FINE LITTERFALL AND ITS NUTRIENTS IN PLANTATIONS OF *ACACIA AURICULIFORMIS*, *EUCALYPTUS TERETICORNIS* AND *TECTONA GRANDIS* IN THE CHIKMAGALUR DISTRICT OF THE WESTERN GHATS, INDIA

H. Ramachandra Swamy

Sri Jagadguru Chandrasekhara Bharati Memorial College, Sringeri 577139, Karnataka, India

&

John Proctor

DBMS, University of Stirling, Stirling, FK9 4LA, United Kingdom

Received November 1995

SWAMY, H.R. & PROCTOR, J. 1997. Fine litterfall and its nutrients in plantations of *Acacia auriculiformis*, *Eucalyptus tereticornis* and *Tectona grandis* in the Chikmagalur District of the Western Ghats, India. A study was made of the soils and litterfall in plantations of *Acacia auriculiformis*, *Eucalyptus tereticornis*, and *Tectona grandis* in Karnataka State in southwest India. All the sites had nutrient-rich soils and occurred under a highly seasonal climate with mean annual rainfalls of 7471 (*Acacia*), 1533 (*Eucalyptus*) and 2003 mm (*Tectona*). The *Eucalyptus* litterfall was measured for two years and for the other two species for three years. The mean total fine litterfall was: *Acacia* 17.5, *Eucalyptus* 8.6, *Tectona* 11.4 t ha^{-1} y^{-1}. High quantities of nitrogen, phosphorus, potassium, sodium, calcium and magnesium, particularly in the case of *Acacia* moved in the litterfall pathway. The litterfall was seasonal with the highest peaks in the wet season in the case of *Acacia*, and in the dry season for the other two species.

Key words: *Acacia auriculiformis* - *Eucalyptus tereticornis* - India - litterfall - mineral nutrients - plantations - *Tectona grandis* - tropical

SWAMY, H.R. & PROCTOR, J. 1997. Jatuhan sarap halus dan nutrien di ladang *Acacia auriculiformis*, *Eucalyptus tereticornis* dan *Tectona grandis* di Daerah Chikmagalur di Ghat Barat, India. Kajian dijalankan terhadap tanah dan jatuhan sarap di ladang *Acacia auriculiformis*, *Eucalyptus tereticornis*, dan *Tectona grandis* di negeri Karnataka, di barat daya India. Semua tapak mengandungi tanah yang kaya nutrien di bawah cuaca bermusim dengan min hujan tahunan sebanyak 7471 (*Acacia*), 1533 (*Eucalyptus*) dan 2003 mm (*Tectona*). Jatuhan sarap *Eucalyptus* disukat selama dua tahun dan dua spesies yang lain selama tiga tahun. Purata jumlah jatuhan sarap halus ialah: *Acacia* 17.5, *Eucalyptus* 8.6, *Tectona* 11.4 t ha^{-1} y^{-1}. Jumlah nitrogen, fosforus, potassium, sodium, kalsium dan magnesium yang tinggi terutamanya bagi *Acacia*, memasuki laluan jatuhan sarap. Jatuhan sarap adalah bermusim dengan jatuhan tertinggi pada musim hujan bagi *Acacia* dan pada musim kemarau bagi kedua-dua spesies.

Introduction

The rain forests of the Western Ghats mountain range of southwest India are remarkable in several ways. They have been the subject of many studies of which the most comprehensive (for forests of low and medium elevations) is that of Pascal (1988). Perhaps the most unusual feature of the Western Ghats' rain forests is their strongly seasonal climate, often but not always associated with a very high annual rainfall. The Ghats' forests have a floristically tropical vegetation; yet in the winter dry season they are exposed to temperatures that are considered low for tropical rain forests. For example, an extreme minimum of 8.3 °C has been recorded in a Stevenson screen at Sringeri town (altitude 724 m). These low temperatures are well below those normally regarded as causing chilling injuries in tropical plants (Crawford 1989). A further feature of the Western Ghats' forests is that they occur on soils which are exceptionally rich in nutrients (Swamy & Proctor 1995a).

The fine litterfall in four undisturbed examples of the Western Ghat's forests has been measured by Swamy and Proctor (1995b) and the values for total fine litterfall ranged from 11.6 t ha^{-1} y^{-1} (moist deciduous forest) to 13.9 t ha^{-1} y^{-1} (shola forest). Swamy and Proctor (1995b) also quantified the fluxes of nutrients in the litterfall and found them to be relatively high in all four forest types which they studied. The Western Ghats are being increasingly planted with exotic trees but there is little information on their litterfall. Such information is useful because litterfall is an index of production and an important pathway for nutrient cycling. In this paper we report on litterfall studies made in three contrasting plantations: *Acacia auriculiformis* A. Cunn. *ex* Benth., *Eucalyptus tereticornis* Sm. and *Tectona grandis* L.f. Henceforth these species are referred to by their generic names only and their plantations are abbreviated: AC (*Acacia*), EU (*Eucalyptus*) and TK (*Tectona*).

The *Acacia* and *Eucalyptus* are native to New Guinea and Australia, and the *Tectona* is indigenous to the Indian sub-continent, Thailand and Cambodia (Boland *et al.* 1991, Redhead & Hall 1992). *Acacia* has leaf-like petioles (phyllodia), the other two species have normal leaves, and both the phyllodia and normal leaves are referred to as leaves in this paper.

Materials and methods

The study plots

One plot of 1 ha was set up in each of three plantations in the Chikmagalur District of Karnataka, India. The plot locations are shown in Figure 1 and some further details about them are given in Table 1. In 1987 at the time of the descriptive study, AC was still a pure species stand but EU had been invaded by three, and TK by thirteen other tree species.

Table 1. The forest types (with abbreviation in parentheses), their dates of planting, their location and altitudes in the three plantations in the Chikmagalur District, India

Forest type	Date of planting	Location	Altitude (m)
Acacia auriculiformis (AC)	1977	Guddekeri	899
Eucalyptus tereticornis (EU)	1968	Harokoppa	810
Tectona grandis (TK)	1932	Kaggadalu	585

The rainfall at all the sites is highly seasonal with most of it falling between April and October. The mean annual rainfall for the nearest stations to the sites is given in Table 2. AC is by far the wettest of the three plantations and EU is substantially drier than TK. Temperature data are lacking but all are likely to be fairly similar to those at the town in Sringeri (724 m) (Figure 1), allowing for a lapse rate of about 0.8 - 0.9 °C 100 m^{-1} (Pascal 1988). The mean daily maximum temperature at Sringeri varied between 22.8 °C (July) and 35.1°C (April), the mean daily minimum temperature between 13.2 °C (January) and 19.8 °C (May), and the extreme maximum temperature was 35.6 °C and the minimum 8.3 °C (Swamy & Proctor 1995a).

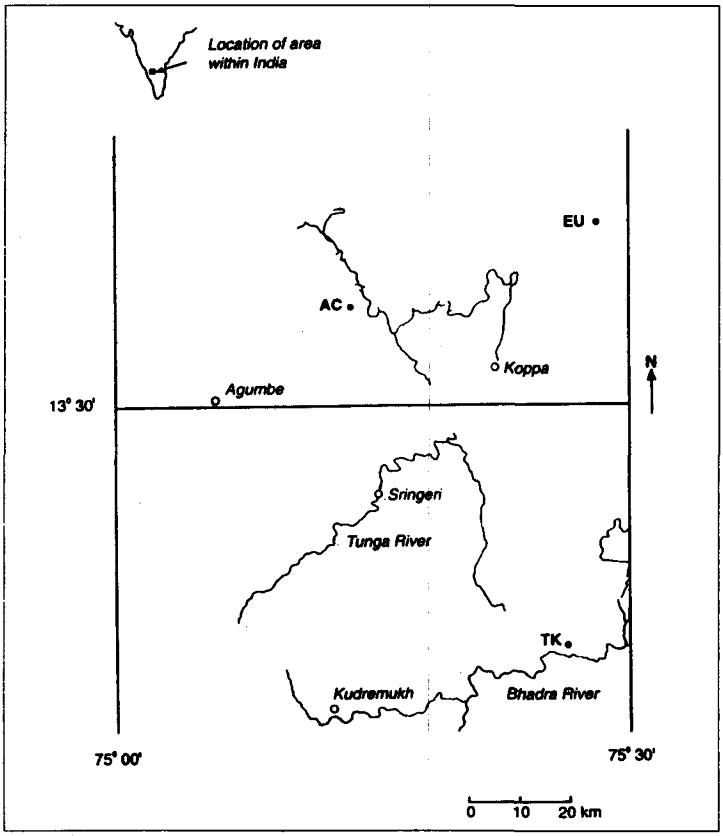

Figure 1. Location of the three forest plantations: AC, *Acacia*; EU, *Eucalyptus*; and TK, *Tectona*

Journal of Tropical Forest Science 10(1): 73 - 85 (1997)

Table 2. Mean annual rainfall (with ranges in parentheses) recorded at stations near the three plantation forests in the Chikmagalur District, India

Plantation	Mean rainfall	Years recorded	Station	Distance from plantation (km)
AC	7471 (5245-10300)	1976-1988	Agumbe	9
EU	1533 (413-2381)	1977-1987	N.R.Pura	10
TK	2003 (1367-2533)	1976-1988	Magundi	7

Soil sampling and analysis

Soil pits (1 × 1 m) were dug up to a depth of about 2 m (except where the bedrock or the water table was reached earlier) in each of ten random locations within the plots. About 3 kg of soil were taken from the following depths (cm) in each pit: 0-5, 5-10, 10-20, 20-30, 30-50, 50-70, 70-100, 100-130, 130-170, > 170. The soil-sample depths were not related to depths of soil horizons.

Electrical conductivity and pH were determined in a 1:2.5 mix of fresh soil: water using an Elico Digital Mhos pH meter (model PE-133). The soils were air dried, ground and passed through a 2-mm mesh. The soils were then oven-dried at 85 °C and sieved through a 0.5-mm mesh. The coarse sand [(2.00-0.50) mm fraction] was weighed and subsequent analyses made on the ≤ 0.50 mm fraction. Before further particle-size analysis, sub-samples were treated with hydrogen peroxide to oxidise soil organic matter, and dispersed with sodium hexametaphosphate. The medium, fine and very fine sands were wet-sieved on standard sieves, and the silt and clay measured by a pipette method (Black *et al.* 1965). Organic carbon was measured by the Walkley-Black wet oxidation procedure and total nitrogen estimated by digestion of the soil in sulphuric acid followed by a Kjeldahl distillation. Exchangeable cations were extracted with 1 M ammonium acetate solution adjusted to pH 7. Potassium and sodium were determined by flame emission photometry and calcium and magnesium by EDTA titration. Cation-exchange capacity was determined by estimating the amount of ammonium ions on the residual soil after extraction for exchangeable cations described above (Jackson 1958). Available phosphorus was extracted by 0.03 M ammonium fluoride in 0.025M hydrochloric acid (Bray & Kurtz 1945) and determined by a spectrophotometer. Copper, iron manganese and zinc were extracted in a solution of 0.005M DTPA (diethylenetriaminopentaacetic acid), 0.1M triethanolamine, and 0.01M calcium chloride. Boron was extracted using hot deionized water. All micronutrients were estimated by atomic absorption spectrophotometry.

Vegetation description

The trees (≥ 10 cm dbh) in each plot were sampled in 1987 using the point-centred quarter method of Cottam and Curtis (1956). Fifty-one points spaced at not less than 10 m intervals were randomly located along transects separated from each other by more than 10 m. At each point, the nearest tree in each quadrant (NE, SE, SW and NW) was located, its distance from the point was recorded and its dbh and height measured. No tree was recorded twice. Fertile specimens were collected over the study period from all the species and their identification was confirmed at the Herbarium of the Centre for Ecological Sciences, Indian Institute of Science, Bangalore.

Fine litterfall

Collection

Fine litterfall was collected from ten collectors randomly placed on the 1-ha plot. The collectors were 1 × 1 m quadrats on the forest floor which were covered with polythene sheets tied to pegs at the corners. Collection began in the first week of February 1986 and litterfall was collected on the same date of each month for 36 months at AC and TK and 24 months at EU. For each collector the monthly litterfall was kept separate, dried at 55 °C for 48 h and weighed. The litterfall for all collectors was then combined for each plot on a monthly basis and sorted into leaves, twigs (<3 cm diameter), fruits, flowers and epiphytes.

Chemical analysis

The fine litter was ground and sub-sampled for chemical analysis using the methods described by Wilde *et al.* (1979). Nitrogen was determined in concentrated sulphuric acid digests by the micro-Kjeldahl's method. Phosphorus, potassium, sodium, calcium and magnesium analyses were made on sub-samples ashed in a muffle furnace at 550 °C for 1 hour and subsequently dissolved in hydrochloric acid. For phosphorus the procedure of ashing with magnesium nitrate was followed. Phosphorus was determined as phosphomolybdate blue, using a spectrophotometer; potassium and sodium by flame emission photometry; and calcium and magnesium by EDTA titration.

Results

Plot vegetation

Data for tree species, basal area and density are given in Table 3. In 1987 AC (then ten years old) remained a pure stand while the invading species accounted for 23.7 % of the basal area in EU (nineteen years old) and 12.7 % of the basal area in

TK (forty-five years old). The mean heights of all the trees in the plots were: AC, 14.0 m; EU, 24.7 m; and TK, 26.1 m. AC was the youngest plantation and had the least mean tree height but was second in terms of basal area and biomass and had the highest tree density. TK was the oldest plantation and ranked first for all measures except tree density.

Table 3. The tree (> 10cm dbh) species recorded, their basal area and density in the three tree plantations in the Chikmagalur District, India

Plantation	Species	Basal area ($m^2 ha^{-1}$)	Density (ha^{-1})
AC	*Acacia auriculiformis*	29.1	897
EU	*Eucalyptus tereticornis*	19.9	530
	Terminalia paniculata	4.62	20
	Syzygium cumini	1.45	10
	Diospyros melanoxylon	0.13	10
TK	*Tectona grandis*	31.0	413
	Grewia tiliifolia	1.14	17
	Dalbergia latifolia	0.80	83
	Albizia chinensis	0.79	8
	Terminalia paniculata	0.49	18
	Butea frondosa	0.34	16
	Pterocarpus marsupium	0.21	17
	Dillenia pentagyna	0.16	8
	Wrightia tinctoria	0.16	16
	Bombax ceiba	0.13	9
	Schleichera oleosa	0.12	17
	Emblica officinalis	0.10	8
	Terminalia bellirica	0.05	16
	Hydnocarpus laurifolia	0.04	8

Soils

It should be noted that the soils were dried at 85 °C before analysis. It is well known that drying soils, particularly at high temperatures, may affect the quantities of minerals extracted by the usual laboratory methods (Jackson 1958). A further point is that the analyses were made on the ≤ 0.5 mm fraction of soil instead of the conventional ≤ 2 mm fraction. In this case a correction can easily be made by applying a factor (which ranges from about 11 to 30%) calculated from the values for percentage sand (0.5 - 2 mm) (Table 4). It can be assumed that this medium sand fraction is virtually inert as far as plant-available mineral elements are concerned.

Analytical data for the surface soil samples are given in Table 4. Full analytical data for the deeper soil samples are given by Swamy (1989). The soils are all mildly acid with pH ranging from 5.7 to 6.3; C/N quotients from 18.7 to 22.7 (except for the EU plot where the C/N quotient at 5-10 cm was 5.6); and extractable phosphorus concentrations were high (28-48 $\mu g\ g^{-1}$). All the soils had a preponderance of calcium amongst the exchangeable bases and base saturation was high (80.7 - 97.3 %). The soils had fairly similar amounts of clay (21.3 - 34.2 %) but differed more substantially in the amounts of sand (37.2 % - 77.4 %) and silt (2.2 %-28.6 %). The TK plot had the least sand and most silt.

Table 4. Soil analytical data for samples (n=10) collected from (a) 0-5 cm, and (b) 5-10 cm depths from the three plantation forests in the Chikmagalur District, India

	AC		EU		TK	
	(a)	(b)	(a)	(b)	(a)	(b)
pH_{H_2O} (log units)	6.0	5.9	5.8	5.7	6.3	5.7
Coarse sand (0.5 - 2.0 mm)(%)	29.1	32.2	3.0	12.4	12.0	11.9
Medium sand (0.25 - 0.5 mm) (%)	18.8	13.8	6.8	12.9	10.9	6.0
Fine sand (0.05 - 0.25 mm) (%)	24.7	21.0	67.6	41.7	34.0	17.0
Silt (0.002 -0.05 mm) (%)	3.8	2.9	2.2	2.7	21.8	28.6
Clay (< 0.002 mm) (%)	23.9	27.6	21.3	30.7	25.5	33.2
Organic carbon (%)	4.94	4.23	4.64	0.52	7.11	4.82
Total nitrogen (%)	0.27	0.21	0.20	0.09	0.33	0.24
C/N	18.7	19.9	22.7	5.6	21.3	19.9
Extractable phosphorus ($ug\ g^{-1}$)	41	28	48	30	45	28
Exchangeable K^+ (m-equivs kg^{-1})	3.3	2.9	3.6	1.5	9.2	7.0
Exchangeable Na^+ (m-equivs kg^{-1})	7.9	6.0	3.5	3.5	3.1	3.1
Exchangeable Ca^+ (m-equivs kg^{-1})	70	60	90	62	127.5	115.0
Exchangeable Mg^{2+} (m-equivs kg^{-1})	11.5	13.0	14.5	16.0	27.5	17.0
Cation exchange capacity (m-equivs kg^{-1})	103.4	93.4	126.0	103.5	171.9	163.0
Base saturation (%)	89.7	87.7	88.6	80.7	97.3	87.2
Extractable B ($ug\ g^{-1}$)	1.34	0.61	0.31	0.11	0.66	0.44
Extractable Cu ($ug\ g^{-1}$)	0.99	1.24	2.08	3.06	2.66	4.07
Extractable Fe ($ug\ g^{-1}$)	27.0	15.5	25.2	29.2	29.8	35.7
Extractable Mn ($ug\ g^{-1}$)	38	39	61	15	109	92
Extractable Zn ($ug\ g^{-1}$)	0.5	0.6	2.1	0.8	2.4	1.8

Journal of Tropical Forest Science 10(1): 73 - 85 (1997)

Litterfall

The results for litterfall mass are given in Tables 5 and 6 and Figure 2. The highest values for leaves (12.6 t ha^{-1} y^{-1}) and twigs (4.6 t ha^{-1} y^{-1}) were for AC and the lowest for EU for which the corresponding values were 4.2 and 3.9 t ha^{-1} y^{-1}. The confidence limits for the yearly values of total small litterfall varied from 11.6 to 17.5 % of the mean values (Table 5). The litterfall was highest in the wet months in AC and the dry months in TK.

Table 5. The annual means (t ha^{-1} y^{-1} ± 95% C.L.'s) for three years (AC and TK) or two years (EU) of total oven-dried (55 °C) litterfall measured from ten 1 × 1 m collection areas in one plot in each of the three plantation forests in the Chikmagalur District, India

	1 March 1986 - 28 February 1987	1 March 1987 - 29 February 1988	1 March 1988 - 28 February 1989
Plot			
AC	16.23 ± 1.88	17.92 ± 2.17	18.34 ± 2.38
EU	9.75 ± 1.71	7.50 ± 1.00	-
TK	12.60 ± 1.89	11.10 ± 1.59	10.37 ± 1.54

Table 6. The overall means (with the ranges of three annual means) of oven-dried (55 °C) fine litterfall measured from ten 1 × 1 m collection areas from 1 March 1986 to 1 February 1989 in each of the plantation forests AC and TK and from 1 March 1986 to 1 February 1988 in the plantation forest EU in the Chikmagalur District, India

Plot	Litterfall (t ha^{-1} y^{-1})			
	Leaves	Twigs	Flowers and fruits	Total
AC	12.57 (10.81-13.93)	4.56 (3.46-5.40)	0.37 (0.032-0.95)	17.50 (16.23-18.34)
EU	4.17 (3.76-4.58)	3.93 (3.40-4.46)	0.33 (0.30-0.35)	8.62 (7.50-9.75)
TK	8.20 (7.73-8.61)	2.35 (1.52-3.04)	0.80 (0.58-0.95)	11.35 (10.37-12.6)

Fine litterfall nutrient concentrations (Table 7) and annual input (Table 8) showed substantial differences between plots. In several cases differences in concentrations (Table 7) were not reflected in input values (Table 8) because of the differences in litterfall mass. AC had the highest input for all elements except for phosphorus and potassium which were highest at TK. The high nitrogen values for AC presumably reflect the nitrogen-fixing ability of the species.

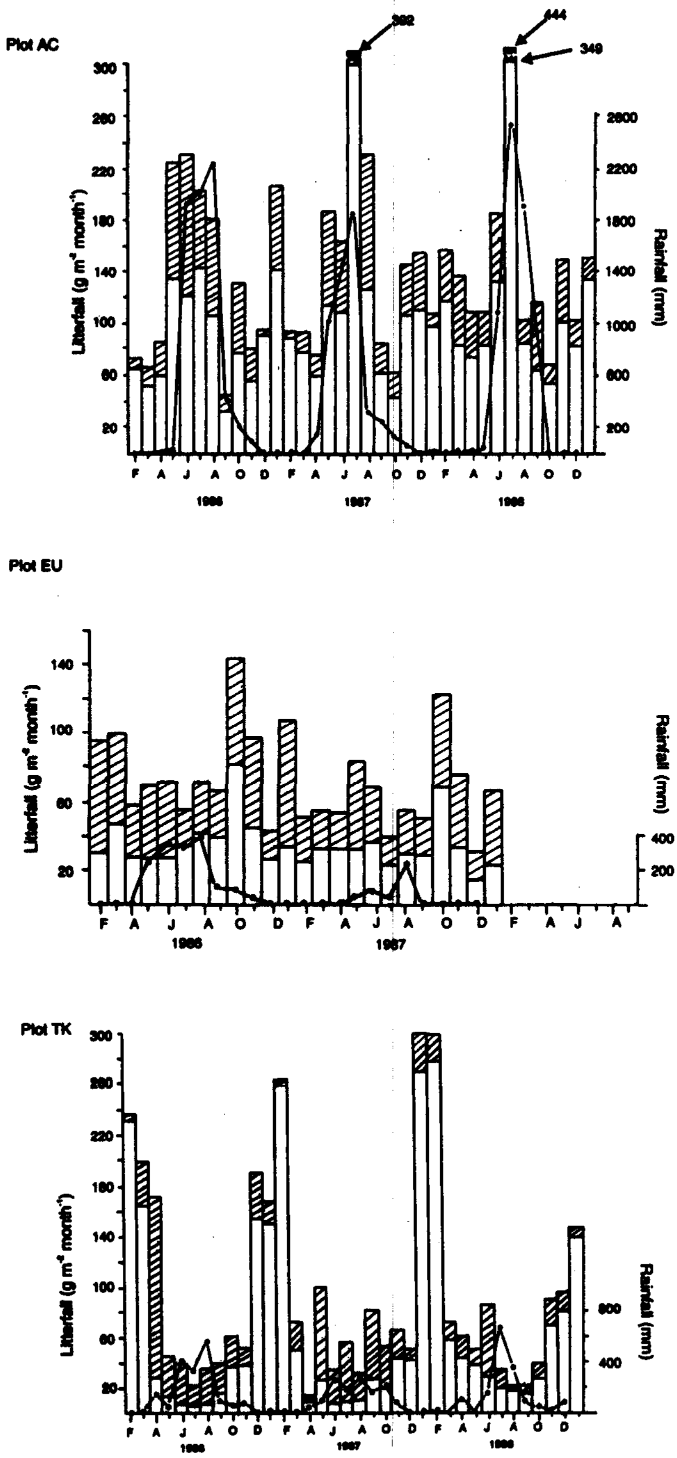

Figure 2. Litterfall (□, leaf ; ▨ (non-leaf) and ●-●-● rainfall on the three forest plantations: AC, *Acacia* ; Eu, *Eucalyptus* ; and TK, *Tectona*

Table 7. The mean foliar (a) and total (b) nutrient concentrations (%) in fine litterfall collected from 1 March 1986 to 1 February 1989 in the plantation forests AC and TK, and from 1 March 1986 to 1 February 1988 in the plantation forest EU

Plot		N	P	K	Na	Ca	Mg
(a)	AC	1.85	0.09	0.40	0.17	2.65	0.52
	EU	0.82	0.12	0.65	0.14	1.46	0.34
	TK	1.35	0.17	0.82	0.05	1.90	0.50
(b)	AC	2.04	0.12	0.89	0.13	1.73	0.44
	EU	0.85	0.12	1.01	0.17	1.10	0.31
	TK	1.50	0.19	0.98	0.06	1.49	0.57

Table 8. The mean annual inputs (kg ha^{-1}) of nutrients in fine litterfall leaves (a) and total fine litterfall (b) collections from 1 March 1986 to 1 February 1989 in the plantation forests AC and TK, and from 1 March 1986 to 1 February 1988 in the plantation forest EU

Plot		N	P	K	Na	Ca	Mg
(a)	AC	231	10.5	46.8	17.3	324	60.6
	EU	35.5	5.0	28.0	6.0	62.3	14.9
	TK	110	13.6	67.6	4.0	156	40.8
(b)	AC	297	14.4	63.4	21.0	444	75.2
	EU	67.7	9.4	54.0	11.5	122	30.8
	TK	143	17.6	84.4	5.4	218	57.8

Discussion

Soils

The soil data (Table 4) are in general agreement with those made elsewhere in the Ghats (e.g. Singh 1968a, Bourgeon 1989) and show that the soils are nutrient rich when compared with those from other rain forest areas in the world (Swamy & Proctor 1995a).

Litterfall

The litterfall mass for AC is exceptionally high (Proctor 1984) and also remarkable since *Acacia* is regarded as suitable for relatively dry areas (1000 - 1800 mm y^1 rainfall) and for poor soils (Evans 1992) [although Boland *et al.* (1991) recorded it as growing naturally in nutrient rich soils and in areas with 3430 mm rainfall]. The Guddekeri site is very wet (*c.* 7000 mm y^1 rainfall) and the soils are rich in nutrients. The *Acacia* is distinct in producing its highest litterfall in the wet season and in this respect it differs from trees in other Western Ghats forests, natural or planted, discussed in the present paper or by Swamy and Proctor

(1995b). EU is the driest plot (*c.* 1500 mm y^1 rainfall) and is remarkable for its relatively low leaf litterfall production mainly by the evergreen *Eucalyptus*. This species, along with *Tectona* is regarded as suitable for planting in areas with 1000 - 1800 mm annual rainfall (Evans 1992). TK has a moderately high leaf and total fine litterfall production which is mainly from the deciduous *Tectona*.

The three species were tested along with many others for response to fertiliser addition (500 kg ha^{-1} NPK, 17: 5:22) on a poor soil in Papua New Guinea (Lamb 1975). *Acacia* responded the best and had a three-year height increment of 6.98 m on fertilisation compared with 2.22 m on the unfertilised control. *Eucalyptus* responded less well with a three-year height increment of 2.01 m, fertilised and 1.10 mm, control. All other species including *Tectona* responded poorly to fertilisation. The very high *Acacia* litterfall on the fertile soils of Guddekeri may be a further indication of a strong nutrient response by this species.

Table 9. The mass and nutrient content (kg ha^{-1} y^1) of fine litterfall recorded from plantation forests of (a) *Eucalyptus tereticornis* and (b) *Tectona grandis*

Place and forest type	Litterfall mass		Mineral nutrient mass					Authors
	Leaf	Total	N	P	K	Ca	Mg	
(a) North India, Central Himalaya, 8-y-old plantation	3.59	6.50	42.8*	2.23*	13.1*	-	-	Bargali *et al.* (1992a,b)
North India, Gangetic Plain, 9-y-old plantation	4.00	5.42	-	-	-	-	-	Singh (1982)
Southwest India, Karnataka, 18-y-old plantation	4.17	8.62	67.7*	9.4*	54.0*	122*	30.8*	This study
(b) North India, Garhwal Shiwaliks, 40-y-old plantation	2.4	-	70.4†	20.6†	23.5†	19.9†	-	Agrawal (1987)
Southwest India, Karnataka. Plantation age not specified	4.7	5.09	-	-	-	-	-	Bhat (1990)
Nigeria, 7-y-old plantation	8.5	9.02	91*	10*	71*	188*	21.6*	Egunjobi (1974)
India , Dehra Dun. Plantation age not specified	-	-	52†	11†	19†	131†	5†	Seth *et al.* (1963)
India, Varanasi Natural forest	5.02	-	36†	8†	20†	120†	11†	Singh (1968b)
Southwest India, Karnataka, 54-y-old plantation	8.2	11.4	143*	18*	84*	218*	58*	This study

*nutrient data for total fine litterfall,
†for leaf litterfall.

Comparative data for litterfall mass and chemical composition are available for *Eucalyptus* and *Tectona* (Table 9) which show values for both mass and chemistry that only rarely exceed those of the present study. This can be attributed to the greater age of the Ghats' plantations and perhaps by the nutrient-richness of the soils (Table 4).

The nutrient concentrations (Table 7) in the litterfall are nearly all relatively high when compared with those from other forests in the world (cf. Proctor 1984) and in this respect match those of the natural forests of the Ghats investigated by Swamy and Proctor (199Sb). In the case of *Acacia* the high litterfall nutrient concentrations combined with the high litterfall mass result in some very high rates of nitrogen, sodium, calcium and magnesium input (Table 8).

It is noteworthy that the peak quantities of nutrient-rich litterfall on AC are out of synchrony with the overall phenologies of the native forests and with the two plantations EU and TK (which occurred in much drier areas than AC). These unusual litterfall features should be borne in mind in work with *Acacia* plantations in the Western Ghats but may not be of general occurrence but a consequence of the unusual soils and climate of that area.

References

AGRAWAL, A.K. 1987. Nutrient release through litterfall in natural forests and plantations in Garhwal Shiwaliks. *Journal of Tree Science* 6 : 10 - 12.

BARGALI, S.S., SINGH, S.P. & SINGH, R.P. 1992a. Structure and function of an age series of eucalypt plantations in Central Himalaya. I. Dry matter dynamics. *Annals of Botany* 69 : 405 - 411.

BARGALI, S.S., SINGH, R.P. & SINGH, S.P. 1992b. Structure and function of an age series of eucalypt plantations in Central Himalaya. II. Nutrient dynamics. *Annals of Botany* 69 : 413 - 421.

BHAT, D.M. 1990. Litter production and seasonality in tropical moist forest ecosystems of Uttara Kannada district, Karnataka. *Proceedings of the Indian Academy of Sciences (Plant Science)* 100 : 139 - 152.

BLACK, C.A., EVANS, D.D., WHITE, J.L., ENSMINGER, L.E. & CLARK, F.E. 1965. *Methods of Soil Analysis.* American Society of Agronomy, Madison, Wisconsin.

BOLAND, D.J., PINYOPUSARERK, K., MCDONALD, M.W., JOVANAVIC, T. & BOOTH, T.H. 1991. The habitat of *Acacia auriculiformis* and probable factors associated with its distribution. *Journal of Tropical Forest Science* 3(2) : 159 -180.

BOURGEON, G. 1989. *Explanatory Booklet on the Reconnaissance Soil Map of Forest Area.* French Institute, Pondicherry, India.

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

COTTAM, G. & CURTIS, J.T. 1956. The use of distance measurement in phytosociological sampling. *Ecology* 37 : 451- 460.

CRAWFORD, R.M.M. 1989. *Studies in Plant Survival.* Blackwell Scientific Publications, Oxford.

EGUNJOBI, J.K. 1974. Litterfall and mineralization in a teak (*Tectona grandis*) stand. *Oikos* 25 : 222 - 226.

EVANS, J. 1992. *Plantation Forestry in the Tropics.* Second edition. Clarendon Press, Oxford. 472 pp.

JACKSON, M.L. 1958. *Soil Chemical Analysis.* Constable, London.

LAMB, D. 1975. *Kunjingini Plantations, 1965-1975.* Tropical Forestry Research Note SR 24. Office of Forests, Papua New Guinea.

PASCAL, J.-P. 1988. *Wet Evergreen Forests of the Western Ghats of India.* French Institute, Pondicherry, India.

PROCTOR J. 1984. Tropical forest litterfall II: the data set. Pp. 83 - 113 in Chadwick, A.C. & Sutton, S.L. (Eds.) *Tropical Rainforest: the Leeds Symposium.* Leeds Philosophical and Literary Society, Leeds, England.

REDHEAD, J.F. & HALL, J.B. 1992. *Tropical Forestry*. Intermediate Tropical Agriculture Series, Longman, Harlow, United Kingdom.

SETH, S.K., KAUL, O.N. & GUPTA, A.C. 1963. Some observations on nutrition cycle and return of nutrients in plantations at New Forest. *Indian Forester* 89 : 90 - 98.

SINGH, K.P. 1968a. Nutrient status of forest soils in humid tropical regions of Western Ghats. *Tropical Ecology* 9 : 119 - 130.

SINGH, K.P. 1968b. Litter production and nutrient turnover in deciduous forests of Varanasi. Pp. 655 - 666 in Misra, R. & Gopal, B. (Eds.) *Recent Advances in Tropical Ecology*. International Society of Tropical Ecology, Varanasi, India.

SINGH, R.P. 1982. Net primary productivity and productive structure of *Eucalyptus tereticornis* Smith plantations grown in Gangetic Plain. *Indian Forester* 108 : 261 - 269.

SWAMY, H.R. 1989. *Study of Organic Productivity, Nutrient Cycle and Small Watershed Hydrology in Natural Forests and in Monoculture Plantations in Chikmagulur District, Karnataka.* Report to the Department of Environment and Forests, Government of Karnataka, India.

SWAMY, H.R. & PRICTOR, J. 1995a. Rain forests and their soils in the Sringeri area of the Indian Western Ghats. *Global Ecology and Biogeography Letters* 4 : 140 - 154.

SWAMY, H.R. & PROCTOR, J. 1995b. Litterfall and nutrient cycling in four rain forests in the Sringeri area of the Indian Western Ghats. *Global Ecology and Biogeography Letters* 4 : 155 - 165.

WILDE, S.A., COREY, R.B., IYER, J.G. & VOIGHT, G.K. 1979. *Soil and Plant Analysis for Tree Culture*. 5th edition. Oxford & IBH, New Dehli, India.