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Rainfall interception in relation to the tree architecture of *Pinus wallichiana* A.B. Jackson

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Vegetation cover protects the topsoil by way of intercepting precipitation and reducing its direct impact on the soil. This communication presents the results of observations of rainfall interception in relation to the tree architecture and other features of *Pinus wallichiana* stand in Dal Lake catchment in Kashmir Himalayas. Stemflow (mm) was significantly ($P < 0.05$) influenced by diameter at breast height (DBH, cm), tree height (m), nature of bark and attachment angles of lateral branches in tree height resulted into 1.5% decrease in stemflow. Also, smooth-barked trees conducted around 5.0% more of stemflow than rough-barked ones. Throughfall decreased significantly ($P < 0.001$) with the increase in both DBH (cm) and height (m) and increased along the gradient of crown area. Throughfall was negatively correlated with downward branching pattern ($r = 0.83$; $P < 0.05$). Of the total average rainfall of 66.5 mm during the course of study, throughfall, stemflow and interception for the whole stand was calculated as 26.7%, 36.3% and 36.9% respectively. Interception percentage decreased significantly ($P < 0.001$) with increase in rainfall. The amount (mm) of interception ($r = 0.90$; $P < 0.001$), stemflow ($r = 0.96$; $P < 0.001$) and throughfall (r =

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0.99; $P < 0.001$) increased significantly with increase in gross precipitation.

Keywords: Interception, *Pinus wallichiana*, stemflow, throughfall, tree architecture.

VEGETATION provides a protective cover on the topsoil and plays an important role by way of intercepting precipitation and reducing its direct impact on the soil. The precipitation so intercepted percolates to the soil as throughfall and stemflow, whereas some part of it gets lost to the process of evaporation or is absorbed by the aerial foliage itself.

Interception being an important component of the hydrological cycle has twofold significance. First, it changes the amount and distribution of precipitation over the soil surface, and reduces the run-off which in turn has an influence on soil erosion and floods. Secondly, it enhances the nutrient status of forest soil due to leaching of elements from leaves and twigs. A number of studies on interception of precipitation under different canopy covers, impact of different species in mono or polyculture, their branching pattern, density, qualitative and quantitative changes of percolates have been conducted[1–16]. The present study was conducted in *Pinus wallichiana* A.B. Jackson stands with objectives to understand: (i) relationship between branching pattern and stemflow and throughfall; (ii) relationship between crown area and interception; (iii) correlation between precipitation over and under the canopy and (iv) correlation between gross precipitation and interception in the whole stand.

The present study was conducted at the reserved Zeathyar Experimental Watershed in Dal Lake catchment of the Department of Soil Conservation, Srinagar, India. The watershed has an altitudinal range of 1700–2300 m amsl and geographical coordinates of 74°8′–74°9′E long. and 34°9′–34°10′N lat. The watershed has a dendritic stream order and covers a total area of 71 ha. The whole watershed is somewhat triangular in shape with difference of 500 m between its lowest and highest point. Stress gradient in the watershed varies between 3° and 9° and all the streams of the catchment converge into a main stream which drains the watershed. Topography of the whole watershed is undulating, steep with hilly terrain. The slope ranged from 0% to 10% under ill-drained swamps, 15% to 50% in grasslands and 10% to 90% in forest land.

Climate of the study site is temperate with average temperature ranging between 35°C and – 1.4°C (Figure 1). December to February are the coldest months and the whole study area was covered by snow during this period. Most of rainfall is received during March and April. Soil is rich in humus content, having good topsoil and deep sub-soil with high density of pebbles, stones and boulders. The coverage pattern in the watershed was 41.0% under conifers, 21.5% under broadleaved trees, 32.6% under grasses and 4.9% under shrubs. *P. wallichiana* is the dominant species among conifers. Details of *P. wallichiana* stand are given in Table 1.

Enumeration of all the trees in the stand was followed with determination of their diameter at breast height (DBH). Height of the trees was estimated using Ravi altimeter. Characteristics of samples trees are given in Table 2. All the studies were restricted to six sample trees of various diameters representing the complete structure of the stand. A total of 25 precipitation events in a span of one year were studied (three events per month), except in October and December when only two events occurred. Terminology of Leonard[17] and Gautam *et al.*[18] was followed for fitting of the collars, and collecting and measuring the stemflow and throughfall. Stemflow was caught in narrow watertight collars fitted around the stem at DBH of trees. A spout of suitable diameter and length was connected with a rubber tube of sufficient length for collecting stemflow into an empty trough with dimensions $91.44 \times 22.80 \times 29.35$ cm^3, covered with metal lid to check direct input of rainwater into the containers. The bark of the sample tree was smoothened for about 60 cm above the level of the collars to facilitate flow of water into the latter. Around this portion non-absorbent cotton rolls were wrapped with central wick deep into the spout. For collecting stemflow, the collars were made water tight at the base by sealing with tape. The water collected in stemflow troughs was measured after each event of

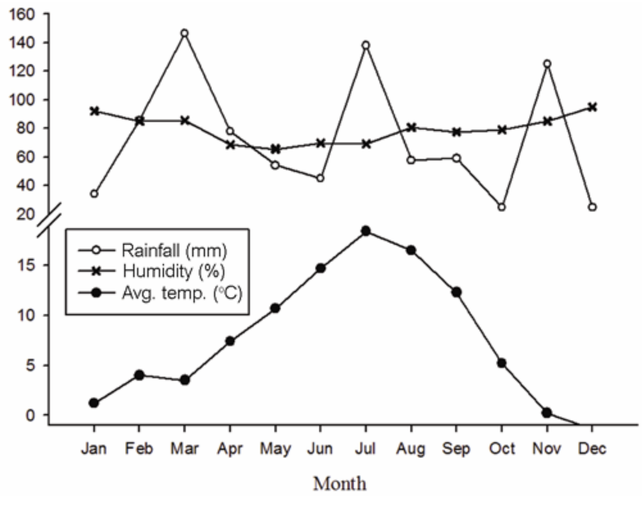

Figure 1. Mean monthly rainfall (mm), temperature (°C) and humidity (%) of the study site during the study period.

Table 1. Details of *Pinus wallichiana* stand

Area of study plot	0.32 ha (26.82 m × 12.90 m)
Age of plantation	Approx. 29 years
Density of trees	700 trees/ha
Mean diameter at breast height of trees	33.93 cm
Mean height of trees	13.86 m
Crown density of the stand	75%

Table 2. Characteristic of sampled trees

Tree no.	DBH	Height (m)	Area of crown (m^2)	Branching pattern (%)	Bark class
1	48.76	13.10	49.29	50% U, 40% D and 10% d	H
2	45.90	13.56	78.39	45% U, 40% D and 15% d	H
3	41.14	13.61	48.82	50% U, 40% D and 15% d	H
4	36.06	13.25	56.98	50% U and 50% D	H
5	30.73	13.41	35.10	50% U and 50% D	L
6	25.65	11.58	45.66	45% U, 50% D and 10% d	L

U, Upwards; D, Downwards; d, Drooping; H, Rough or thick; L, Smooth or thin.

rainfall with the help of a measuring cylinder. The volume of water collected as stemflow was brought to scale with that of DBH of the tree.

Gross precipitation (GP) was measured in the open area adjacent to the study area by means of self-recording siphon-type raingauges with a resolution of 0.1 mm providing information on the number and duration of the showers, and on total rainfall. Throughfall under each tree canopy was collected in 12 number G.I. metallic empty cylinders of $33.0 \times 12.7 \times 40.6$ cm^3 dimension. The cylinders were placed in two rows with the distance between the rows and cylinders being 120 and 90 cm respectively. The orifices of throughfall gauges were levelled at 36 cm above the ground level to prevent any addition from ground splash. The rainwater collected in the cylinders was measured after each rainfall with the help of measuring cylinders and the quantity of water measured in litres was then converted by multiplying it by 1000 mm to have the depth recorded in millimetres. To minimize the size of error we took as many events as possible and the throughfall collectors were also calibrated against standard raingauges in the open.

Interception or interception loss (In) was calculated as the difference between GP and net precipitation (NP). NP is made up of stemflow (SF) and throughfall (TF).

$$\text{In} = \text{GP} - \text{NP, or}$$

$$\text{In} = \text{GP} - (\text{SF} + \text{TF}).$$

Pearson's correlation analysis was performed to evaluate the influence of DBH, height, branching pattern and crown area of trees on stemflow, throughfall and interception. Homogeneity of variance was achieved as needed through log transformations. Microsoft EXCEL and STATISTICA software were used for various statistical analyses.

Tree architecture of *P. wallichiana* showed 95° to 30° variation in attachment angles of lateral branches growing above 4.5 ft (Figure 2). On the branches of first order (with attachment angles of 95–80°), angles from the first secondary branches to the terminal branch on the lower side ranged between 50° and 60°. However, on the upper side similar angles were in the range 70–65°. In regard to branches of second order (attachment angle 70–65°), the angles varied between 65° and 80° in case of the upper first secondary to terminal branch. In the case of branches on the lower side in the same order the angles were, however, measured between 60° and 20°. Branching pattern of third order (with attachment angles between 50° and 30°) showed angular variations of 30° to 15° and 50° to 30° in case of the lower and upper sides respectively. Tertiary branches on the lower side of secondary branches of first, second and third order showed angles of 55° to 20°, 40° to 15° and 10° to 15° respectively. Majority of tertiary branches in all the three orders, however, described the angles of 10–60° resulting in the formation of a dense canopy.

Expectedly, the maximum interception was noticed in October with the lowest rainfall and minimum interception in July with the highest rainfall (Figure 3). A marked decrease in interception was observed with an increase in gross precipitation. In case of tree no. 1, the average values for stemflow, throughfall and interception from the total rainfall of 66.3 mm were found at 26.8%, 35.8% and 37.5% respectively. Comparatively higher crown retention of rainfall was recorded by tree no. 2. Average percentage values of interception and net precipitation were 40.4 and 59.6 respectively. Average ratio of interception to net precipitation in tree no. 3 was 0.6%. Highest and lowest values of interception were 67.3% and 22.3%, recorded in the minimum and maximum rainfall months respectively. Tree no. 4 intercepted 39.1% of the gross precipitation. The proportion of stemflow increased slightly with an increase in heavy showers, though no such trend was observed for throughfall. Maximum and minimum crown retention of 58.3% and 19.1% was recorded for October and November respectively, in tree no. 5. The stemflow was found to increase with heavy showers, presumably a consequence of the smooth nature of the bark. The average interception values were calculated at 32.5% in the case of tree no. 6, average net interception was 34.0% (Figure 3). The ANOVA of interception ($F = 2.55$; $P < 0.05$), stemflow ($F = 3.60$; $P < 0.01$) and throughfall ($F = 2.64$; $P < 0.05$) shows that the values varied significantly throughout the year.

Correlation between the various attributes shows that stemflow (mm) increased significantly ($r = 0.65$; $P < 0.05$) with increase in tree DBH (Figure 4 *a*). Height of the trees ($r = 0.68$; $P < 0.05$) and crown area ($r = 0.66$;

$P < 0.05$) were also positively correlated with stemflow (Figure 4 *b* and *c*). Other statistically significant positive correlations were found between percentage throughfall and DBH ($r = 0.94$; $P < 0.001$), height of the trees ($r = 0.96$; $P < 0.001$) and crown area ($r = 0.90$; $P < 0.001$; Figure 5). Throughfall was negatively correlated with downward branching pattern ($r = 0.83$; $P < 0.05$).

Further analysis of data shows that as the gross precipitation increased, the interception percentage decreased ($r = 0.78$; $P < 0.001$), whereas stemflow percentage ($r = 0.67$; $P < 0.001$) and throughfall percentage ($r = 0.67$; $P < 0.001$) increased significantly (Figure 6). The amount (mm) of interception ($r = 0.90$; $P < 0.001$), stemflow ($r = 0.96$; $P < 0.001$) and throughfall ($r = 0.99$; $P < 0.001$) increased significantly with increase in gross precipitation (Figure 7). The linear equation between total precipitation and interception, however, holds true for precipitation in range 15–144 mm only. Mann–Whitney's *U*-test of interception, stemflow and throughfall between rough and smooth-barked trees shows that interception was significantly higher in rough-barked ($P < 0.001$) and stemflow in smooth-barked trees ($P < 0.01$).

Correlation between stemflow and rainfall events showed that stemflow conduction increases with increase

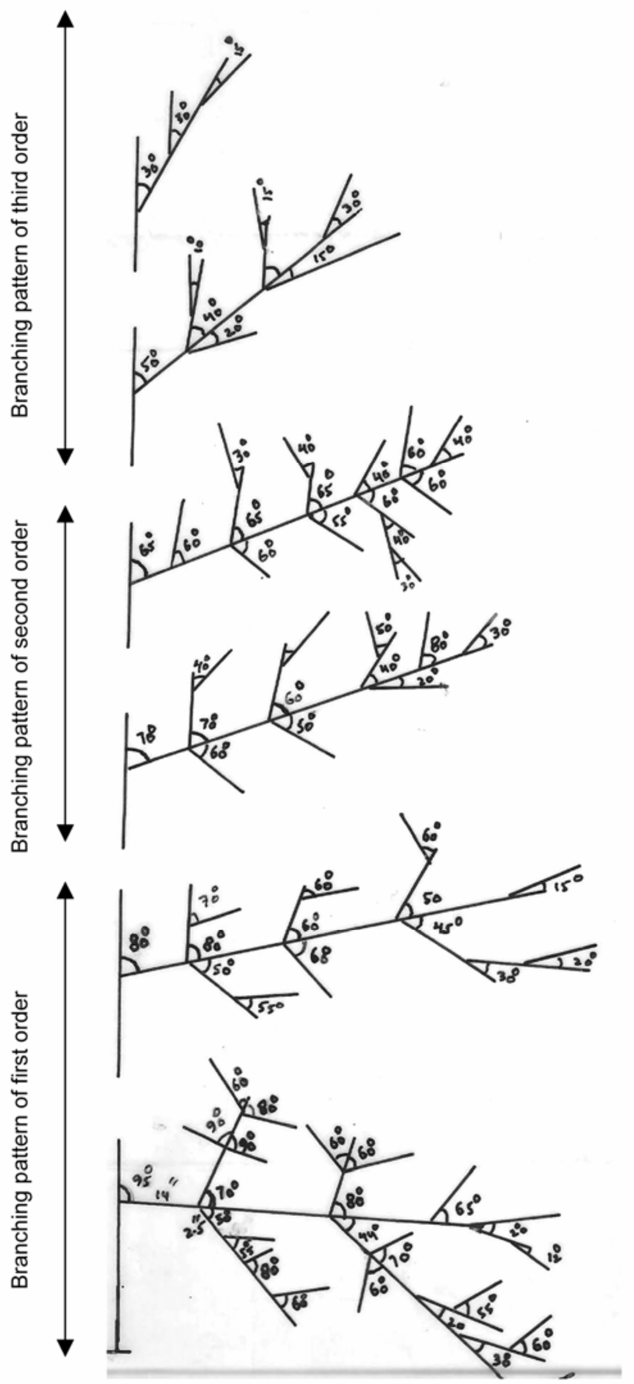

Figure 2. Branching pattern of *Pinus wallichiana* in the watershed.

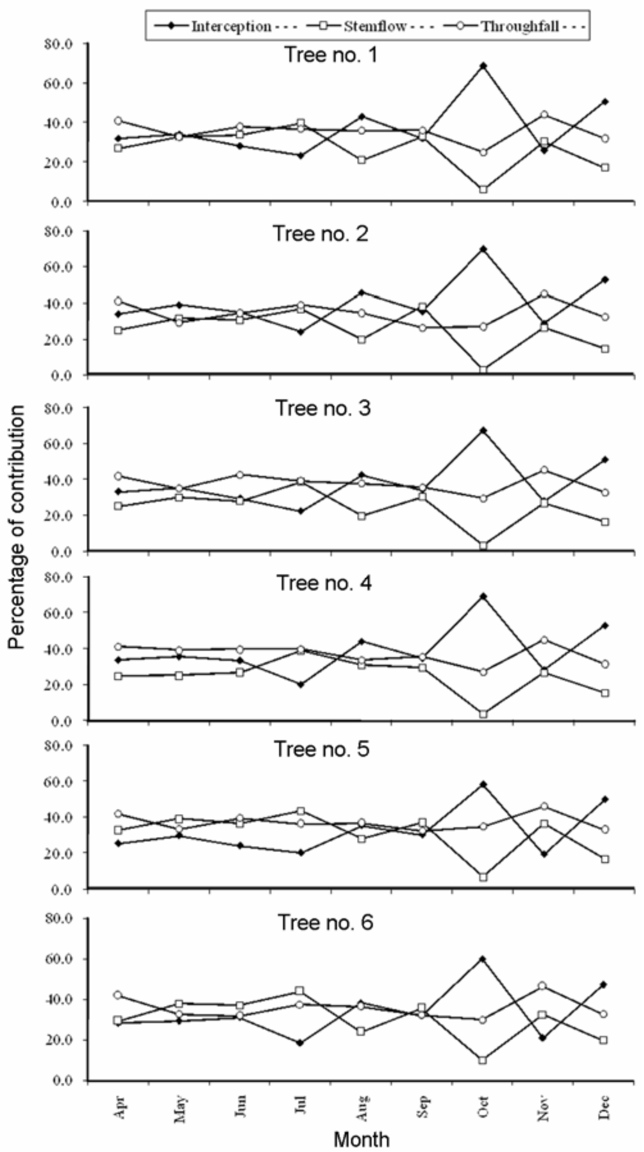

Figure 3. Monthly mean stemflow, throughfall and interception in six different trees of *P. wallichiana* during the study period.

in DBH in all rainfall months. The magnitude of increase though small is significant. On an average a 5 cm increase in DBH leads to 1.5% increase in stemflow conduction. This holds true for both rough and smooth-barked trees falling in the DBH range 25–50 cm. This could be attributed to the fact that larger girth would provide more space for stemflow conduction[7]. Other reasons could be crown characteristics, such as branching pattern, attachment angles of lateral branches with main stem and crown area of the tree. Moreover, trees with larger girth have usually larger crown area resulting in the conduction of more stemflow[8]. Higher percentage of upward branching in *P. wallichiana* showed maximum of stemflow conduction compared to trees with high percentage of drooping branches. The branching pattern in this genus is such that maximum of lateral branches is found sloping towards the main trunk forming sloping angles between 30° and 90° from top to base of the tree, which appreciably channels intercepted water towards the main trunk. Again, smooth-barked trees were estimated to conduct more of stemflow than rough-barked ones. Higher absorption capacity of rough bark restricts the flow of rainwater[1], whereas the small crevices and furrows retain maximum of the same. Occurrence of higher moss growth on bark of the tree under discussion may be due to plenty of moisture and minerals available in the crevices of rough bark. Voth[19] has also reported the abundant growth of epiphytes such as lichens, liverworts and mosses on woody stems.

Height also influenced the stemflow. On an average 10 cm increase in tree height led to 1.5% decrease in stemflow. Rainwater intercepted by tall trees has to traverse more distance before reaching the forest floor. In the transition maximum of rainfall is either absorbed by the fissures in the bark or gets lost through evaporation, as has been reported by Hamilton and Rowe[1]. Except for three rainfall months (April, August and September), all other months showed increased stemflow percentage with increased amount of incident precipitation in all the DBH classes. During light showers of 15 cm intensity, most of the precipitation falling on the tree is either absorbed by the foliage or evaporated. Thus stemflow was very low while in the case of heavy showers of 23.0–40 mm, the conducting channels were found to become loaded to capacity by rainwater, thereby maintaining continuous influx of rainwater which ultimately reaches the soil. During extremely heavy shower there is a tendency of stemflow to decrease as the limit to the capacity of tree

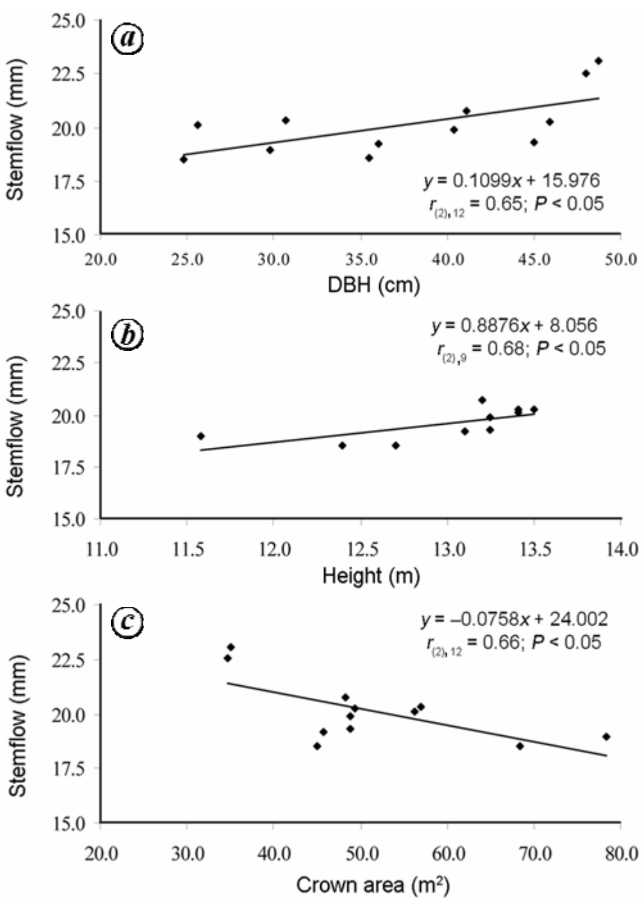

Figure 4 ***a–c*****.** Regression equation and relation of stemflow (mm) to diameter at breast height, height of trees and crown area.

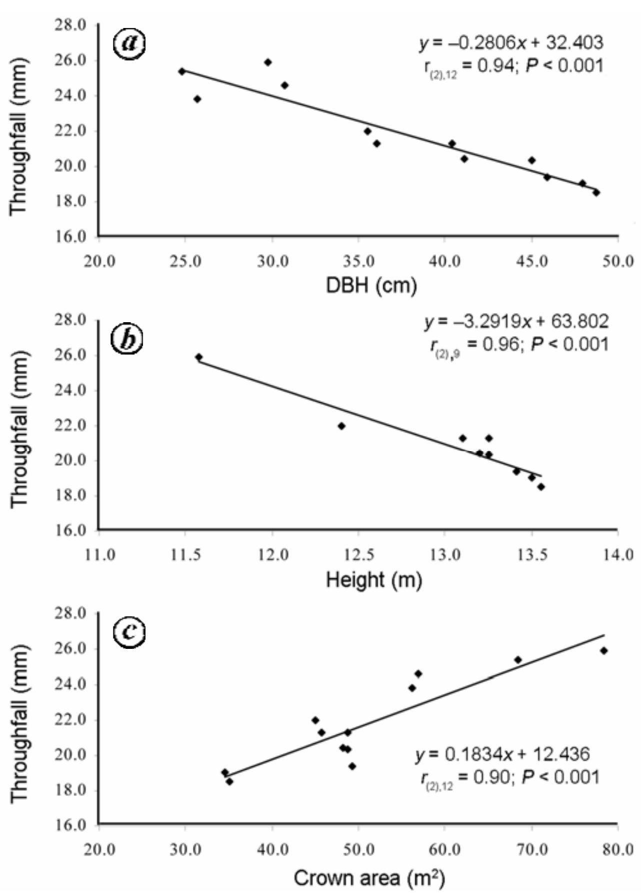

Figure 5 ***a–c*****.** Regression equation and relation between throughfall (mm) and diameter at breast height, height of trees and crown area.

surfaces to conduct stemflow is reached, beyond which excess of precipitation jumps off in the form of water drops from the conducting surfaces. Average value of stemflow in both rough and smooth-barked trees was 24.9% and 30.4%, respectively, in all rainfall months and DBH classes. The values are 20% higher than those reported by Singh[12].

Percentage throughfall increased both with rainfall and downward branching pattern in both smooth and rough-barked trees. The increase in throughfall values could be due to heavy incident intermediate showers of short duration which wet the canopy to saturation point and make conducting channels loaded to full capacity. A general tendency for throughfall percentage to increase while stemflow percentage remains constant during extremely heavy showers has been also noticed. This is in consonance with the findings of Dabral and Subba Rao[7] in *Pinus roxburghii* and *Tectona grandis* plantations and Singh and coworkers[12,20] in *Cedrus deodara* and *P. wallichiana* plantations.

Interception percentage decreased with an increase in rainfall in all DBH classes (Figure 6 *a*). This is in conformity with the findings of several workers[12,20–22]. However, exceptionally higher values of interception were observed in high-rainfall months of May and August. This is seemingly due to occurrence of low-intensity intermittent showers. Among a multitude of factors which influence interception include intensity, duration of rainfall, number of rainy days, crown characteristics, crown area, species, season, wind velocity, etc. Interception for the whole study period varied from 21.4% to 65.6%, with an average of 36.9% in all DBH classes. It was found that the canopy withheld maximum interception during light showers. Pine trees have been found to intercept comparatively more of precipitation[22] than deciduous plants[23] for the reason that the large number of small linear leaves in conifers hinders the free flow of rain drops and presents numerous cavities in which rainwater can be trapped. Rutter[22] has reported an interception of 32.0% in *Pinus sylvestris* plantation with little seasonal variations.

A comparison of the observed interception and expected interception values for the two types of cases proved the applicability of the hypothesis that each day's interception is affected by interception on the previous day in the stand. Mean observed interception for June

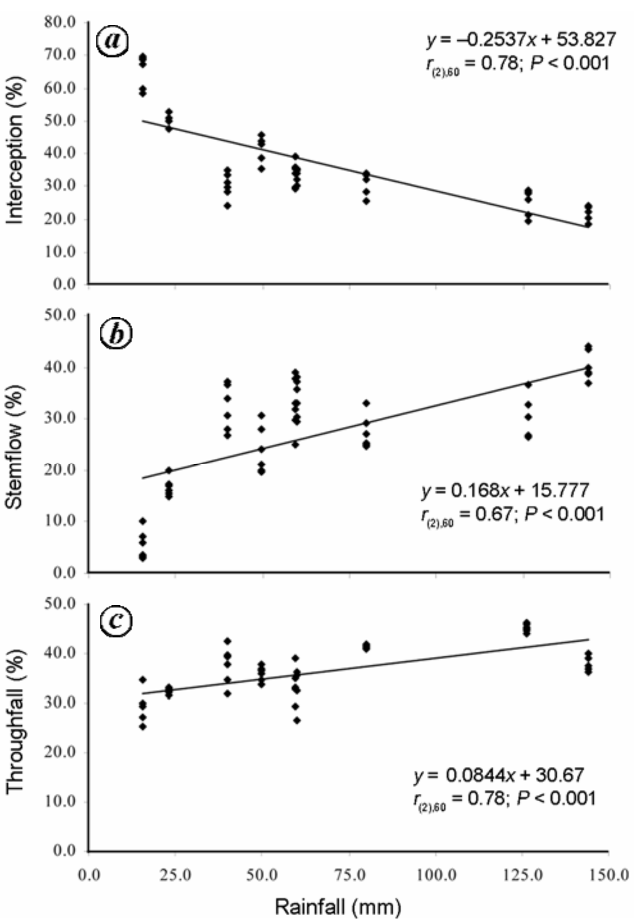

Figure 6 *a*–*c*. Regression equation and relation between rainfall (mm) and interception (%), stemflow (%) and throughfall (%).

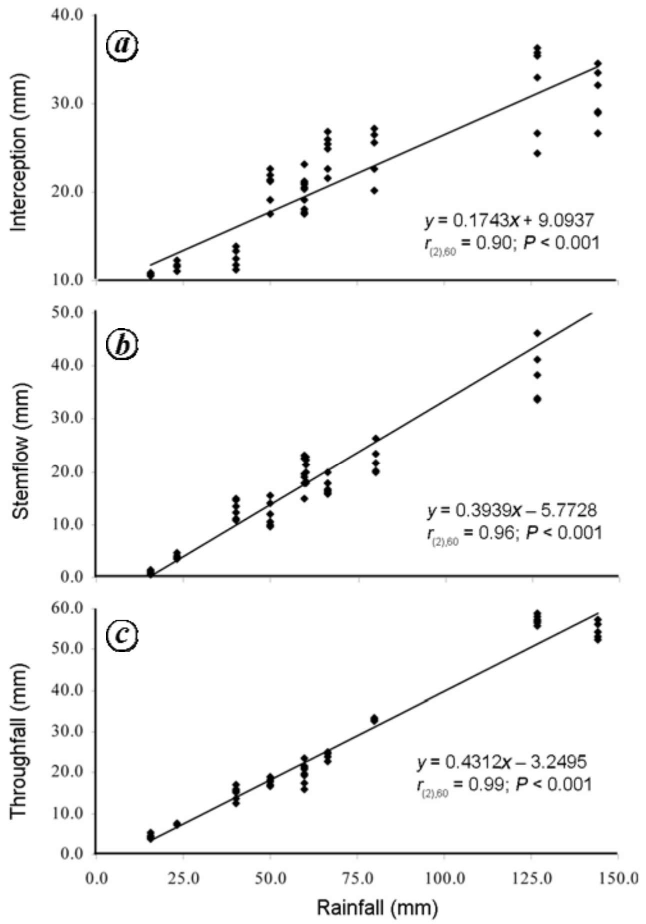

Figure 7 *a*–*c*. Regression equation and relation between rainfall (mm) and interception (mm), stemflow (mm) and throughfall (mm).

was 10 mm day^{-1} compared to the expected values of 11.5 mm day^{-1}. While in July the mean observed interception was 22 mm day^{-1} compared with the expected values of 27.0 mm day^{-1}.

It was found that in all the lower rainfall months there was a marked increase in interception with increase in crown area. Examinations of interception in periods of several consecutive rainy days have confirmed that interception is greatly reduced by the rainfall remaining from previous day's rain. This could be due to reduced evaporation or due to minimum absorption by the foliage.

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Structure and context of female song in a tropical bird, the Pied Bush Chat

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Songbirds have been regarded as an important model system in the field of animal communication focusing mainly on songs by male birds. However, the occurrence, structure and sociobiological significance of song in female birds have been a long-neglected field. We describe here the structure and context of female song in a tropical avian species, the Pied Bush Chat (*Saxicola caprata*). All the females sang occasionally prior to nest-building through egglaying and rarely during incubation. We did not find significant difference in any of the song type characteristics of the female song when compared with male. However, mean song repertoire size for females was significantly smaller than males. Females sang during aggressive interactions with floater or neighbouring females. Females also sang during intersexual vocal communi-

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