup at the time of hardening during the preparation of RT plants. Each of these air pruned roots develop into 3-5 geotropic roots within the MRTP. It has been documented that in rubber the tap root should not be damaged at any stages of its development as once it get damaged, the tap root development may be affected adversely. In the present study it is obvious that the density of the geotropically growing tap root can be increased by inducing stress to the tap root either through mechanical means or natural air pruning, which is contradicting to the existing concept about tap root and its further development in *Hevea*. As the air pruning of geotropic roots is not possible to any of the planting materials of rubber other than the root trainer plants, these modifications to the root architecture in a desired manner could be achieved only with root trainer plants.

Splitting of RT cup and RET is needed for taking out the root core in an intact manner as the root system possess a deep constriction (Fig.4). The widening of drainage hole at the bottom of the RT cup enables the air pruned roots of the plant to establish the second tier of root system in the new rooting medium of RET. The stress developed due to air pruning and the urge of the plant for further development have certain strong implications in the fast development of geotropic roots to form the bottom tier. Hence, two step procedures are needed for developing MRTP instead of merely increasing the length of root trainer cup.

As in the RT cup, vertical ridges in the inner wall of the cup for directing the root to grow straight and to avoid root coiling (Soman *et al.,* 2010) is absent in RET. The fast growing geotropic roots, presumably the future tap roots of the plant, are running down straight along the inner walls of the RET even without the presence of vertical ridges. In the RT cup vertical ridges are needed as the lateral roots are being trained where as in RET most of the roots are geotropic in nature and can grow there without tap root coiling. According to Riedacker *et al.* (1982); Lamond *et al.* (1983); Pages *et al.* (1992) lateral roots are more numerous or grow longer and faster when the main axis is prevented from elongating or removed. The root system of MRTP consists of two tiers in which the upper part consist of large number of laterals as the tap root growth was restricted due to air pruning while in extended region of the root within the RET, more tap root development than laterals was noticed as the geotropic roots were allowed to grow without any inhibition.

A planting material with a lengthy root core comprising of large number of both lateral and geotropic roots may have great implications in field establishment. Soman and Saraswathyamma (2005) reported that a hardened root trainer was found to consist of 1-3 tap roots with lateral roots. The plants thus developed by this methodology have certain unique features such as a lengthy root core of about 90cm, more than 27 healthy and straight geotropic tap roots, large number of laterals and fine roots, etc. which may have implications in better anchorage, establishment and uptake. There is no scope for coiled tap root in MRTP hence, after transplanting in the field, establishment of a good root system at a deeper layer in the soil will be possible. This is one of the prime advantages expected of MRTP over root trainer (RT) plants. If so, in addition to the deep mining of minerals and water by the deep root system, the top soil itself can play major role as natural mulch in order to protect the roots from the extreme day temperature experienced in drought prone areas which may lead to better survival rate and proper establishment. If so, the effort and cost for early establishment of the plant can be reduced for developing rubber plantations.

According to physical chemistry, the chemical properties of a substance do not change with the change of its physical state; but rate of chemical reactions do depend upon the physical state. In a biological system, the surrounding corresponds with the physical state, and the genetic make up of the rubber plant is proved to be having immense potential in modulating the tropism of roots according to the necessity and availability. The guy in the plant system that controls the tropism of roots like a solenoid switch is an area of interest to be explored.

From the study it is obvious that root architecture of root trainer plants of *Hevea* could be engineered for better root system by adopting appropriate methodology. Better anchorage, mining of both water and minerals from a good extent of the soil in a vertical file including deeper strata, better survival and establishment even in drought prone regions are the added advantages of the modified root trainer plants (MRTP). Further studies are envisaged for refining the present technique and exploring the possibilities of MRTP as a planting material of rubber.

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