J. Bamboo and Rattan, Vol. 3, No. 1, pp. 3–11 (2004)

Also available online - www.vsppub.com

Root development in rattans 2. Soil requirements and efficiency of the root systems of *Calamus thwaitesii* Becc. and Hook. f. and *Calamus rotang* L. in the seedling stage

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Abstract—The function and activity of a root system is closely linked to its normal environment, the soil. The soil volume exploited by the two species was calculated and a comparison showed that *Calamus rotang* exploited more soil volume than *C. thwaitesii*. The effective soil volume was also found to show an increase in *C. rotang* when compared to *C. thwaitesii*. Knowing the effective soil volume, the size of the polybag to be used in the nursery can be adjusted. The root spread of the two species shows that a 30 × 30 × 30 cm pit size will be sufficient for seedlings up to 2 years old. Rooting density is found to be more in the upper 30 cm layer of soil in both species. Root density, total root intensity and fine root intensity are higher in *C. thwaitesii* when compared to *C. rotang*. Root surface area also is more in *C. thwaitesii*. Hence, this species will be more efficient in water and nutrient uptake in the seedling stage. Both species are good soil binders.

Key words: Rattans; effective soil volume; rooting density; root intensity; root surface area; soil binding capacity.

INTRODUCTION

The function and activity of a root system is closely linked to its normal environment, the soil. A plant is dependent on a volume of soil for supply of water and mineral resources and for physical support. Efficiency in nutrient uptake is influenced by the rooting density. The number of roots and root surface area also are indicators of root system efficiency. Soil binding capacity, which is a measure of the binding effect on the soil particles, is of direct value in soil conservation. A knowledge of these aspects of a root system will aid in management decisions when a species is to be raised on a large scale. In this paper, soil requirements and efficiency of the root

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system of selected species of commercially important rattans, *Calamus thwaitesii* and *C. rotang*, in their seedling stages, are discussed. The growth characteristics and root spread were discussed in the first part of this paper [1].

MATERIALS AND METHODS

The experimental design has been published in the first paper of this series [1]. In addition, at the third year soil samples were collected using a 4-cm diameter core from four different depths (0–15 cm, 15–30 cm, 30–45 cm and 40–60 cm) at 0,10, and 30 cm from the base of the plant. There were three randomly selected sampling points around a single plant in order to get fragments of the roots from all directions. There were a total of 28 samples from a single plant. Root fragments were separated from each sample and used for determining the different root parameters like root length, total root weight , fine root weight, rooting density, etc.

The soil volume exploited by the root system for the two species of *Calamus* was calculated on a yearly basis using the formula $\pi(h/2)^2 v$, where 'h' is the mean horizontal spread of the root system in each year obtained from the data collected at two-month intervals and 'v' is the mean vertical depth of the roots. The two species were compared based on the soil exploited by their root system.

The effective soil volume for the two species in each year was calculated from the graph drawn by plotting exploited soil volume against rooting density for each period, and soil volume at which rooting density shows a sharp decline was noted [2].

The rooting density of each species was calculated on a yearly basis applying the formula $R_{\max}/s$, where '$R_{\max}$' is the total length of the main roots, laterals and sublaterals and 's' is the soil volume exploited by the entire root system. Rooting density was also calculated making use of the data with respect to core samples of soil taken at the end of the third year.

The root intensity of each species was calculated from the total number of roots present in unit area of the soil. Percentage root intensity contributed by fine roots less than 2 mm in diameter was also calculated by considering the number of fine roots alone.

The root surface area, a measure of the total absorptive area of the roots, was calculated separately for roots less than 2 mm diameter and greater than or equal to 2 mm diameter, using the formula $2\pi rl$ where 'r' is the radius of the root and 'l', the length.

The soil binding capacity for lateral and sublateral roots was found by using the formula v/r^2, where 'v' is the average root volume obtained and 'r' the mean radius of the roots of the plants. The root volume was found using the formula $\pi r^2 l$ where 'r' stands for mean radius of the laterals/sublaterals of the plants considered for the study and 'l' their mean length.

RESULTS AND DISCUSSION

Root spread

The root spread has been discussed in Ref. [1]. The data are repeated here for easy reference. In a 3 year old *C. thwaitesii* the average horizontal spread was 61.6 cm and in *C. rotang* 91.8 cm. They grow vertically downward up to a distance of 29.8 cm in *C. rotang* and 39.1 cm in *C. thwaitesii* (Table 1).

Soil exploitation

The volume of soil available for rooting is an important factor governing the growth of seedlings. In fact, the soil is only partly utilised and a large proportion of the soil is not exploited by the roots. In *C. rotang*, soil volume exploited in the second year is about 30 times the volume exploited in the first year. There is an about 220-times increase in the exploited soil volume in the third year. In *C. thwaitesii*, in the first two years the soil volume exploited is more or less the same, while a more than 60-times increase is seen in the third year (Table 2). A comparison between species shows that *C. rotang* is exploiting more soil volume than *C. thwaitesii*.

Effective soil volume

In the nursery, the plant seldom has enough soil at its disposal to allow optimal development of its root system. However, such a restriction of soil volume hardly

Table 1.
Horizontal and vertical spread (cm)

Period (months)	Horizontal spread		Vertical spread	
	Cr	*Ct*	*Cr*	*Ct*
2	—	—	11.5	14.1
14	9.5	12.3	13.3	15.3
26	48.7	10.3	26.4	16.5
38	91.8	61.6	29.8	39.1

$n = 5$ replicates; *Cr* — *C. rotang*; *Ct* — *C. thwaitesii.*

Table 2.
Comparison of soil volume exploited

Period (year)	Soil exploited (cm^3)	
	Cr	*Ct*
First	877	1843
Second	25 769	1821
Third	192 219	113 742

$n = 5$ replicates; *Cr* — *C. rotang*; *Ct* — *C. thwaitesii.*

impairs the growth of the plant and plants absorb only a small part of the nutrients present.

Stevenson [2] defined the effective soil volume as the volume of soil that is able to supply water to a root system and which does not restrict the growth of those roots. By calculation, effective soil volume or V_e is a maximal 78.5% (90.5% with triangular spacing of roots) of a total volume that does not restrict growth. Below this level root density will decline sharply as soil volume increases. For maximum effects from nutritional or water content treatments, plants should be provided with sufficient soil at least to approach the conditions laid down in the definition of effective soil volume. The smaller the plant, the easier it is to meet this provision.

In this study it is seen that rooting density declines year by year (Table 3). This shows that the effective soil volume has been attained in the two species. The effective soil volume in the first year for *C. rotang* was 447 cm^3, and 632 cm^3 for *C. thwaitesii*. Hence, the polybag or other container should hold this amount of soil to attain the maximum growth of roots. In the second year, the effective soil volume was found to increase in *C. rotang* compared to *C. thwaitesii*. In the third year, while the effective soil volume showed an enormous increase in *C. rotang*, it remained the same as that of the second year in *C. thwaitesii* (Table 4).

Cultivation practices in the nursery can be based on this observation. For an optimal development of the root system, the bag should contain the effective soil volume. For *C. rotang*, since the vertical spread is 13.3 cm, the bag size should be

Table 3.
Rooting density

Period (year)	*C. rotang*				*C. thwaitesii*			
	Soil volume (cm^3)	Rooting density (cm per cm^3)			Soil volume (cm^3)	Rooting density ($cm\ cm^{-3}$)		
		Main	Lateral	Sublateral		Main	Lateral	Sublateral
First	877	0.08	0.06	0.00	1843	0.04	0.02	0.00
Second	25 739	0.02	0.03	0.06	1821	0.09	0.10	0.03
Third	192 219	0.01	0.004	0.001	113 742	0.01	0.01	0.001

$n = 5$ replicates.

Table 4.
Comparison of effective soil volume

Period (year)	Effective soil volume (cm^3)	
	C. rotang	*C. thwaitesii*
First	447	632
Second	3813	1376
Third	17 767	1376

$n = 5$ replicates.

about 14 × 10 cm, of which 14 cm is the height of the bag and 10 cm is the width. When the bag is filled with soil, it will attain a diameter of approximately 6.4 cm. For *C. thwaitesii*, it should be 16 × 11.15 cm (Table 1). If the seedlings need to be kept for the second year, the bag size should be about 27 × 21 cm for *C. rotang* and 18 × 15.5 cm for *C. thwaitesii.*

Rattan seedlings can be out planted from the polybag generally after one year of hardening in the nursery. For one year seedlings a pit size of 30 × 30 × 30 cm will be sufficient for the two species. For two year old seedlings also the same pit size will suffice since the vertical spread is below 30 cm in both species.

Rooting density

The efficiency in nutrient uptake is influenced by the rooting density. Rooting density can be expressed relative to either soil surface area (L_A in cm/cm^2) or soil volume (L_V in cm/cm^3). Atkinson and Wilson [3, 4] have described the consequences of a low L_A value. When a plant transpires, water will come initially from soil immediately adjacent to the root with this zone being replenished from bulk soil. If the rate of withdrawal exceeds the rate of water movement through the soil to the root (i.e. the rate of uptake exceeds soil hydraulic conductivity), then the soil adjacent to the root will become drier than the soil bulk and the rate of water flow into the root will decrease and may result in water stress. Localized drying occurs and, thus, the gradients of water potential at the root surface will reduce the uptake of minerals thought to be moved by mass flow. If root density is high, flow rates will always tend to be low and gradients at the root surface will be rare. Where root density is low, as in fruit trees, the contrary will be true.

Root density varies with depth. Hence reduced soil water potentials will not be the same at all depths and this will affect the balance of nutrient uptake from different parts of the soil profile.

In the present study, while *C. rotang* possesses a higher rooting density during the first year of growth, *C. thwaitesii* does so later. The rooting density in both species is found to be inversely related to the amount of soil exploited by the root system. There is a major contribution of the laterals and sublaterals towards rooting density of the plant occurs during the second year in both species (Table 3).

Measurements using the core method at different depths and radial distances in the third year reveal that rooting density is greater in *C. thwaitesii* compared to that of *C. rotang*. With respect to depth, rooting density is much higher in the upper 30 cm of soil compared to the lower 30 cm in both species. While 81% of the total rooting density is the contribution of the upper 30 cm of soil in *C. rotang*, 89% of the total rooting density is contributed by the upper 30 cm in *C. thwaitesii*. At all depths other than 30–45 cm, rooting density is found to be more in *C. thwaitesii* compared to *C. rotang* (Table 5).

As far as the different lateral distances from the base of the plant are concerned, the percentage contribution of the rooting density within a soil depth of 0–60 cm at the centre of the rooting zone and at 10 cm away from the base of the plant is

Table 5.
Root density at different radial distances and depths from the base of the plant

RD (cm)	*C. rotang*					*C. thwaitesii*				
	Depth (cm)					Depth (cm)				
	0–15	15–30	30–45	45–60	Average	0–15	15–30	30–45	45–60	Average
0	0.67	0.10	0.09	0.06	0.23	1.01	0.40	0.04	0.08	0.38
10	0.54	0.20	0.11	0.06	0.23	0.53	0.23	0.09	0.06	0.23
30	0.40	0.11	0.11	0.05	0.17	0.49	0.17	0.06	0.12	0.21
0–30	0.50	0.15	0.10	0.06		0.58	0.23	0.07	0.09	

RD — radial distance; $n = 5$ replicates.

Table 6.
Depth-wise distribution of total roots and contribution of fine roots

Depth (cm)	Total roots (%)		Fine roots (%)	
	C. rotang	*C. thwaitesii*	*C. rotang*	*C. thwaitesii*
0–15	57	68	46	57
15–30	20	18	17	16
30–45	15	8	13	8
45–60	8	6	7	6

36% and 37%, respectively in *C. rotang*. While *C. rotang* shows almost the same rooting density at these regions, *C. thwaitesii* shows markedly more percentage root density (46%) at the centre of the rooting zone than at 10 cm away from the plant (29%) (calculated from Table 5). Since a higher rooting density is observed in *C. thwaitesii*, this species will be more efficient in nutrient uptake.

Root intensity

When total root intensity is considered, *C. thwaitesii* is more efficient in absorption compared to *C. rotang* (Table 6), the percentage of total intensity being more in the surface layer (0–15 cm depth). Published data are often difficult to assess. For instance, according to Wright [5] the absorbing roots of oil palm are concentrated in the upper 10 cm of soil, whereas Grey [6] observed predominance of the absorbing roots in the upper 30 cm soil. In the two rattan species studied, the absorbing roots are found to be more in the upper 15 cm of soil. In *C. rotang*, 83% of the total root intensity is contributed by fine roots while in *C. thwaitesii*, 87% of the total root intensity is the contribution of fine roots. Thus, *C. thwaitesii* is more efficient in absorption, even when only the fine absorbing roots are taken into account.

Table 7 shows the lateral distribution of roots. In *C. rotang*, more absorbing roots are found at a lateral distance of 10 cm, whereas in *C. thwaitesii* fine roots are maximal at the centre of the rooting zone.

Table 7.
Lateral distribution of total roots and contribution of fine roots

Radial distances (cm)	Total roots (%)		Fine roots (%)	
	Cr	*Ct*	*Cr*	*Ct*
0	33	46	24	36
10	37	29	33	27
30	30	25	26	24
Total	100	100	83	87

Cr — *C. rotang*; *Ct* — *C. thwaitesii.*

Table 8.
Comparison of root surface area per plant

Period (months)	Root surface area (cm^2)					
	C. rotang			*C. thwaitesii*		
	<2 mm	⩾2 mm	Total	<2 mm	⩾2 mm	Total
2	6	0	6	9	0	9
14	29	4	33	21	22	43
26	178	338	516	75	162	237
38	366	997	1363	284	1644	1928

Root surface area per plant.

Root activity decreased with increasing soil depth. In *C. rotang* about 76% of the active roots are located at 0–30 cm depth, while 86% of the active roots in *C. thwaitesii* are located at 0–30 cm depth. Wright [5] reported that 70–80% of the active roots of oil palm are located at 0–20 cm depth.

Root surface area

In the two species main roots alone are present in the initial stage and *C. thwaitesii* has more root surface area at this stage. With the initiation of laterals in the first year the total surface area/plant is also more in *C. thwaitesii*. However, in the second year, *C. rotang* has more surface area due to the occurrence of more roots, both <2 mm and ⩾2 mm. At the end of the third year, the trend was reversed (Table 8).

However, the surface area of the fine roots, even though few in number, was found to be greater in *C. rotang* due to their increased length and diameter. This is supported by the statement that plants with greater 'specific root surface area' are more efficient and opportunistic absorbers of ions and water [7]. Such plants also appear to be more competitive in single and mixed plant communities [8]. The root system of *C. thwaitesii* is seen to be more efficient as measured by more specific root surface area.

Table 9.
Comparison of soil binding factor

Period (year)	*C. rotang*	*C. thwaitesii*
First	175	150
Second	303	401
Third	334	285

Soil binding capacity

The binding of soil particles and the promotion of soil aggregation are of direct value in soil conservation. The length and thickness of roots play an important role in binding soil particles: fine roots with their close and elaborate network have greater binding capacity than thicker roots. Soil binding capacity shows an increase with age in *C. rotang*, while in *C. thwaitesii* soil binding is highest in the second year (Table 9).

The soil binding capacity of grass roots was studied by Bhaskaran and Chakrabarty [9], and the binding capacity ranged from 219 to 876 in four species of grasses. Mathur *et al.* [10] noted that in *Populus ciliata*, a promising species for soil conservation, the soil binding factor after one year growth was 61.29 and after two years 106.65. Dhyani *et al.* [11] have calculated soil binding capacity factor for five tree genera, and *Ougeinea*, *Leucaena* and *Grewia* were shown to be useful for conservation in this respect.

Compared with grasses and trees, rattans appear to be good soil binders. Banik and Ahamed [12] also pointed out that another rattan, *C. viminalis*, is likely to check soil erosion.

Final inference

It can be inferred that *C. thwaitesii* is more efficient than *C. rotang* in water and nutrient uptake, because its root density, total root intensity, fine root intensity and root surface area are higher. However, one could also argue the case the other way round: *C. rotang* is more efficient, because it is able to survive and grow with less dry matter investment in root structure than *C. thwaitesii*; *C. thwaitesii* is less efficient because it needs more root surface area to survive. Nonetheless, both species are good soil binders.

Acknowledgements

We are grateful to Dr. J. K. Sharma, Director, KFRI, for providing the facilities for the work. The first author gratefully acknowledges the University Grants Commission for permitting the benefit of FIP under the IXth plan for the completion of her PhD work. Thanks are due to Mr. K. K. Unni, Officer-in-charge, Field research station, Palappilly, for his unreserved help in the field.

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