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Nutrients in precipitation components for pine and oak forests in Kumaun Himalaya

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ABSTRACT

Concentrations and inputs of certain nutrients in precipitation of pine and oak forests in Kumaun Himalaya were quantified. The mean concentration of nutrients was higher in throughfall and stemflow than in rainfall in open gauges. Among the nutrients, the leachability of K from the canopy was greatest and that of N lowest. The net gain of nutrients (kg ha^{-1} yr^{-1}) from the canopy was higher in oak forests, except for P and followed the order: K > Ca > Mg > N > P. Precipitation and throughfall inputs play a significant role in the nutrient cycling of these forests.

1. Introduction

Nutrients primarily move from the canopy in litterfall to the forest floor, where they are subsequently leached by percolating water and released from the organic matter by decomposition. Another pathway involves the transfer from the canopy directly to the available nutrient pool through stemflow and throughfall. The forest canopy traps a substantial amount of dust particles containing organic and inorganic nutrients. These are washed down to the forest floor as precipitation moves through the canopy. Further, precipitation which drips from the foliage or runs down the boles of trees may be substantially enriched in bioelements due to leaching. Some nutrients may also be absorbed from the precipitation by the canopy (Carroll, 1980). The term net gain (or net removal as used by Eaton et al., 1973) refers only to the nutrients leached from the vegetation, plus those washed off the surface in excess of the canopy absorption, minus nutrients in the incident precipitation. The total nutrient input to the forest soil is the sum of the canopy gain and that in the incident rainfall.

In some situations, the influx of nutrients from the atmosphere through rainfall becomes the major net source of nutrients (Kellman et al., 1982). The present study estimates this input for pine and oak forests in Kumaun Himalaya and evaluates the role of throughfall and stem flow as pathways of nutrient transfer to the soil.

2. Material and methods

The sites are located near Naini Tal (29°24′N 79°28′E). One site is covered with a pine (*Pinus roxburghii* Sarg.) forest and the other with an oak (*Quercus leucotrichophora* A. Camus and *Q. floribunda* Lindle) forest. The majority of annual rainfall (72%) occurs during the monsoon period (middle of June to middle of September). The mean minimum temperature varies from 3.6 °C in January to 16.9 °C in June; and the mean maximum from 10.3 °C in January to 27.7 °C in May. Details of the climate are given in Pandey and Singh (1981).

A 20 × 20 m representative plot was demarcated on each site. Six trees representing different girth classes were selected in each plot and their circumferences at breast height (cbh) were measured. Canopy cover (% ground surface) and area (m^2 $tree^{-1}$) were measured through line interception (Misra, 1968). Altitude, average dbh (diameter at breast height), average crown area and canopy cover are given in Table 1. Measurements of precipitation components were made on 17 days for pine and 21 days for oak forest within the 1981 and 82 monsoon seasons.

Incident rainfall. Incident rainfall was measured in three collection flasks on each site mounted with a 20 cm diameter, screened funnel (Carlisle et al., 1966). These flasks were placed in open areas well away from the influence of the plant canopy. Measurement was taken at the end of each rain shower.

Throughfall. Throughfall was measured by placing six similar flasks beneath the canopy of each marked tree on different radii extending 10 cm from the tree trunk to the edge of the canopy. The flasks were moved to different positions after each collection.

Stemflow. Stemflow from the marked trees was collected through polyethylene collars (Likens and Eaton, 1970) into polyethylene containers. The proportion of incident precipitation received as stemflow for a tree was calculated by dividing the stemflow volume by its crown area. Canopy retention was calculated by subtracting the net precipitation (throughfall + stemflow) from gross precipitation.

Chemical analysis. Aliquots of precipitation components collected as above were pooled in proportion to volume and stored at 0–1 °C after adding 2 ml of chloroform as preservative. These samples were analysed for total N (Kjeldahl method), Ca (by titration), P (colorimetrically), Mg (gravimetrically), K (by titration) and organic carbon (by wet oxidation). Methods given by Jackson (1958) were followed. Nutrient contents of precipitation components were calculated by multiplying the mean concentrations with respective volumes.

3. Results and discussion

3.1. *Volume of precipitation*

Gross monsoon rainfall averaged 1239.1 mm and 1263.6 mm in the pine and oak forests, respectively (Table 2). Throughfall (as percent of gross rainfall) was higher (78%) in the oak forest compared to the pine forest (71%). Stemflow volume was extremely small in relation to gross rainfall. It was slightly higher (0.7% of gross rainfall) in the oak forest compared to the pine forest (0.5%). Canopy retention was markedly higher in the pine forest (28.5% of gross rainfall) than in the oak forest (21.5%).

3.2. *Concentration of nutrients in precipitation components*

The mean nutrient concentrations are given in Table 3. Canopy precipitation were richer in all

Table 2. *Volumes (mm) of precipitation components (percent of gross precipitation in parentheses)*

Forest	Precipitation component	1981	1982	Mean
Pine forest	Rainfall	1029.40	1448.80	1239.10
	Throughfall	694.02 (67.4)	1066.30 (73.6)	880.16 (71.0)
	Stemflow	5.15 (0.50)	7.39 (0.51)	6.27 (0.50)
	Retained by canopy	330.23 (32.10)	375.11 (25.9)	352.67 (28.5)
Oak forest	Rainfall	1166.70	1560.50	1363.6
	Throughfall	920.96 (78.92)	1213.29 (77.75)	1067.12 (78.26)
	Stemflow	5.37 (0.46)	14.35 (0.92)	9.86 (0.72)
	Retained by canopy	240.37 (20.6)	347.21 (22.5)	293.75 (21.54)

Table 1. *Site characteristics*

Site	Forest	Species	Altitude (m)	Average dbh (cm tree^{-1})	Average crown area (m^2 tree^{-1})	Canopy cover (%)
Baldiakhan	Pine	*Pinus roxburghii* Sarg.	1750	26.3 ± 4.6	33 ± 8	91
Naini Tal	Oak	*Quercus leucotrichophora* A. Camus. and *Q. floribunda* Lindle.	2000	27.8 ± 8.4	32 ± 10	81

Table 3. *Mean nutrient concentration (±1 SE) of precipitation components and foliage*

Forest	Nutrient concentration N	Ca	Mg	K	P	Organic carbon
Pine forest			(mg l^{-1})			
Rainfall	0.60 ± 0.07	1.46 ± 0.05	0.98 ± 0.04	1.04 ± 0.14	0.13 ± 0.02	0.50 ± 0.04
Throughfall	1.07 ± 0.16	2.39 ± 0.12	1.54 ± 0.11	2.18 ± 0.08	0.18 ± 0.01	1.09 ± 0.26
Stemflow	1.49 ± 0.12	4.97 ± 0.49	2.10 ± 0.20	6.16 ± 0.40	0.67 ± 0.05	1.45 ± 0.23
			(% dry wt)			
Foliage	1.89 ± 0.12	0.75 ± 0.07	—	0.70 ± 0.02	0.15 ± 0.005	—
Oak forest			(mg l^{-1})			
Rainfall	0.60 ± 0.05	1.62 ± 0.05	1.00 ± 0.12	1.00 ± 0.04	0.12 ± 0.02	1.07 ± 0.23
Throughfall	1.10 ± 0.08	2.43 ± 0.15	1.31 ± 0.19	2.39 ± 0.10	0.16 ± 0.03	1.45 ± 0.02
Stemflow	1.70 ± 0.04	5.61 ± 0.63	2.29 ± 0.25	6.08 ± 1.02	0.82 ± 0.06	1.89 ± 0.14
			(% dry wt)			
Foliage	2.04 ± 0.04	1.97 ± 0.04	—	0.59 ± 0.05	0.09 ± 0.002	—

Data for foliage concentration are from Chaturvedi (1983) and Y. S. Rawat (unpublished) respectively for pine and oak.

nutrients ($P < 0.001$) compared to rainfall in open gauges. Nutrient concentrations in throughfall and stemflow were higher in the oak forest than in the pine forest except for Mg and P in throughfall and K in stemflow which were slightly higher in the pine forest. Organic carbon was also higher in the canopy precipitation of oak forest. The concentrations in rainwater in open gauges were not different in the two forests. The stemflow water in both the forests was significantly richer in all nutrients compared to the throughfall water (N, P, Ca at $P < 0.001$; Mg, K at $P < 0.01$ in pine forest; and Ca, K, P at $P < 0.001$, N, Mg at $P < 0.05$ in oak forest). Throughfall water contains the leaf leachates and aerosol and dust deposited on the canopy. Greater nutrient concentration in stemflow is understandable since the percolating water also washes down the decomposition products of the bark. The pattern of nutrient concentration in the precipitation components followed the order: Ca $\lesseqgtr$ K > Mg > N > P, which is in conformity with that reported by Carlisle et al. (1966), Killingbeck and Wali (1978), Szabo' (1977) and George (1979).

Eaton et al. (1973) suggested that elements which are in large amounts in the leaves may leach in higher amounts. Henderson et al. (1977) found a poor correlation between foliar concentration and leaching. In the present study, leaching of elements, as represented by the concentration in throughfall and stemflow water, was independent of foliar concentration (Table 3). Tukey (1970), Eaton et al. (1973) and Hart and Parent (1974) emphasized the physical and physiological conditions of the leaves as important factors in leaching. Attiwill (1966) argued that the occurrence, intensity and duration of precipitation are important factors influencing the leaching rates.

The Ca:Mg ratio in rainfall reflects the source of airborne chemicals (Eriksson, 1952). This ratio when it approaches a value of 0.196 (as in seawater) indicates rainfall from air masses directly off the ocean, whereas in continental precipitation, the ratio is much higher. Jones (1960) found a Ca:Mg ratio of 0.34 in northern Nigeria. This ratio was 3.7 for the Hubbard Brook ecosystem (Eaton et al., 1973) and 11.9 for recovering forest ecosystem in Turrialba, Costa Rica (Harcombe 1977). In the present study, this ratio averaged at 1.55 indicating a limited mixing of oceanic and continental air masses. Compared to the deciduous forests of Central India (Yadav and Mishra, 1979), the rainfall input in the present forests was 3, 2.2, and 3 times higher for P, K and Ca respectively.

The pH of the rain water averaged 6.8. Compared to this, the pH of stemflow and throughfall water in the pine forest was 6.4 and 6.6, respectively, and in the oak forest 6.5 and 6.7, respectively.

3.3. *Net gain from canopy*

Total rainy season inputs of nutrients through rainfall was highest for Ca and lowest for P in both the forests (Table 4). Because of the greater bulk, the rainfall added more nutrients to the oak forest compared with the pine forest. The net gain of nutrients, except for P, was also higher in the oak forest (Table 4). The net gain of nutrients from the canopy was in the order: K > Ca > Mg > N > P, and was comparable to the values reported by Henderson et al. (1977) and Peterson and Rolfe (1982).

Eaton et al. (1973) calculated the ratio of net gain to foliar nutrient content to express the relative leachability of bioelements. In the northern hardwood forest this ratio followed the order K > Mg > Ca > N > P (Eaton et al., 1973). Similar calculations by Henderson et al. (1977) showed the pattern K > Ca > Mg > P > N for four forests in the Walker Branch Watershed in eastern Tennessee. In the present study also the leachability of K was greatest and that of N lowest (Table 5).

The elements which are primarily in ionic form in cell sap, such as K are cycled rapidly and move predominantly in throughfall while elements of predominantly non-ionic form such as N and P which are associated with plant tissues and storage, cycle slowly and move largely in litterfall (Eaton et al., 1973; Cole and Rapp, 1980). Nutrient inputs to the soil through litterfall and precipitation components are compared in Table 6. From 10% to 54% of total inputs was accounted for by the precipitation. It is clear that the precipitation inputs play a significant role in the nutrient cycling in these forests, especially since nutrients in precipitation are in "available" form (opposed to "bound" in litterfall).

4. Acknowledgement

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Table 4. *Mean annual nutrient inputs and net gain (kg ha^{-1}) from precipitation components. Gain from canopy was calculated as: (1) the difference between the nutrient content of rainfall and throughfall for a given volume of throughfall and (2) the difference between the nutrient content of rainfall and stemflow for a given volume of stemflow*

Precipitation components	N	Ca	Mg	K	P	Organic carbon
Pine forest						
Rainfall	5.28	12.85	8.62	9.15	1.14	4.40
Throughfall						
Total	9.42	21.03	13.55	19.18	1.70	9.59
Gain from canopy	4.14	8.18	4.93	10.03	0.56	5.19
Stemflow						
Total	0.09	0.31	0.13	0.38	0.04	0.09
Gain from canopy	0.06	0.22	0.07	0.32	0.03	0.06
Throughfall + stemflow						
Total	9.51	21.34	13.68	19.56	1.74	9.68
Net gain from canopy	4.20	8.40	5.0	10.35	0.59	5.25
Oak forest						
Rainfall	6.40	17.28	10.67	10.68	1.28	11.40
Throughfall						
Total	11.74	25.90	16.11	25.5	1.70	15.47
Gain from canopy	5.34	8.62	5.44	14.82	0.42	4.07
Stemflow						
Total	0.16	0.55	0.22	0.60	0.08	0.18
Gain from canopy	0.11	0.39	0.12	0.50	0.10	0.10
Throughfall + stemflow						
Total	11.90	26.45	16.33	26.10	1.78	15.65
Net gain from canopy	5.45	9.01	5.56	15.32	0.52	4.17

Table 5. *Relationship between net gain and foliar nutrient content in pine and oak forests*

Forest	Nutrients	Foliage content (kg ha^{-1})	Annual net gain from canopy (kg ha^{-1})	Ratio $\left(\frac{\text{net gain}}{\text{foliage content}}\right)$
Pine forest	N	148.7	4.20	0.03
	Ca	58.5	8.40	0.14
	Mg	25.0	5.0	0.20
	K	52.8	10.35	0.20
	P	11.9	0.59	0.05
Oak forest	N	285.2	5.45	0.02
	Ca	274.7	9.01	0.03
	Mg	N.A.	5.56	—
	K	82.9	15.32	0.18
	P	12.9	0.52	0.04

Foliage contents are from Chaturvedi (1983) and Y. S. Rawat (unpublished).
N.A. = not analysed.

Table 6. *Annual input of nutrients (kg ha^{-1}) by rainfall and litterfall. Input by rainfall was calculated from table 4 by multiplying by the canopy cover fraction. For example N, input into pine forest with 100% canopy was 9.51, and the canopy cover of this forest on the site was 91%, so 9.51 × 0.91 = 8.65 kg ha^{-1}. To this quantity was added the input from rainwater falling through canopy openings, i.e., 5.28 × 0.09 = 0.47, and total rainfall input was 8.65 + 0.47 = 9.12 kg ha^{-1}; the values are rounded to one decimal for rainfall input*

Forest	Nutrients	Input by precipitation	Input by litterfall	Total input (rainfall + litterfall)	% input of nutrients by precipitation
Pine forest	N	9.1	54.6	63.7	14
	Ca	20.6	30.0	50.6	41
	Mg	13.2	N.A.	—	—
	K	18.6	19.2	37.8	49
	P	1.7	5.1	6.8	25
Oak forest	N	10.8	93.8	104.6	10
	Ca	24.7	95.5	120.2	21
	Mg	15.25	N.A.	—	—
	K	23.2	19.6	42.8	54
	P	1.7	6.6	8.3	20

Values for litter input are from Chaturvedi (1983) and Y. S. Rawat (unpublished).
N.A. = not analysed.

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