Journal of Plantation Crops, 2010, 38 (2): 92-96

Influence of soil moisture and nutrient status on fine root dynamics of rubber trees (*Hevea brasiliensis*)

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(Manuscript Received: 06-02-09, Revised: 25-01-10, Accepted: 16-05-10)

Abstract

Fine roots are important for water and nutrient acquisition and their dynamics have profound influence on the below ground resource capture efficiency of trees. The present investigation was taken up to study the effect of environmental variables viz., soil moisture and soil nutrient status on the fine root dynamics of rubber trees, and to find out the period of highest fine root density to optimize the timing of pre-monsoon fertilizer application. The study was conducted at two locations, Kottayam and Chethackal with distinct variation in soil nutrient status, comparatively lower status at Kottayam and higher at Chethackal. Root observations were recorded during 2006 and 2007. Soil moisture stress during summer season was less during 2006 compared to 2007. At both the locations, the clone was RRII 105 and trees were 17 years old. Fine root density in the surface layer (0-7.5 cm) was quantified during summer season and after the onset of rains till the root density stabilized or declined. Soil moisture was recorded periodically. With the onset of rains, fine roots began to develop and the highest root density was observed after a period of 35 to 45 days at both the locations during both the years. After this period, the root density declined. The fine root density was nearly twofold at the low fertility site (Kottayam) compared to the other site (Chethackal). The intensity of soil moisture stress during preceding summer season influenced the time taken for fine root development after the onset of rains and the biomass allocated for fine root production at the low fertility site. When the soil moisture stress was low, there was gradual increase in fine root density, whereas, when the soil moisture stress was more, the time lag for initiating root proliferation was longer. The data indicate the necessity of a more precise timing of fertilizer application to maximize uptake of applied nutrients.

Keywords: Fine root dynamics, moisture stress, soil nutrient status

Introduction

Fine root production represents a large proportion of total annual net primary production in most ecosystems. Of the total net primary production in forest ecosystems, 40 to 73 per cent has been reported to be allocated below ground for fine root production (Agren *et al.*, 1980). Fine roots (roots thinner than 2 mm) are in constant flux with death and replacement taking place simultaneously and are the organs of water and nutrient acquisition. The plasticity in root development enables the plants to alter their root morphological features so as to explore their surroundings more efficiently for essential resources at a minimum resource investment. Since fine roots comprise most of the total root length of any root system and have very tiny diameter, they are in intimate contact with the large volume of soil per unit root volume and of major importance in water and nutrient acquisition.

Fine root production and turnover are highly sensitive to changing soil environments. Leuschner and Hertel (2002) identified water availability as the single factor with largest influence on fine root biomass in beech forests. Nutrient availability is also an important soil factor which influence fine root production and mortality. In most cases the responses to nutrient availability are adaptive, they serve to increase efficiency of nutrient capture under situations of nutrient limitation (Forde and Lorenzo, 2001) Extensive root proliferation and branching is seen in the organic horizon of many forest ecosystems to increase nutrient acquisition particularly when growth is limited by nutrient availability (Vogt *et al.*, 1996).

The variations in the monsoon pattern and varying drought intensities experienced in recent years necessitate refinement of some of the agro-management techniques. A more precise timing of the fertilizer application when there is a re-growth of adequate active fine roots after the decline in root biomass during the summer season will ensure higher fertilizer use efficiency. Moreover there is a growing concern over the soil acidification in agricultural systems. Nitrate leaching has been identified as a cause for soil acidification, which can be minimized by applying fertilizers when crop uptake efficiency is higher (Barak *et al.*, 1997).

The present investigation was taken up to study the fine root dynamics of rubber trees in relation to soil moisture and nutrient and to find out the period of highest fine root density to optimize the timing of pre-monsoon fertilizer application.

Materials and Methods

Root measurements were recorded from two rubber plantations (clone RRII 105) established in 1989 at the Rubber Research Institute of India, Kottayam, Kerala, (9° 32' N, 76° 86'E, at an altitude of 73 m above msl) and Central Experiment Station, Chethackal, Kerala (9° 22' N, 76° 50'E, at an altitude of 50 m). Both the sites differed appreciably in soil nutrient status, soil pH and gravel content (Table 1). Typical warm humid tropical climate is experienced in both the locations with definite wet and dry periods. The mean annual rainfall at Kottayam is around 3000 mm, but it is not well distributed. Dry season extend from December to April which is a period of definite soil moisture stress. Chethackal receives comparatively more rainfall (average annual rainfall ranges from 3000 to 3500 mm) both in terms of total quantity and distribution.

Table 1. Soil nutrient status and gravel content of the study sites

Location	Gravel content (%)	pH	Org C (%)	Av.P	Av.K	Av.Ca	Av.Mg
				mg/ 100 g soil			
Chethackal	4	4.75	2.49	7.20	8.52	11.04	3.88
Kottayam	12.86	4.40	1.99	0.96	2.81	1.37	0.55

Fine root density (kg dry matter m^{-3} soil volume) was measured by core sampling. Since the highest root density in mature rubber plantations was observed in the surface 0-7.5 cm soil layer (Soong, 1976), root density sampling was confined to this layer. Eight sites in the inter-row area with representative tree height and girth were selected at random for root sampling. Quadrates of 3x3 m were delimitated at each site and root samples were collected with a sharp corer 50 mm in diameter. At each of the sampling site, six samples were collected at each sampling (48 samples at a time). Samples were collected at variable distances from the base of the tree. Sampling was done at monthly intervals during summer season and at shorter intervals after the onset of the rains till the root density more or less stabilized or started to decline.

Samples were soaked in water and cleaned from soil and organic residues by sieving in a gentle stream of water. Soon after washing, dead roots were carefully removed. Fine roots of other plants were separated based on colour, branching pattern and texture. Live roots (biomass) were dried at 70 °C and weighed.

Soil moisture (0-30 cm) was recorded gravimetrically from both the sites periodically and expressed as percentage. Composite soil samples (0-30 cm) were collected from the study sites and analyzed for pH (1:2.5 soil water ratio), organic carbon (Walkley and Black's method as described by Jackson, 1973) available P (Bray and Kurtz, 1945), available K (Morgan, 1941) and available Ca and Mg (Vogel, 1969). Rainfall data from both the locations were collected from the agro-meteorological observatories located near the study sites. The data were subjected to analysis of variance- one-way classification for comparison.

Results and Discussion

Organic carbon and available nutrient status was comparatively higher at Chethackal. Soil acidity was also lower at Chethackal. Gravel content in 0-30 cm soil layer was only 4 per cent at Chethackal whereas it was 12.86 per cent at Kottayam.

Daily rainfall during the study period at the two locations is given in Fig 1 & 2. At Kottayam, the days after rainfall were counted from 31st March and 2 nd April during 2006 and 2007 respectively. The corresponding dates were March 4th and April 9th at Chethackal. After the onset of rains, fine root development did not commence immediately at both the locations. The highest fine root density was observed 45 and 43 days after rainfall at Kottayam during 2006 and

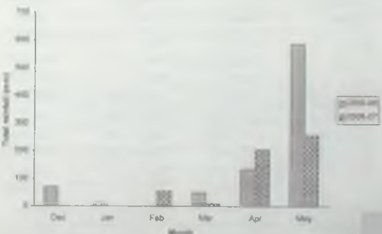

Fig. 1. Monthly rainfall at Kottayam during the study period

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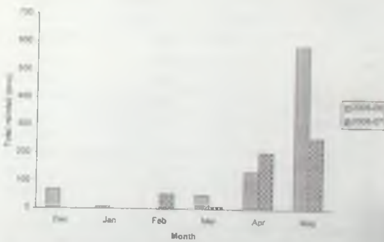

Fig. 1. Monthly rainfall at Kottayam during the study period

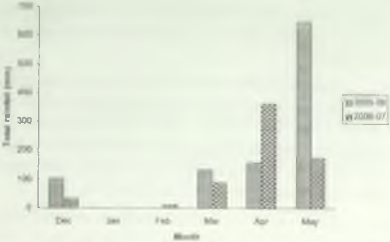

Fig. 2. Monthly rainfall at Chethackal during the study period

2007 respectively. The same trend was observed at Chethackal also; the highest values were observed 36 and 38 days after rainfall (Table 2). This indicates that after the onset of rains a minimum recovery period is required for further initiation of fine root development. According to Mc Cully (1999), fine roots play an important role in drought resistance and recovery in many plants. Drought induces development of fine root primordia in plants, often in response to death or exhaustion of the parent root apical meristem. These primordia are drought resistant and when watered, rapidly develop into fine roots, which resume water and nutrient uptake. Jessy *et al.* (2005) also observed a time lag for fine root production after the onset of rainfall. In the present study, after attaining the highest value, the root density declined rapidly particularly at Kottayam. A mat of fresh fine roots are seen scavenging the litter layer during the period of highest fine root development and these roots are lost along with the decaying litter rapidly. The fine roots on the litter layer are also lost through the splashing of the rain drops or erosion during the high intensity rainfall during June. This effect was more pronounced at Kottayam possibly due to the more sloppy nature (15 per cent) of the study site.

Fine root density in the surface 0-7.5 cm soil layer decreased as the summer season advanced and showed a remarkable increase after the receipt of the rain at both the locations (Table 2). However, the fine root density was significantly higher at Kottayam which is a low fertility site compared to Chethackal (Table 3). The fine root density was 2.57 kgm^{-3} soil during the peak period at Chethackal during 2006 and it was 4.57 kgm^{-3} soil at Kottayam. The corresponding values were 2.69 and 5.90 kgm^{-3} soil respectively during 2007. We attribute this variation in fine root density to the remarkable difference in soil properties. Available P content of the soil has a profound influence on the fine root production and mortality and there was appreciable difference in the available P content at Kottayam (0.96 mg/100 g soil) and Chethackal (7.20 mg/100 g soil). When available P content is low, trees produce more fine roots in the surface soil to enhance P acquisition. Other factors which promote surface root proliferation like soil acidity (Forde and Lorenzo, 2001) and gravel content (Soong, 1976) were also higher at Kottayam. This higher fine root density in soils with low fertility status might be an adaptive mechanism of trees to enhance nutrient acquisition.

The soil moisture data indicate that the intensity of drought during 2007 was higher compared to 2006 at both the locations (Fig 3). However, the difference in drought intensity at Chethackal was only marginal, but it was appreciable at Kottayam. The data on fine root density clearly shows the profound influence of drought intensity on fine root dynamics. Significant differences

Table 2. Fine root density in the 0-7.5 cm soil layer (kgm^{-3} soil)

Kottayam				Chethackal			
2006		2007		2006		2007	
Sampling period	Fine root density	Sampling period	Fine root density	Sampling period	Fine root density	Sampling period	Fine root density
Jan	2.38 (1.04)	Jan	1.09 (0.46)	Jan	2.49 (0.88)	Jan	1.43 (0.65)
Feb	1.84 (1.06)	Feb	0.84 (0.31)	Feb	1.36 (0.49)	Feb	1.08 (0.56)
Mar	1.54 (0.81)	Mar	0.69 (0.47)	Mar	0.88 (0.53)	Mar	0.88 (0.43)
Apr (16 dar)*	1.72 (0.63)	Apr (10 dar)	0.93 (0.52)	Mar (23 dar)	1.41 (0.60)	Apr (9 dar)	1.48 9 (0.68)
Apr (23 dar)	2.59 (1.18)	Apr (21 dar)	1.14 (0.31)	Apr (30 dar)	2.06 (0.68)	Apr (15 dar)	1.62 (0.53)
Mar (31 dar)	3.75 (1.34)	May (30 dar)	2.82 (0.86)	Apr (36dar)	2.57 (0.74)	May (24 dar)	2.06 (0.65)
May (45 dar)	4.57 (1.40)	May (43 dar)	5.90 (0.98)	May	2.29 (0.98)	May (38 dar)	2.69 (0.81)
Jun	2.70 (0.79)	Jun	3.17 (0.71)	Jun	1.90 (0.76)	Jun	2.57 (0.95)
Jul	2.31 (0.79)	Jul	2.16 (0.76)	Jul	1.86 (0.68)	Jul	1.96 (0.95)
SE	0.17		0.09		0.11		0.12
CD (p<0.05)	0.97		0.26		0.32		0.34

*days after rain fall Values in parentheses are standard deviations

Table 3. Comparison of peak fine root density (kg m^{-3} soil) between locations

Year	Kottayam	Chethackal	t -value
2006	4.57	2.57	7.95**
2007	5.90	2.69	16.65**

**significant at 1 % level

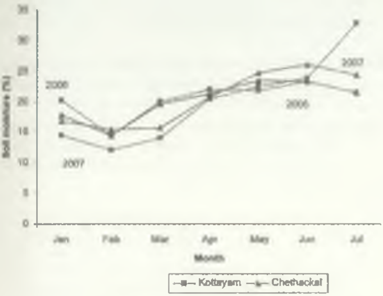

Fig. 3. Soil moisture status during the study period

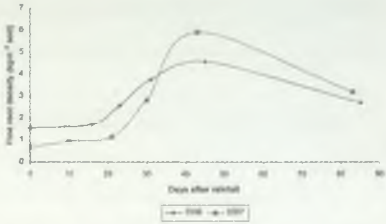

Fig. 4. Fine root dynamics after rains at Kottayam

were observed between 2006 and 2007 at Kottayam with respect to the decline in fine root density during summer and highest fine root density produced after rains (Table 4). Keyes and Grier (1981) observed that above ground production of Douglas fir was reduced in favour of fine root production on more droughty, nutrient poor soils. Joslin and Wolfe (1998) also reported that trees experiencing repeated and/or extended shortages of available water would allocate a greater proportion of their carbon below ground in an attempt to increase their root shoot ratio. Another interesting observation was that the time taken for fine root development was longer when the intensity of preceding drought stress was higher (Table 2). When the drought intensity was lower, there was a gradual root development whereas when the preceding drought stress was more, fine roots took more time for recovery. Fine root development during the initial period was very low and after 30 days, there was very rapid root development (Fig 4).

Table 4. Comparison of fine root dynamics between years

Location	Fine root density (kg m^{-3} soil)	2006	2007	t-value
Kottayam	Lowest (at the end of summer)	1.54	0.69	6.41**
	Highest (after rains)	4.57	5.90	5.61**
Chethackal	Lowest (at the end of summer)	0.88	0.88	ns
	Highest (after rains)	2.57	2.69	ns

**significant at 1 % level

The high degree of plasticity of fine roots in the surface soil layer shows the agronomic efficiency of rubber trees. This plasticity helps the trees to explore the soil for water and nutrients efficiently. During refoliation in January – February, large quantity of biomass is diverted for leaf production. Just like in refoliation, large quantity of biomass is allocated for fine root production after the onset of pre-monsoon showers. Since these fine roots are ultimately added to the soil carbon pool, fine root turn over is as important as litter recycling in rubber plantations.

Conclusion

After the onset of rains, a period ranging from 35 to 45 days is required to attain highest fine root development. Fine root density is higher when soil nutrient status is lower indicating the adaptive mechanism of trees to enhance nutrient acquisition under such situations. When intensity of preceding drought stress is more, more biomass is diverted for fine root production and a longer period is needed for fine root development. Since fine roots are the primary organs of nutrient acquisition, these factors should be considered while scheduling fertilizer application to maximize uptake of applied nutrients particularly in the context of growing concern over soil acidification in agricultural systems and increasing frequency and severity of drought stress predicted due to climate change.

References

Agren, G., Axelsson, B., Flower-Ellis,J.G.K., Linder, T., Person, H., Staaf, H. and Troeng, E. 1980. Annual carbon budget for a young Scots pine. *Ecological Bulletin,* **32**: 307-313.

Barak, P., Jobe, B.O., Krueger, A.R., Peterson, L.A. and Laird, D.A. 1997. Effects of long term soil acidification due to nitrogen inputs in Wisconsin. *Pl. Soil* **197**: 61-69.

Bray, R.H. and Kurtz, L.T. 1945. Determination of total, organic and available forms of phosphorus in soils. *Soil Science* **59**: 39-45.

Forde, B. and Lorenzo, H. 2001. The nutritional control of root development. *Pl. Soil* **232**: 51-68.

Jackson, M.L.1973. *Soil chemical analysis*, Prentice Hall Inc. New York. 498 p.

Jessy M.D., Thomas, V. and Vijayakumar, K.R. 2005. Fine root production of rubber trees (*Hevea brasiliensis*) in relation to precipitation. Preprints of papers, International Natural Rubber Conference, Cochin 156-163.

Joslin, J.D. and Wolfe, M.H. 1998. Impacts of water input manipulations on fine root production and mortality in a mature hardwood forest. *Pl. Soil* **204** 204: 165-174.

Keyes, M.R. and Grier, C.C. 1981. Above and below ground production in 40 year old Douglas fir stands on low and high productivity sites. *Can. J. For. Sci.* **11**: 599-605.

Leuschner, C., and Hertel, D. 2002. Fine root biomass of temperate forests in relation to soil acidity and fertility, climate, age and species. *Prog. Bot.* **64**: 405-438.

Mc Cully, M.E. 1999. Roots in soil: Unearthing the complexities of roots and their rhizospheres. *Ann. Rev. Pl. Physiol. Pl. Mol. Biol.* **50**: 695-718.

Morgan, M.F. 1941. Chemical diagnosis by the universal soil testing system. Bulletin of the Connecticut Agric. Experiment Station 450p.

Soong, N.K. 1976. Feeder root development of *Hevea brasiliensis* in relation to clones and environment. *J. Rubb. Res. Inst. Malaysia* **24**: 283-298.

Vogel, A.I. 1969. A text *book of the qualitative inorganic analysis including elementary instrumental analysis*. The English Language book Society and Longman, pp. 744-745.

Vogt, K.A., Vogt, D.J., Palmiotto, P.A. Boon, P., Jennifer O'Hara and Asbjornsen. 1996. Review of root dynamics in forest ecosystems grouped by climate, climatic forest type and species. *Pl. Soil* **187**: 159-219.