Research Article

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Rainfall interception and nutrient flux in rubber plantation

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Abstract

Matured rubber plantation partitioned 80.5, 8.5 and 11 per cent of total rainfall as through fall, stem flow and interception, respectively. Interception and trunk storage capacity of rubber was 0.8 and 1.0 mm, respectively. Maximum litter interception was 0.9 mm and annual litter interception estimated as 15.0 mm. Acidity of rainwater reduced after passing through rubber foliage, whereas, that of stem flow did not, indicating the role of foliage in reducing the acidity. Gross nutrient addition through rainfall was 45.2, 13.2, 23.8, 4.7, 0.6, 0.5 and 0.6 kg N, K, Ca, Mg, Fe, Cu and Zn/ha, respectively, Similarly rubber canopy also enriched nutrients except N. Nutrient leachability from rubber canopy was in the order of Ca>K>Cu>Mg>Fe. Throughfall N content was lower than rainwater indicating absorption by foliage. Nutrient addition through rainfall process was to the extent of 30-50 per cent of that supplied through leaf litter, indicating the importance of rainfall process in cycling of nutrient in ecosystem.

Keywords: Hevea, nutrient flux, nutrient leachability, rainfall interception

Introduction

Under any vegetation cover, complete rainfall entry into soil is impossible. When rainfall occurs over tree crops, rainfall is distributed as throughfall (TF) and stem flow (SF). Tree foliage, twigs and branches retain some amount of rainfall and is called as interception. After passing through tree canopy, rainwater again passes through leaf litter and during this process some amount of rainfall will be held by leaf litter and is called as litter interception. After passing through leaf litter, rainwater reaches soil surface and the process of infiltration begins. Interception by canopy and litter and its subsequent evaporation constitute net loss to the system which assumes considerable values under certain conditions. Capacity of vegetation to intercept and store water is of great practical importance, especially in measurement and modeling of interception loss from forest or vegetation area and for effect of forest/plantation on water yield of catchments. Significant species effect is also noticed in altering the chemistry of rainwater which in turn affects the chemistry of water stream of watershed (Mahendrappa, 1989). The presence or absence of vegetation not only affects the amount of rainfall reaching the soil surface but also its kinetic energy. Rainfall interception by tree canopy is a major hydrological process, which play an important role in water yield and stream flow from of watershed area and in protecting mineral soil surface from raindrop energy.

Input of major nutrients through precipitation process forms another important and integral part of nutrient cycle especially in forest and perennial vegetation. Therefore, estimation of fluxes of elements from incident precipitation, through fall and stem flow have been a routine part of nutrient budget studies (Lockaby 1986, Moughalu, 2003). This has been characterized for wide variety of forest and tree ecosystems (Mark *et al.*, 1980; Lockaby, 1986 and Moughalu, 2003). A great deal of work has been done on rainfall interception by hardwood forest and many plantation crops (Cantu and Okumura, 1996 and Germer *et al.*, 2006). However corresponding studies in tropical rubber plantation of Asia are rare. Hence the present study was conducted to analyze the distribution of rainfall under the matured rubber plantation and to model them. It also aimed to quantify the nutrient flux through the rainfall process and to know the chemical changes rainwater under goes while passing through canopy.

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Materials and Methods

Site description

Investigation was carried out at the experimental farm of Rubber Research Institute of India (RRII) (9^0 32‘N, $76^0$36‘E), located in the Kottayam district of Kerala state, India. One hectare of 16 year old rubber plantation of clone RRII 105 planted in contour line during with average spacing of 8.1 x 3.5 m was selected for the study. Average girth of rubber was 67.2 cm. Mean annual rainfall was 3200 mm. Rainfall distribution is bimodal with peak during July and September/October. Mean annual maximum air temperature was 31.6°C. Soil of the experimental farm belongs to the order Ultisols and subgroup Ustic Kandihumults high in organic carbon, medium in available Mg and low in available P, K and Ca.

Collection method

Gross rainfall, through fall and stem flow were monitored for 150 events during July 2004 to December 2005. Nutrient flux through rainfall, throughfall and stemflow were monitored for 12 months during September 2004 to August 2005. Twenty through fall collectors were fabricated using 15.3 cm diameter plastic funnel and fixed randomly using one-meter high PVC pipes. Rainwater from funnel channeled using hose pipe to bottles kept on the ground. One identical collector was fixed in open area near the experimental plot to record the rainfall. For stemflow ten trees were selected randomly fixed with 2.5 cm diameter transparent hose pipe after slicing 1/3 circumference longitudinally. One edge of sliced pipe was stapled to tree for half spiral length on two sides and made leak proof with bitumen compound. Using funnel and hose pipe, stem flow water was channeled to 35 liter capacity plastic cans kept on the ground. Plastic mesh was fixed in the funnels of throughfall, rainfall and stem flow collectors to separate the inert materials. Rainfall, throughfall and stemflow volume were recorded at 8.30 am daily. Fifty ml composite sample for each rainfall event was collected and stored in bottle with a few drops of toluene added to avoid fungus growth. At the end of the month 250 ml sample was drawn, a few drops of toluene was added and stored in refrigerator for further nutrient analysis. Immediately after rainfall event on 6th and 13th June; 1st August and 14th November 2005 water samples were drawn from rainfall, throughfall and stemflow collector to record pH and electrical conductivity. On 14th November 2005 throughfall from vegetation standing below rubber canopy was also collected at ten representative locations to record pH.

Lab procedure and data analysis

For each rainfall event, mean volume of rainfall, throughfall and stemflow were converted to depth (mm) of precipitation and interception calculated as difference between rainfall and sum of throughfall and stemflow. Readings with more than one rain event were excluded for data analysis. Maximum interception or canopy storage capacity was estimated based on regression relation between through fall and gross rainfall less than 10 mm. Stem saturation capacity, which is depth of water required to saturate trunk was estimated using method outlined by Leyton *et al.* (1967). An attempt was made to improve predictability of rainfall interception regression equation by including peak rainfall intensity as additional independent variable. For this, a subset of data having rainfall intensity parameters was used.

Rainfall, throughfall and stemflow samples were analysed for nitrogen by auto analyzer (Kjeltec 2300), potash by flame photometer and calcium, magnesium, copper, iron and zinc content using atomic absorption spectrophotometer (GBC Avanta). Nutrient addition (kg/ha) per month and annum was estimated for each nutrient using respective nutrient concentration and volume of water. Net nutrient deposition was calculated as deposition through throughfall and stemflow minus deposition by rainfall. Nutrient supplied through litter decomposition (Philip *et al.*, 2003) was compared with nutrients deposited through rainfall to calculate the relative supply. Ease of nutrient leachability was calculated as ratio between net annual nutrient added through TF (kg/ha) (TF – RF) to total nutrient content in foliage (Lockaby, 1986). Nutrient content in rubber foliage (kg/ha) reported by Jessy (2004) was used for calculating ease of leachability. Nitrogen and Zinc content in TF was less than that of rainfall and hence leachability was not calculated.

pH and Electrical Conductivity were recorded using standard procedures. Maximum litter water holding capacity and drying curve of rubber litter was determined by placing oven dried litter in 30 cm^2 nylon mesh bag at the rate of 15, 20 and 25 g per bag and replicated five times. Nylon bags were sealed and immersed in water overnight and then took wet weight after complete draining of water. Difference between wet weight and dry weight of litter was considered as maximum water holding capacity of litter. Rate of litter drying was recorded by placing litter containing nylon bags close to ground in experimental area and weight recorded at daily interval till attainment of constant weight. Monthly litter interception was estimated using the estimated maximum water holding capacity and drying rate of litter and the average litters fall of 4.5 tons per hectare and litter decomposition rate reported by Philip *et al.* (2003).

Results and Discussion

Rainfall partitioning

Matured rubber plantation partitioned gross rainfall of 4648.6 mm into 3744.1 mm (80.5 per cent) throughfall, 394.5 mm (8.5 per cent) stemflow resulting in interception of 515.3mm (11 per cent) (Table 1). Mean rainfall interception observed during study period was 15.5 per cent. Haridas and Subramanian (1985) and Teoh (1971) reported 79-83, 1.6-2.0 and 15-19 per cent of rainfall as throughfall, stemflow and interception respectively in *Hevea* clones under the Malaysian condition. This variation could be attributed to different clone and rainfall pattern. Teoh (1971) and Mahendrappa (1989) have reported significant effect of species and clone in partitioning of rainfall. However the present result is within the range of 11-18 per cent reported in tree crops like acacia (Bruijnzeel and Wiersum, 1987), eucalyptus (Preble and Stirk, 1980), white Oak (Cantu and Okumara, 1996) and tropical rainforest (Veneklas and Van Ek, 1990). Seasonal variation in rainfall partitioning was not observed. Interception was low during May to August. On storm basis mean TF and SF was 17.8, 1.7 mm with a range of 68.1 mm, 8.9 mm and SD of 15.9, 2.0 mm, respectively (Table1). Rainfall interception ranged from 0.07-10.2 mm with standard deviation of 2.0 mm and mean per cent interception as 15.5. During majority of months interception was lower than open pan evaporation. Rainfall showed significantly higher positive correlation with TF (r = 0.99) and SF (r = 0.93) compared to interception (r = 0.64). Per cent interception showed a negative relation with rainfall (r = -0.42). Regression models for TF and SF explained 99 and 84 per cent variability respectively, whereas it was only 40 per cent for interception. Interception varied for same amount of rainfall. Variation in interception was due to difference in rainfall intensity. Similarly Llorens *et al.* (1997) reported that duration and intensity of rainfall influences interception. Among the rainfall parameters, peak rainfall intensity showed better correlation with rainfall interception (r = 0.6). Coefficient of determination of interception regression equation improved to 0.6 when additional variable peak rainfall intensity was included:

Table 1. Descriptive statistics of rainfall components

Parameters	Rainfall (mm)	Through fall (mm)	Stem flow (mm)	Interception (mm)	Percent Interception
Mean	22	17.8	1.7	2.4	15.5
Minimum	0.4	0.3	0.0	0.07	0.5
Maximum	80.0	68.4	8.9	10.2	54.7
Range	79.6	68.1	8.9	10.2	54.2
S.D	18.9	15.9	2.0	2.0	10.4
Total	4648.4	3744.1	394.5	515.3	---

$$Y = 0.47 + 0.19\ x_1 + 0.12\ x_2$$

where Y = Square root of rainfall interception (mm)

x_1 = Square root of rainfall (mm)

x_2 = Peak rainfall intensity (mm/h)

Regression models for TF and SF have indicated that, more than 0.9 and 3.7 mm rainfall is required to initiate TF and SF respectively (Table 2). Analysis of SF data has showed that volume of SF significantly related with girth of tree (Fig.1). Masukata *et al.* (1990) reported that SF volume depended mainly on tree form in evergreen broad leaf forest. Thus, different clones differing in growth habit differ in partitioning of rainfall into TF and SF and this plays an important role in hydrological cycle and ultimately water flow from watershed area. Stemflow water enters soil around basal area of tree only. On tree basal area basis, SF represented on an average two times more precipitation than any other places below canopy. Stemflow may help in conserving rainwater close to tree root system particularly in medium rainfall period. Pressland (1976) reported that in arid zone shrub community of Mulga (*Acacia aneura*), SF was instrumental in storing water at depth in soil, particularly

Table 2. Regression models for rainfall components

Parameters	Equation	R2	S.E
Through fall	-0.69 + 0.84 x RF	0.99	1.6
Stem flow	-0.37 + 0.10 x RF	0.84	0.8
Interception	1.10 + 0.06 x RF	0.40	1.6

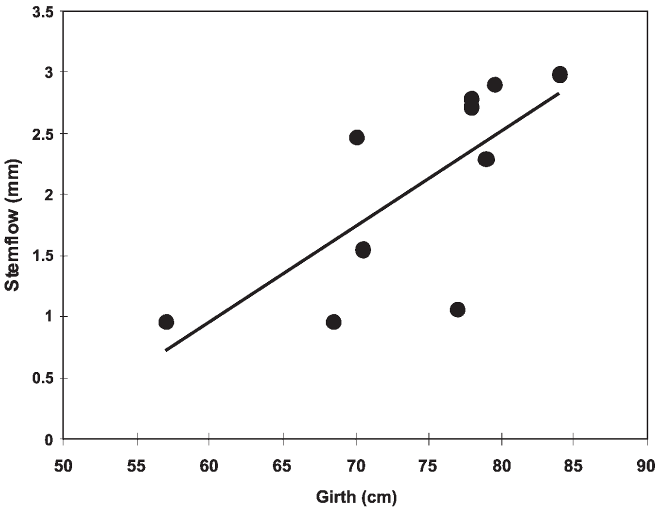

Fig. 1. Stemflow Vs Girth

with medium rainfall, thus helping the survival and growth of trees and associated ground flora. But at the same time during heavy rainfall period, huge quantity of rainwater will be added around basal area. This makes the soil too wet and loose, particularly top soil giving loose anchorage to rubber root system. This may be the reason why uprooting of big trees is noticed whenever heavy wind blows after heavy shower.

Interception Loss

The sources of interception loss are canopy interception and litter interception. Canopy interception loss of rubber plantation observed during the study period was 515.3 mm, about 10 per cent of gross rainfall. Per cent canopy interception was relatively variable through out the study period with a range of 54.2. Interception storage capacity or canopy storage capacity of rubber was estimated as 0.8 mm (Fig. 2). Wang and Zhang (2006) reported the canopy rainfall storage capacity of rubber plantation as 0.48-0.71 mm in Xishuangbanna of China. Being characteristic of species, canopy storage capacity ranged from 0.4-0.6 mm in cashew (Rao, 1987), white Oak forest (Cantu and Okumara, 1996) and 2 mm in silver iron bark tree (Prebble and Stirk, 1980). Trunk storage capacity of rubber was 1.0 mm (Fig. 3). Similarly Wang and Zhang (2006) reported rainfall storage capacity of branch and bark of rubber plantation in Xishuangbanna as more than 50 per cent of total storage capacity. Cantu and Okumara (1996) reported trunk storage capacity of mixed white oak forest as 0.2 mm only. In rubber trunk and branches constitute more than 72 per cent of total biomass (Sivakumaran *et al.*, 2000) and hence the trunk storage capacity of rubber was higher.

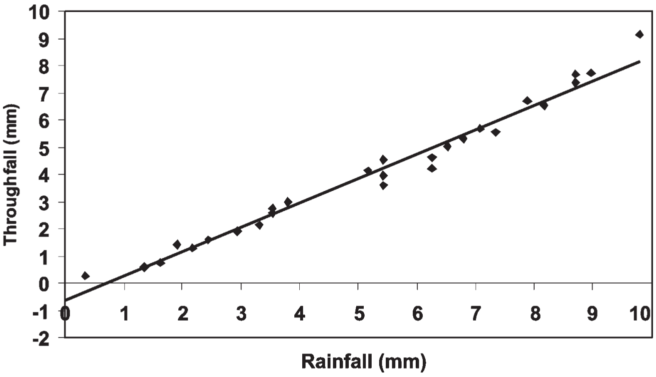

Fig. 2. **Maximum canopy interception**

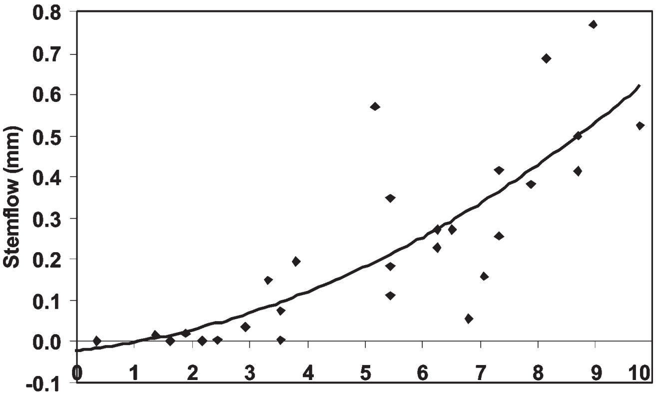

Fig. 3. **Maximum stem wetting capacity**

Litter layer is an important hydrological component in controlling both water and energy transfer between sub canopy atmosphere and soil (Pitman, 1989). Work has been done on quantification and nutrient release from rubber litter decomposition (Krishnakumar and Potty, 1992 and Philip *et al.*, 2003). But no attention has been paid towards its role in hydrological process in rubber plantation. Rainwater after passing through canopy comes into contact with leaf litter accumulated on the ground. Litter interception capacity depends on the moisture holding capacity, quantity of litter, rate of drying and decomposition. Maximum moisture holding capacity of rubber litter was 167 per cent by weight (Fig. 4). Maximum water content of litter varied was reported to vary from 135 per cent in mixed hard wood (Blow, 1955) to 215 per cent in pine (Metz, 1954). Litter mass showed a positive effect on moisture storage and drying. Yoshinobu Sata *et al.* (2004) indicated that maximum water holding capacity of *Cryptomeria japonica* and *Lythocarpus edulis* depended on litter mass regardless of its thickness. Litter drying curve has indicated that, irrespective of litter mass, litter moisture came down to minimum by third day (Fig. 4). This depends on climate, wind speed and litter characters. Time required to dry from saturate to constant weight has been reported as 11 days for pine (Metz, 1954) to 13-20 days for mixed oak (Blow, 1955 and Semago, 1960). Considering the litter fall @ 5 tons per ha, litter interception capacity was estimated as 0.9 mm. The value estimated for the present study falls within the range

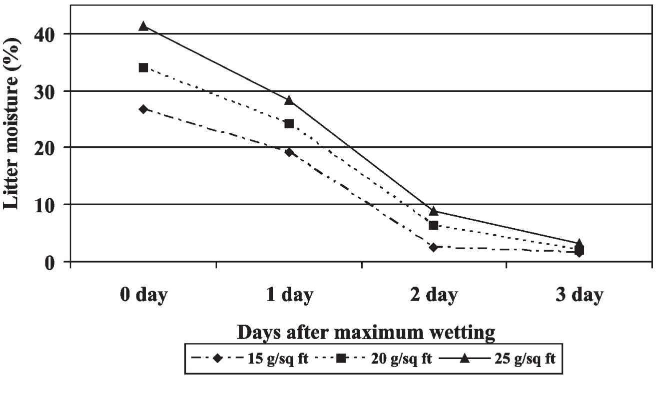

Fig. 4. **Litter drying curve**

reported for other tree crops. According to Pitman (1989) maximum litter interception capacity for *Eucalyptus* and *Pine* was 1.13 and 0.97 mm, respectively. Similarly for Amazonian forest floor it was 1.51 mm (Tobon-Marin *et al.*, 2000) and for *Cryptomeria japonica* and *Lythocarpus edules* it was 1.59 and 1.56 mm, respectively (Yoshinobu Sato *et al.,* 2004). The monthly rubber litter interception estimated for 2005-06 (Table 6) has indicated that majority of litter interception was during April to July months. Annual litter interception was estimated as 15.04 mm. Annual rubber litter interception of 15.04 mm estimated in the present study was comparatively lower than 5.0 to 10.0 cm reported by Helvey (1964) in cove hardwood stand at North Carolina. Litter interception is determined by amount of litter on the ground, its rate of drying and decomposition and distribution of rainfall (Helvey and Patric, 1965). In traditional rubber belt of India, rubber normally sheds leaves during December and 92 per cent of rubber litter decomposes by August (Philip *et al.*, 2003). Rainfall is mainly received during south west monsoon (May-August) and north east monsoon (October-November). Hence, much litter is not left on the ground to intercept rain water. So the annual litter interception was low compared to the mixed forest in temperate region.

Table 3. Estimated monthly litter interception

Month	Rainfall (mm)	Litter interception (mm)
January 2005	0.0	0.0
February	0.0	0.0
March	0.0	0.0
April	267.0	3.09
May	180.6	1.57
June	598.3	3.05
July	672.3	2.9
August	245.1	1.04
September	461.7	1.07
October	319.0	1.07
November	362.25	0.90
December	51.4	0.35
Total	3157.65	15.04

Chemistry of rainwater

Chemistry of rainwater changed after passing through rubber canopy (Table 4). Rainfall pH was low compared to that of TF water indicating reduction in acidity of rainwater after passing through canopy. Extent of reduction in acidity was more during onset of wet season. Acidity of throughfall water was further reduced to 5.9 after passing through vegetation standing below rubber canopy. Stemflow pH was same as that of rainwater. This indicates the role of foliage in removing the H^+ from rain water through cation exchange mechanism thus reducing the acidity (Lockaby, 1986). Hoffman *et al.* (1980) detecting similar rise in pH upon contact with deciduous canopy, speculated that exchange of cation occurs at broken edges on the cuticular layers of leaves. Cronan and Reiners (1983) reported that neutralization of acid precipitation in hardwood canopy appears to occur through two major processes such as ion exchange removal of H^+ by foliage and base leaching from canopy. Electrical conductivity of both TF and SF was higher than rain water. Unlike pH, EC of both throughfall, and stemflow increased compared to rainwater. From the field observation, the colour of SF water was light brownish compared to rainfall and TF. This may be due to the washing/leaching of tannin from bark. Cations and elements are also added to rain water while passing through foliage (Cronan and Reiners, 1983). Thus, EC of both throughfall and stemflow increased compared to the rainfall.

Table 4. pH and electrical conductivity (EC) of rainfall component

Date	pH			EC (µm/cm)		
	Rain-fall	Through-fall	Stem-flow	Rain-fall	Through-fall	Stem-flow
06/06/2005	4.9	5.44	4.8	4.0	5.9	5.2
13/06/2005	4.6	5.0	4.5	6.3	7.0	8.5
01/08/2005	5.2	5.5	5.1	---	---	---
14/11/2005	5.2	5.6	5.5	---	---	---

Nutrient flux

Peak concentration for most of the nutrients was observed during April to May. Tree canopies are known to trap substantial amount of dust particles and aerosols containing organic and inorganic nutrients (Servant *et al.*, 1984 and Stoorvogel, 1993) and they are washed down along with the rainwater. Rubber normally refoliates during dry period and foliage might have trapped dust and aerosol particles produced during the summer month. Pre- monsoon showers received during April/May washed down them and hence, the nutrient concentration was more during these months. Brassell and Gilmour (1980) while studying the cation composition of precipitation at four sites in far north Queensland found higher concentration of cations during dry season than wet season. Supporting the above view, Moughalu and Johnson (2000) reported that total suspended solids were higher at the beginning of the rainy season in Negerian lowland rain forest. Hence, the peak nutrient concentration during April/May might be due to more contribution from aerosol and dust particles and leaf leachates from new reflushes. Monthly variation in nutrient content was more with N followed by K. Nutrient

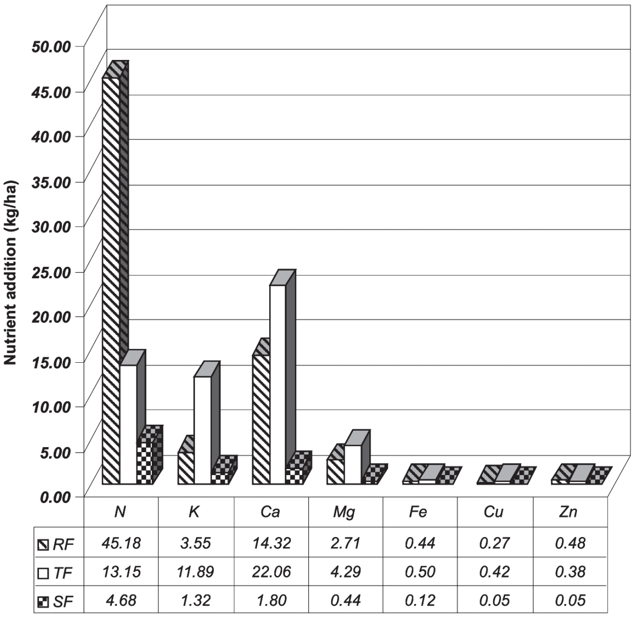

Fig. 5. Annual nutrient addition (kg/ha)

flux to soil through precipitation is an important source of nutrient supply to ecosystem. Annual nutrient fluxes (kg/ha) through rainfall, TF and SF are presented in Fig. 5. Nutrient deposition through precipitation in open was 45.2, 3.55, 14.3, 2.7, 0.4, 0.27 and 0.48 kg per ha of N, K, Ca, Mg, Fe, Cu and Zn, respectively. No such reports are available from traditional rubber growing areas. Nutrient flux through precipitation has been reported in temperate and tropical rain forests (Sollins *et al*., 1980; Lockaby, 1986; Cantu and Okumara, 1996 and Moughalu, 2003). Net nutrient deposition through TF and SF was -27.3, 9.65, 9.54, 2.02, 0.18, 0.2, -0.05 kg/ha of N, K, Ca, Mg, Fe, Cu and Zn, respectively (Table 5). Net nutrient addition through throughfall and stemflow was positive for all nutrients except N and Zn. Apart from washout of dust and aerosol particles, tree canopy is known to enrich rainwater with nutrient by washout of leaching matter from internal of leaf (Pathak and Singh, 1984). Nutrient enrichment by rubber canopy was seen mainly for K, Ca and Mg. Similar reports of nutrient enrichment by foliage are available (Lockaby, 1986), but the extent of enrichment by rubber foliage was low compared to the other ecosystems reported. Enrichment depends on the species, nutrient status of foliage and rainfall. Miller *et al.* (1976) have noted that quantity of nutrients leached may increase with increasing foliar concentration. Similarly Crockford and Khanna (1998) while comparing the nutrient removal/ leaching in TF and SF of *Pinus radiata* found that leaching of cations (Ca, Mg, Na and K) was greater for fertilized plot compared to the control plot. Soils of the traditional belt of rubber are highly leached, acidic in nature and medium to low in nutrient content. So the nutrient enrichment by rubber foliage was low compared to the extent of enrichment reported in other ecosystems. Total flux of N and Zn through SF and TF was lower than total flux of N and Zn through open precipitation. This indicates that foliage has taken up these nutrients present in the rain water and hence, their content in the precipitation water after passing through canopy was low especially in TF. This is the reason why the net addition of N and Zn was negative compared to other nutrients. Lockaby (1986) reported that in Cotton wood (*Populus deltoides*), the quantity of N in rain was higher prior to contact with canopy. Pryor and Barthelmle (2005) while reporting the total atmospheric flux of inorganic N of 14-18 kg/ha/year noticed that approximately half was taken up by the canopy of deciduous forest. Similar observations have been reported in many tree crops including *Corsicane pine* (Miller *et al.*, 1976), subtropical moist forest (Wenyao Liu *et al.,* 2002) and Amazonian rainforest (Jordan *et al*., 1980). So nutrient enrichment by rainfall process supplements the nutrient supplied from soil and litter. This supports the view that atmospheric deposition of nutrients forms an important contribution to the nutrient cycle in humid tropical region where soils are often low in fertility (Vitousek and Sanford, 1986). Based on the total pool of nutrient in the foliage versus quantity washed/leached annually, an ease of leachability factor was projected (Table 5). This shows more leachability for Ca followed by K, Cu, Mg and Fe. The present order of leachability is slightly different from that reported in forest ecosystem. Henderson *et al.* (1977) reported leachability order of K>Ca>Mg whereas Eaton *et al.* (1973) and Lockaby (1986) reported leachability order as K>Mg>Ca for the northern hardwood forest and eastern cottonwood, respectively. Philip *et al.* (2003) reported annual nutrient addition through rubber litter

Table 5. Comparison of nutrient deposition through precipitation and litter and nutrient leached against quantity in foliage

Nutrient	Net nutrient deposition from rainfall (kg/ha)	Nutrient deposition through litter (kg/ha)*	Ratio of rainfall to litter nutrient deposition	Nutrient present in the foliage (kg/ha)**	Nutrient Leachability (%)
N	-27.3	88	0.51	432.8	--
K	+9.65	45	0.20	218	3.8
Ca	+9.54	60	0.40	129	6.0
Mg	+2.02	16	0.29	51	3.1
Fe	+0.18	--	--	4.5	1.0
Cu	+0.2	--	--	4.5	3.3
Zn	-0.05	0.25	2.20	0.6	--

Note: * From Philip *et al*. (2003)
** From Jessy (2004)

decomposition as 88, 45, 60, 16 and 0.25 kg N, K, Ca, Mg and Zn, respectively. Precipitation added 51, 29, 40, and 29 per cent of N, K, Ca and Mg, respectively supplied through litter (Table 5). However, Zn enrichment by rainfall was more than Zn added through litter decomposition. Importance of precipitation in recycling of nutrient in comparison with leaf litter was in the order of N>Ca>K=Mg. Henderson *et al.* (1977) reported that importance of TF in comparison to litter fall as nutrient return mechanism in forest decreased in the order of K>Ca=Mg>P=N. Similarly Moughalu (2003) found cycling of K, Mg, Na, Zn and P through precipitation compared to litter fall in low land rain forest of Nigeria. The order of nutrient cycling through rainfall observed in the present study is similar that reported for forest. In contrast to forest, the quantity of nutrient cycled through precipitation in rubber plantation was slightly low compared to nutrient cycled through litter fall. However, it is to be noted that litter fall occurs when there was little or no decomposition and takes five to six months to release nutrients (Philip *et al.,* 2003) whereas, nutrients cycled through precipitation are readily available and supply coincides with active growth period. Hence, the nutrients cycled through precipitation will significantly help in meeting the plant demand until the release of nutrient through litter decomposition. Thus nutrient deposition through precipitation is supplementary to the nutrient supply through litter fall.

Conclusion

Matured rubber plantation partitioned rainfall as throughfall (80.5 per cent), stemflow (8.5 per cent) and interception (11 per cent), respectively. Flow of rainwater through stem hinders the tapping process in rubber and the extent of stem flow observed in the present study was more than earlier reports. This indicates the need for evolving clones with canopy which partition less rainfall into stemflow thus reducing the hindrance in tapping process. The minimum rainfall to initiate throughfall and stemflow was 0.9 and 3.7 mm, respectively. The estimated canopy and stem storage capacity values can be used to model the runoff from watershed area. The extent of litter interception was low compared other tree crops. There is a need to protect the soil from raindrop impact and subsequent soil erosion by maintaining underground vegetation and integrated farming. Rubber canopy was able to reduce the acidity of rainwater, thus, reducing the bad effect of acidic rain on soil and micro flora. Rubber utilized more than 50 per cent of readily available nitrogen present in rainwater. At the same time rubber also recycled nutrients, mainly calcium and potassium, through leaf washout. This indicates matured rubber plantation is self sustainable and this may be the reason for poor response of matured rubber plantation to applied nutrients in majority instances. Compared to leaf litter, precipitation was important in recycling of nutrient in the order of K>Ca=Mg>P=N. Nutrients deposited through precipitation was a supplementary to the nutrients recycled through leaf litter.

References

Blow, F.E. 1955. Quantity and hydrologic characteristics of litter under upland oak forest in eastern Tennessee. *J. For.* **53**: 190-195.

Brassell, H.M. and Gilmour, D.A. 1980. The cation composition of precipitation at four sites in far north Queensland. *Austral Ecol.* **5**(4): 397.

Bruijnzeel, L.A. and Wiersum, K.F. 1987. Rainfall interception by a young *Acacia auriculiformis* plantation forest, Java, Indonesia: Application of Gash's analysis model. *Hydrol. Process* **1**(4): 309-319.

Cantu, S.I. and Okumara, T. 1996. Rainfall partitioning in mixed white Oak forest with dwarf bamboo undergrowth. *J. Environ. Hydrol.* **4**: 1-15.

Clements, R.G. and Colon, J.A. 1974. The rainfall interception process and mineral cycling in a Mont Forest in Eastern Puerto Rico. In: *Mineral cycling in southeastern ecosystems symposium,* Augusta, Georgia, USA, 1 May 1974.

Crockford, R.H. and Khanna, P.K. 1998. Chemistry of throughfall, stemflow and litterfall in fertilized and irrigated *Pinus radiata Hydrol. Process* **11**(11): 1493-1507.

Cronan, C.S. and Reiners, W.A. 1983. Canopy processing of acidic precipitation and hardwood forests in New England. *Oecologia* **59**(2-3): 216-223.

Eaton, J.S., Likens, G.E. and Bromann, F.H. 1973. Throughfall and stemflow chemistry in a northern hardwood forest. *J. Ecol.* **61**: 495-508.

Germer, S., Elsenbeer, H. and Moraes, J.M. 2006. Throughfall and temporal trends of rainfall distribution in an open tropical rainforest of south-west Amazonia. *Hydrol. Earth Syst. Sc.*. **10**: 383-393.

Haridas, G. and Subramaniam, T. 1985. A critical study of the hydrological cycle in a mature stand of rubber (*Hevea brasiliensis*). *J. of Rub. Res. Inst. Malay.* **33**(2): 70-82.

Helvey, J.D. 1964. Rainfall interception by hardwood forest litter in the southern Appalanchians. *US For. Sserv. Res. Paper* SE-8.

Helvey, J.D. and Patric, J.H 1965. Canopy and litter interception of rainfall by hardwoods of eastern United States. *Water Reso. Res.* **1**(2): 193-206.

Henderson, G.S., Harris, W.F., Todd Jr., D.E. and Grizzard, T. 1977. Quantity and chemistry of throughfall as influenced by forest type and season. *Journal of Ecology* **65:** 365-374.

Hoffman, W.A., Lindberg, S.E. and Turner, R.R. 1980. Precipitation acidity: the role of the forest canopy in acid exchange. *J. Environ. Qual.* **9**: 95-100.

Jessy, M.D. 2004. Phosphorus nutrioperiodism in rubber. *Ph.D. Thesis,* Kerala Agricultural University, Vellayani, Thrivandrum, India.

Jordan, C., Golley, F. and Hall, J. 1980. Nutrient scavenging of rainfall by the canopy of an Amazonian rainforest. *Biotropica* **12**: 61-66.

Krishnakumar, A.K. and Potty, S.N. 1992. Nutrition of Hevea. pp. 239-262. In: Natural rubber: Biology, cultivation and Technology. (Ed.) Sethuraj, M.R. and Mathew, N.M, Elsevier, Amsterdam.

Leyton, L., Reynolds, E.R.C. and Thompson, F.B. 1967. *Rainfall interception in Forest and Moorland.* pp.163-178. In: *Int. Symp. For. Hydrol*. (Ed). Sooper W.E. and Lull, H.W. Pergamon Press, Oxford.

Llorens, P., Poch, R., Latron, J. and Gallart, F. 1997. Rainfall interception by a *Pinus sylvestris* forest patch overgrown in a Mediterranean mountains abandoned area I: monitoring design and results down to the event scale. *J. Hydrol*. **199**(3): 331-345.

Lockaby, B.G. 1986. Nutrient transfer associated with precipitation in plantation of eastern cottonwood (*Populus deltoids*). *For. Ecol. and Manag.* **17**: 13-24.

Mahendrappa, M.K. 1989. Impact of forest on water chemistry. *Water, Air and Soil pollution* **46**(1-4): 61-72.

Mark, M.B., Hansel, D.B., Rusel, N.H. and Joseph, B.E.Jr. 1980. Litter fall, stem flow and through fall nutrient flux in an alluvial swamp forest. *Ecol.* **61**(4): 827-835.

Masukata, H. Makio Ando and Ogawa H. 1990. Through fall stem flow and interception of rainwater in an evergreen broadleaved forest. *Ecol. Res.* **5**(3): 303-316.

Metz, Louis J. 1954. Forest floor in the piedmont region of South Carolina. *Soil Sc. Soc. America Proc.* **18**(3): 335-338.

Miller, H.G., Cooper, J.M. and Miller, J.D. 1976. Effect of nitrogen supply on nutrients in litter fall and crown leaching in a stand of Corsican pine. *J. Appl. Ecol.* **13**(1): 233-248.

Moughalu, J.I. and Johnson, S.A. 2000. Interception, pH and solid content of rainfall in a lowland rainforest. *African J. Ecol.* **38**(1): 38.

Moughalu, J.I 2003. Contributions of through fall, stem flow and litter fall to nutrient cycling in a secondary lowland rainforest in ILE-IE Nigeria. *J. Trop. For. Sc.* **15**(3): 399-410.

Parker, G.G. 1983. Throughfall and stemflow in the forest nutrient cycle. *Adv. Ecol. Res.* **13**: 57-133.

Pathak, P.C. and Singh, J.S. 1984. Nutrients in precipitation components for pine and oak forests in Kumaun Himalaya, *Tellus* 36B: **44**-49.

Philip, A., Varghese, P., George, S.E., Punnoose, K.I. and Mathew, M. 2003. Leaf litter decomposition and nutrient release in fifteen year old rubber plantation. *Ind. J. Nat. Rub. Res.* **16**(1&2): 81-84.

Pitman, J.I. 1989. Rainfall interception by brackenlitter-relationship between biomass, storage and drainage rate. *J. Hydrol.* **111**: 281-291.

Prebble, R.E. and Stirk, G.B. 1980. Throughfall and stemflow on silver leaf iron bark (*Eucalyptus melanophloia*) trees. *Austral Ecol.* **5**: 419.

Pressland, A.J. 1976. Soil moisture redistribution as affected by throughfall and stemflow in an arid zone shrub community. *Aust. J. Bot.* **24**(5): 641-649.

Pryor, S.C. and Barthelmle, R.J. 2005. Liquid and chemical fluxes in precipitation, throughfall and stem flow: observation from a deciduous forest and a red pine plantation in the mideastern USA. *Water, Air and Soil Pollution* **163**(1-4): 203-227.

Rao, A.S. 1987. Interception loss of rainfall from cashew trees. *J. Hydrol*. **90**(3-4): 293-301.

Semago, W.T. 1960. Interception of precipitation by hardwood litter. *Master's Thesis*, University Mo, USA.

Servant, J., Delmas, R., Rancher, J. and Rodriguez, M. 1984. Aspects of the nitrogen cycling in the Okefenokee Cypress swamp forest. *Ecol. Monog.* **48**: 43-65.

Sivakumaran, S., Kheong, Y.F., Hassan, J. and Rahman, A. 2000. Carbon sequestration in rubber: implications and economic models to fund continued cultivation. pp. 79-102. In: *Proc. Indon. Rub. Conf. IRRDB Symp.*

Sollins, P., Grier, C.C., McCorison, F.M., Cromack, K. Jr., Fogel, R. and Fredriksen, R.L. 1980. The internal nutrient cycles of an old growth Douglas-fir stand in western Oregon. *Ecol Monog.* **50**: 261-285.

Stoorvogel, J.J. 1993. Gross inputs and outputs of nutrients in undisturbed forest Tai area, Cote d' ivoire. *Tropebos Series* No. 5. The tropenbos Foundation, Wagenningen. The Netherlands 148 pp.

Teoh, T.S. 1971. Where does all the rainfall go? *Plant.Bul. Rub. Res. Inst. Malay.* No. **115** pp.215.

Tobon-Marin C., Bouten, I.W. and Decker, S. 2000. Forest floor water dynamics and root water uptake in four forest ecosystems in northwest Amazonia. J. *Hydrol.* **237**: 169-183.

Veneklas, E.J. and Van EK, R. 1990. Rainfall interception in two tropical montane rain forest, Columbia. *Hydrol. Process* **4**(4): 311-326.

Vitousek, P.M and Sanford, P.L. 1986. Nutrient cycling in moist tropical forest. *Ann. Rev. Ecol. and Syst*. **17**: 137-167.

Wang, X. and Zhang, Y. 2006. Canopy rainfall storage capacity of tropical seasonal rainforest and rubber plantation in Xishuangbanna. *Ying Yong Sheng Tai Xue Bao,* **17**(10): 1782-1788.

Wenyao Liu, John, E.D. Fox and Zaifu Xu 2002. Nutrient fluxes in bulk precipitation throughfall and stem flow in montone subtropical moist forest in Ailao mountains in Yunnan, south west China. *J. Trop. Ecol.* **18**: 527-548.

Yoshinobu Sato, Tomo, Omi Kumagai, Atsushikme, Kyoichi Otsuki and Shigeru Ogawa 2004. Experiment analysis of moisture dynamics of litter layer- the effect of rainfall conditions and leaf shapes. *Hydrol. Processes* **18**: 3007-3018.