J. Bamboo and Rattan, Vol. 4, No. 2, pp. 183–191 (2005)

Also available online - www.vsppub.com

Root morphology and development in rattans. 4. Root system development in *Calamus thwaitesii* Becc. and Hook.f. and *Calamus rotang* L. in relation to the chemical properties of a degraded lateritic soil

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Abstract—This paper, the fourth and the last one in a series on root morphology and development in rattans, mainly evaluates the influence of the chemical properties of a degraded lateritic soil on root growth in *Calamus*. The study area, soil sampling and methodology remain the same as given in the previous paper on the influence of soil physical properties on root growth of *Calamus*. Results revealed that *C. thwaitesii* favoured more acidic soil compared to *C. rotang*. Organic carbon, available nitrogen and extractable phosphorus are significantly and positively related to root growth in both species while exchange acidity and exchangeable aluminium are significantly and positively correlated with root growth only in *C. thwaitesii*. A significant and positive relation was seen for calcium on the root growth of *C. rotang*. Significant influence of radial distance on root growth was observed with respect to most of the properties while change in depth had no influence. Stepwise regression analysis revealed that root growth during the early stages is generally influenced by properties such as soil moisture, and contents of sand, organic carbon, available N, exchangeable K and exchangeable Ca.

Key words: *Calamus*; degraded lateritic soil; soil chemical properties.

INTRODUCTION

For *Calamus*, with an intention of reducing the pressure on natural forests, attempts are being undertaken in Kerala to establish plantations outside the forests, and especially to re-vegetate degraded lateritic soils. In connection with this, a study has already been conducted [1] to find out the influence of soil physical conditions on root system development. This paper evaluates the influence of the chemical properties of a degraded lateritic soil on root development in *Calamus*. The aim of

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this series of papers has been to recommend how best to establish plantations on soils different from the soils where the species grow naturally.

STUDY AREA AND METHODS

The study area, species, details of plots, soil sampling and processing remain the same as previously detailed [1]. The pH values of soil/water suspension (1 : 2.5), organic carbon (sulphuric acid and potassium dichromate acid digestion), available N (alkaline permanganate method), extractable P (Bray II extraction), exchange acidity (1 M KCl extraction), exchangeable Al (1 M KCl extraction), exchangeable K, Na (ammonium acetate extraction followed by flame photometry), Ca and Mg (EDTA titration) were determined using standard procedures [2]. Correlation coefficients between soil properties and root parameters were determined for each species. Response functions for each species were fitted relating the fine root weight and rooting density to different soil variables.

RESULTS AND DISCUSSION

In order to measure the proliferation of *Calamus* roots in relation to the chemical nature of the soil, various soil properties (pH, organic carbon, available N, extractable P, exchangeable Al, exchange acidity and exchangeable bases) and root parameters (root length, total root weight, fine root weight and rooting density) were determined at different soil depths (0–15, 15–30, 30–45 and 45–60 cm) and radial distances (0, 10 and 30 cm). The relations between each soil property and root growth are presented in Tables 1–6 and are summarised below.

Table 1.
Correlation between soil chemical properties (soil reaction and nutrients) and root growth within a depth of 0–60 cm and up to a radial distance of 30 cm

Soil properties	Root parameters							
	C. rotang				*C. thwaitesii*			
	RL	TRW	FRW	ROD	RL	TRW	FRW	ROD
pH	0.07	0.09	0.05	0.07	0.11	0.06	0.03	0.07
OC	0.55^{**}	0.37^{**}	0.56^{**}	0.55^{**}	0.57^{**}	0.20^{*}	0.53^{**}	0.60^{**}
Av. N	0.32^{**}	0.19^{*}	0.23^{**}	0.33^{**}	0.30^{**}	0.09	0.20^{*}	0.30^{**}
Extr. P	0.24^{**}	0.10	0.25^{**}	0.24^{**}	0.15	0.05	0.22^{*}	0.11

RL, root length; TRW, total root weight; FRW, fine root weight; ROD, rooting density; OC, organic carbon; Av. N, available nitrogen; Extr. P, extractable phosphorous.

* Significant at 5%, **significant at 1%.

Table 2.
Correlation between soil chemical properties (soil reaction and nutrients) and root growth at different distances from the base of the plant

Distance from the base of the plant (cm)	Soil properties	Root parameters							
		C. rotang				*C. thwaitesii*			
		RL	TRW	FRW	ROD	RL	TRW	FRW	ROD
0	pH	0.16	0.15	0.11	0.18	0.19	0.07	0.17	0.18
	OC	0.57**	0.58**	0.59**	0.56*	0.64**	0.31	0.73**	0.54**
	Av. N	0.2	0.21	0.04	0.21	0.56*	0.43	0.33	0.55*
	Extr. P	0.13	0.14	0.26	0.12	−0.15	0.09	−0.02	−0.15
10	pH	0.06	−0.02	0.09	0.06	0.15	−0.04	0.16	0.14
	OC	0.65**	0.57**	0.65**	0.65**	0.61**	0.53**	0.59**	0.64**
	Av. N	0.45**	0.41**	0.33*	0.44**	0.40**	0.26*	0.39**	0.40**
	Extr. P	0.22	0.15	0.23	0.21	0.24	0.28*	0.20	0.24
30	pH	0.03	0.29*	−0.08	0.02	−0.07	−0.02	−0.22	−0.16
	OC	0.47**	0.29*	0.49**	0.49**	0.62**	0.44**	0.50**	0.69**
	Av. N	0.37**	0.22	0.36**	0.39**	0.31*	0.07	0.11	0.31*
	Extr. P	0.34**	0.19	0.34**	0.35**	0.32*	0.11	0.41**	0.20

RL, root length; TRW, total root weight; FRW, fine root weight; ROD, rooting density; OC, organic carbon; Av. N, available nitrogen; Extr. P, extractable phosphorous.

* Significant at 5%, **significant at 1%.

pH, organic carbon and nutrients

The mean values of soil pH for *C. rotang* ranged from 5.0 to 5.2 and for *C. thwaitesii* from 4.5 to 4.7. This showed that soils surrounding *C. thwaitesii* were more acidic than those of *C. rotang* even though both species were grown in similar and uniform conditions. This might be due to the alkaline nature of root exudates of *C. rotang*, probably a mechanism for plants to thrive under low pH conditions. However, root growth was not affected by the pH of soil in either species at any of the lateral distances or depths as shown by the poor correlation with most root parameters.

Within a depth of 0–60 cm and a radial distance of 30 cm, root growth was highly influenced by organic carbon content. There was a highly significant and positive relation with root length, total root weight, fine root weight and rooting density in both species. Organic carbon at different lateral distances from the base of the plant also showed positive correlation with the root parameters. These trends were not observed when different depths were considered separately.

Root growth was also highly influenced by the content of available N in the soil. There were significant and positive relations between available N and root parameters in both species. In relation to lateral distances, the influence of available N on root growth was significant at both 10 cm and 30 cm away from plants. The soil immediately beneath the base of the plant had no influence on root growth in *C. rotang*, while a significant positive relation was observed in *C. thwaitesii*. However, it was not possible to draw any definite relation when different depths were considered separately.

Table 3.
Correlation between soil chemical properties (soil reaction and nutrients) on root growth at different soil depths

Depth (cm)	Soil properties	Root parameters							
		C. rotang				*C. thwaitesii*			
		RL	TRW	FRW	ROD	RL	TRW	FRW	ROD
0–15	pH	0.25	0.13	0.05	0.26	0.46**	0.24	0.16	0.46**
	OC	0.05	−0.22	0.28	0.07	−0.04	−0.43	0.21	−0.10
	Av. N	−0.30	−0.25	−0.41*	−0.29	0.22	−0.03**	0.08	0.19
	Extr. P	−0.19	−0.25	−0.07	−0.18	−0.27	−0.09	0.13	−0.32
15–30	pH	−0.09	0.04	−0.02	−0.09	0.34*	0.23	0.17	0.34*
	OC	0.15	0.31	0.04	0.15	0.28	0.21	0.33	0.29
	Av. N	0.22	0.04	−0.01	0.23	0.19	0.25	0.21	0.19
	Extr. P	0.01	0.10	−0.07	0.01	0.53**	0.49**	0.60**	0.54**
30–45	pH	−0.03	−0.47**	−0.13	−0.07	0.24	0.01	0.14	0.22
	OC	−0.37*	−0.18	−0.04	−0.38*	0.28	0.41*	0.48**	0.29
	Av. N	−0.18	−0.16	−0.01	−0.21	0.54**	0.31	0.21	0.55**
	Extr. P	0.04	0.10	0.21	0.01	0.01	−0.01	−0.02	0.01
40–60	pH	0.02	0.11	0.31	0.08	0.33	0.99	0.22	0.28
	OC	−0.01	0.01	−0.13	0.01	0.23	0.33	0.47**	0.44**
	Av. N	−0.30	−0.25	−0.41*	−0.11	−0.05	−0.08	0.09	0.15
	Av. P	−0.19	−0.25	−0.08	−0.23	0.26	−0.13	−0.01	−0.05

RL, root length; TRW, total root weight; FRW, fine root weight; ROD, rooting density; OC, organic carbon; Av. N, available nitrogen; Av. P, available phosphorous.
* Significant at 5%, ** significant at 1%.

Table 4.
Correlation between soil chemical properties (exchange characteristics) and root growth within a depth of 0–60 cm and up to a radial distance of 30 cm

Soil properties	Root parameters							
	C. rotang				*C. thwaitesii*			
	RL	TRW	FRW	ROD	RL	TRW	FRW	ROD
Ex. acidity	0.09	0.06	0.08	0.09	0.27**	0.02	0.18*	0.28**
Ex. Al	−0.05	−0.04	−0.04	−0.03	0.23**	0.04	0.16	0.25**
Ca	0.22*	0.04*	0.22*	0.22**	0.01	0.02	0.01	−0.01
Mg	0.07	0.07	−0.01	−0.12	0.02	0.03	−0.06	−0.01
Na	0.03	0.07	0.06	−0.15	−0.07	−0.06	−0.03	−0.11
K	−0.02	0.12	0.01	−0.02	0.64**	0.52**	0.60**	0.67**

RL, root length; TRW, total root weight; FRW, fine root weight; ROD, rooting density; Ex. acidity; exchangeable acidity; Ex. Al, exchangeable aluminium.
* Significant at 5%, ** significant at 1%.

Extractable P was found to have a highly significant and positive influence on most of the root parameters in *C. rotang*. Such influence was expressed only by the fine root weight in *C. thwaitesii*. With respect to different lateral distances, influence of extractable P on root growth predominated at 30 cm away from the plant in both

Table 5.
Correlation between soil chemical properties (exchange characteristics) and root growth at different distances from the base of the plant

Distance from the base of the plant (cm)	Soil chemical properties	Root parameters							
		C. rotang				*C. thwaitesii*			
		RL	TRW	FRW	ROD	RL	TRW	FRW	ROD
0	Ex. acidity	0.02	0.08	0.04	0.01	0.32	0.01	0.08	0.32
	Ex. Al	−0.07	−0.05	−0.02	−0.06	0.32	0.01	0.07	0.32
	Ca	−0.16	−0.14	0.03	−0.10	−0.27	−0.21	−0.20	−0.26
	Mg	0.32	0.33	0.26	0.33	−0.19	−0.13	−0.23	−0.20
	Na	0.01	−0.03	0.03	0.02	−0.11	−0.09	−0.07	−0.11
	K	0.06	0.12	0.24	0.10	0.76**	0.73**	0.69**	0.76**
10	Ex. acidity	−0.01	0.05	−0.01	0.01	0.29*	0.24	0.30*	0.29*
	Ex. Al	−0.01	0.04	0.02	−0.01	0.24	0.16	0.24	0.24
	Ca	0.33*	0.23	0.32*	0.33*	0.07	0.11	0.03	0.05
	Mg	−0.03	−0.05	−0.06	−0.03	0.11	−0.09	0.08	0.11
	Na	−0.06	−0.08	0.02	−0.06	−0.12	−0.23	−0.13	−0.14
	K	0.04	0.19	−0.02	0.41	0.55**	0.45**	0.49**	0.59**
30	Ex. acidity	0.23	0.05	0.33*	0.24	0.36**	0.24	0.22	0.39**
	Ex. Al	−0.06	−0.07	−0.05	−0.06	0.26*	0.26*	0.20	0.32*
	Ca	0.28*	0.21	0.21	0.27*	0.09	0.32*	0.09	0.06
	Mg	0.16	0.33*	0.04	0.16	−0.13	−0.26*	−0.14	−0.18
	Na	0.12	0.16	0.07	0.12	−0.05	−0.26*	0.04	−0.16
	K	−0.20	−0.10	−0.19	−0.20	0.55**	0.41**	0.59**	0.62**

RL, root length; TRW, total root weight; FRW, fine root weight; ROD, rooting density; Ex. acidity; exchangeable acidity; Ex. Al, exchangeable aluminium.

* Significant at 5%, **significant at 1%.

species. Here a significant positive relation was noted with root length, fine root weight and rooting density in *C. rotang*, and in *C. thwaitesii* with root length and fine root weight.

Exchangeable bases

The mean content of exchangeable K in the soil varied from 74.8 to 107.9 ppm for *C. rotang*, while in *C. thwaitesii* it was 62.9 to 211.5 ppm. Significant influence of K on root growth, as measured by all parameters, and within a depth of 0–60 cm and radius of 30 cm was noticed only in *C. thwaitesii*.

Potassium was found to have no influence on root growth at any of the lateral distances in *C. rotang* while in *C. thwaitesii* it was significantly and positively correlated with root growth at all radial distances. When different depths were considered separately, no definite impact was observed in any of the species.

The important factor noted in this study was the highly significant positive correlation between K and root growth in *C. thwaitesii*, but no such correlation was found in *C. rotang*.

Table 6.
Correlation between soil chemical properties (exchange characteristics) and root growth at different soil depths and radial distances

Depth (cm)	Soil chemical properties	*C. rotang* Root parameter RL	TRW	FRW	ROD	*C. thwaitesii* Root parameter RL	TRW	FRW	ROD
0–15	Ex. acidity	−0.12	−0.13	−0.14	−0.14	0.23	−0.22	0.07	0.26
	Ex. Al	−0.23	−0.30	−0.16	−0.22	0.28	−0.10	0.10	0.29
	Ca	0.38*	−0.09	0.28	0.43**	−0.08	−0.07	−0.14	−0.17
	Mg	0.01	0.11	−0.12	0.02	0.29	−0.19	0.07	0.30
	Na	0.16	0.35*	0.16	0.18	0.18	0.08	0.23	0.17
	K	−0.33	0.09	−0.16	−0.33	0.17	0.39	0.30	0.17
15–30	Ex. acidity	−0.06	0.10	0.03	−0.06	0.10	−0.17	−0.04	0.10
	Ex. Al	−0.12	0.11	−0.04	−0.12	0.10	−0.08	−0.01	0.11
	Ca	0.19	0.11	0.06	0.18	−0.06	0.22	0.09	−0.06
	Mg	0.23	−0.02	0.01	0.22	−0.05	−0.13	−0.08	−0.05
	Na	−0.13	−0.07	−0.02	−0.11	0.02	−0.13	0.01	0.01
	K	0.14	−0.18	−0.16	0.12	0.29	0.54**	0.53**	0.29
30–45	Ex. acidity	−0.33	−0.10	0.07	−0.30	0.20	0.47**	0.38*	0.22
	Ex. Al	−0.10	−0.10	−0.03	−0.10	0.12	0.30	0.25	0.14
	Ca	−0.18	0.03	−0.07	−0.26	−0.12	0.01	0.05	−0.14
	Mg	−0.04	−0.18	0.18	0.10	−0.04	−0.24	−0.21	−0.06
	Na	−0.09	−0.02	0.10	−0.10	−0.81	−0.16	−0.12	−0.93
	K	0.02	−0.03	0.01	0.01	0.02	−0.07	−0.10	0.01
45–60	Ex. acidity	0.08	−0.04	−0.21	0.04	0.24	0.04	0.25	0.22
	Ex. Al	0.13	0.22	0.09	0.10	−0.13	0.07	0.08	−0.01
	Ca	0.04	0.11	0.35*	0.09	0.11	0.12	0.12	0.33*
	Mg	−0.07	−0.11	−0.23	−0.12	0.14	0.18	0.03	0.04
	Na	0.36*	0.02	0.35*	0.38*	0.28	−0.24	−0.08	0.01
	K	0.41**	0.33	0.37*	0.45**	0.30	0.34**	0.33	0.25

RL, root length; TRW, total root weight; FRW, fine root weight; ROD, rooting density; Ex. acidity; exchangeable acidity; Ex. Al, exchangeable aluminium.
* Significant at 5%, **significant at 1%.

Exchangeable Na had no influence on root growth in both the species within a depth of 60 cm and a radius of 30 cm, not at other radial distances. In *C. rotang*, Na had a significant and positive correlation with root growth in the surface layer and at 45–60 cm depth, in contrast to *C. thwaitesii*.

In the case of Ca, its influence within a depth of 0–60 cm and radius of 30 cm was pronounced only in *C. rotang* and all the root parameters were positively correlated with Ca. The Ca status of a soil is fairly well correlated with its pH. In this study, the mean content of Ca in the soil around both species was more or less the same.

These results indicate that presence of Ca in the root exudates of *C. rotang* may be a probable reason for its positive correlation with root growth. The displacement of Ca ions by Al from the root apoplast exchange sites may be suggested as a reason for lack of any correlation for Ca with root growth in *C. thwaitesii*. Some Al displaces

Ca and Mg from the root apoplast exchange site [3], the active uptake of these essential nutrients is inhibited [4].

Exchange acidity

Within a depth of 0–60 cm and a radius of 30 cm, root growth was not affected by exchange acidity of soil in *C. rotang*, but in *C. thwaitesii* significant and positive impact was noticed on root length, fine root weight and rooting density. When the influence of exchange acidity at different lateral distances was considered, at 10 cm and 30 cm radial distance it was significantly and positively correlated with root growth in both species. There was no definite trend on the influence of exchange acidity at different soil layers.

Exchangeable Al

As in the case of exchange acidity, root growth was not affected by exchangeable Al in *C. rotang* within a depth of 0–60 cm and 30 cm radius, but both root length and rooting density were significantly and positively related to exchangeable Al in *C. thwaitesii*.

At different lateral distances also there was no influence of exchangeable Al on root growth in *C. rotang*, but in *C. thwaitesii* its positive and significant impact was noticed at 30 cm radial distance. None of the root parameters were seen to be influenced by exchangeable Al in the two species when different depths were taken into consideration.

The two soil properties, exchange acidity and exchangeable Al, do not have any influence on root growth in *C. rotang.* The reason for this could be attributed to the nullifying effect on exchange acidity and exchangeable Al by the cation containing exudates of *C. rotang*. The positive correlation between these soil properties and root growth in *C. thwaitesii* suggests that this species is more suitable on acidic soils.

REGRESSION ANALYSIS

Based on the above findings, an attempt was made to fit a regression model. Two response functions relating fine root weight (FRW) and rooting density (ROD) to the soil properties were fitted using stepwise regression techniques in each of these species.

The models fitted through stepwise regression in *C. rotang* were:

$$\underset{}{\mathrm{FRW}} = \underset{(0.0418)}{0.0724} + \underset{(0.0092)}{0.0769\mathrm{OC}} - \underset{(0.0046)}{0.02196\mathrm{SM}} + \underset{(0.4734)}{1.4692\mathrm{Ca}} \qquad (\text{Adj. } R^2 = 0.4326)$$

$$\mathrm{ROD} = \underset{(0.1279)}{-0.0732} + \underset{(0.0232)}{0.1601\mathrm{OC}} + \underset{(0.0017)}{0.0051\mathrm{Sand}} + \underset{(1.1248)}{3.7036\mathrm{Ca}} - \underset{(0.0117)}{0.0346\mathrm{SM}}$$

$$(\text{Adj. } R^2 = 0.4451)$$

in which FRW is fine root weight, ROD rooting density, OC organic carbon, SM soil moisture and Ca calcium.

In the first model, fine root weight of *C. rotang* was found to be influenced significantly by organic carbon, soil moisture and calcium. From the adj. R^2, 43% of the variations in fine root weight of *C. rotang* could be explained by these soil variables. Organic carbon explained 31% of the variations in fine root weight followed by soil moisture and calcium.

In the second model, rooting density of *C. rotang* was influenced significantly by organic carbon, sand, calcium and soil moisture. Adj. R^2 revealed that 45% of the variations in rooting density of *C. rotang* could be explained by these soil variables of which the most correlated variable with the rooting density was organic carbon. It explained 30% of the variations.

The models fitted through stepwise regression in *C. thwaitesii* were:

$$\begin{aligned}
\text{FRW} &= \underset{(0.0679)}{-0.0612} + \underset{(0.0002)}{0.0014\text{K}} + \underset{(0.0011)}{0.0037\text{Sand}} - \underset{(0.0010)}{0.0030\text{Gravel}} \\
&\qquad (\text{Adj. } R^2 = 0.4500) \\
\text{ROD} &= \underset{(0.0890)}{0.1816} + \underset{(0.0003)}{0.0028\text{K}} - \underset{(0.0016)}{0.0085\text{Gravel}} + \underset{(0.0275)}{0.0856\text{OC}} + \underset{(0.2760)}{0.7488\text{Av N}} \\
&\qquad (\text{Adj. } R^2 = 0.6252)
\end{aligned}$$

in which FRW is fine root weight, ROD rooting density, OC organic carbon, K potassium and Av. N available nitrogen.

In the first model, fine root weight of *C. thwaitesii* was influenced significantly by exchangeable potassium, sand and gravel. From the adj. R^2, 45% of the variations in fine root weight of *C. thwaitesii* could be explained by these soil variables. Among the soil properties, the most correlated variable with the fine root weight was exchangeable K. It explained 35% of the variations in fine root weight followed by sand and gravel.

In the second model, rooting density of *C. thwaitesii* was influenced significantly by potassium, gravel, organic carbon and available nitrogen. Adj. R^2 revealed that 63% of the variations in rooting density of *C. thwaitesii* could be explained by these soil variables of which the most correlated variable with the rooting density was K. It explained 44% of the variations followed by gravel explaining 13% of the variation.

Step wise multiple regression analysis carried out in *C. rotang* revealed that variations existing in the fine root weight are due to organic carbon, soil moisture and exchangeable Ca content of the soil. The rooting density of this species was influenced significantly by the above soil properties together with sand. In *C. thwaitesii*, variations in fine root weight were explained by the soil properties, *viz.*, gravel, K and sand and the variation in rooting density of this species is explained by gravel, available N, K and organic carbon. In short, the root growth of

Calamus during the early stages is generally influenced by the soil properties such as soil moisture, sand, organic carbon, available N, potassium and calcium.

CONCLUSIONS

This study revealed that while organic carbon, available nitrogen and extractable phosphorus are significantly and positively related to the root growth in the two species, exchange acidity and exchangeable aluminium have significant positive relation with root growth only in *C. thwaitesii*. A significant and positive relation was noted for calcium with the different root parameters in *C. rotang*. It is clear that *C. thwaitesii* favours more acidic soils than *C. rotang*, and this should be taken into account when establishing plantations.

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