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Episodic stemflow inputs of magnesium and potassium to a tropical forest floor during heavy rainfall events

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Summary. Stemflow inputs of magnesium and potassium were measured from 57 canopy trees representing eight species under heavy rainfall conditions in two tropical forest sites in northeast Queensland, Australia. In the premontane tropical moist forest site on the Atherton Tableland, the stemflow input per unit trunk basal area of 51 canopy trees was found to be 0.46 g m^{-2} of Mg^{2+} and 4.22 g m^{-2} of K^{+} for an average wet season rainday of 99 mm. In the wetter montane tropical rainforest site on Mount Bellenden Ker, the stemflow input per unit trunk basal area of six canopy trees was 5.55 g m^{-2} of Mg^{2+} and 9.12 g m^{-2} of K^{+} for a wet season rainday of 38 mm. These stemflow inputs from single raindays are greater than the mean annual rainfall input and are almost of the same order of magnitude as the mean annual throughfall input of these cations to areas equal to the trunk basal area from which the stemflow was collected. Stemflow cation fluxes of this magnitude are mainly attributable to the funnelling of large quantities of rainwater down the trunks of these canopy trees by their thoroughly wetted, upwardly inclined branches.

Key words: Stemflow – Magnesium – Potassium – Soil input – Tropical rainforest

Several workers have previously noted that stemflow may introduce substantial quantities of nutrients to the bases of individual trees in forested ecosystems (Voight 1960; Eschner 1967; McColl 1970; Gersper and Holowaychuk 1971; Eaton et al. 1973; Clements and Colon 1975; Jordan 1978; Manokaran 1980; Parker 1983). These inputs, however, have been consistently reported in units of kg ha^{-1}. In this study, stemflow inputs of magnesium and potassium were compared with incident rainfall and throughfall inputs to areas equal to the trunk basal area from which the stemflow was collected. The use of basal area is not arbitrary because the volume of rainwater impacting on that part of the crown directly above the trunk basal area can then be calculated. When stemflow exceeds this volume, outlying parts of the crown must be contributing. This funnelling effect becomes significant during heavy rainfall events (Herwitz 1986). Stemflow inputs of Mg^{2+} and K^{+} during these heavy rainfall events are reported in this short communication.

Study areas

Stemflow was collected in two tropical forest sites in northeast Queensland, Australia during three successive wet seasons (1980–1982). Northeast Queensland is a cyclone-prone region that experiences a high frequency of heavy rainfall events during the wet season (January-April) when >60% of the mean annual rainfall occurs. Site 1 was in the Curtain Fig forest (State Forest No. 452) on the Atherton Tableland (17°17′S, 145°35′E, 720 m above sea level, 42 km from the Coral Sea) where the mean annual maximum rainday is 132 mm, and the mean annual rainfall is roughly 1,450 mm. Stemflow was collected at Site 1 from 51 canopy trees representing *Aleurites moluccana* (L.) Willd., *Argyrodendron peralatum* (F.M. Bailey) H.L. Edlin ex I.H. Boas, *Castanospermum australe* A. Cunn. & C. Fraser ex Hook., *Dysoxylum pettigrewianum* F.M. Bailey, and *Toona australis* (F. Muell.) Harms.

Site 2 was on Mount Bellenden Ker (17°17′S, 145°52′E, 1,000 m above sea level, 11 km from the Coral Sea) where the mean annual maximum rainday is >300 mm and the mean annual rainfall is 6,570 mm. Site 2 was accessible only by cablecar which limited the frequency of stemflow sampling and the number of individual trees that could be practically monitored. Stemflow was collected at Site 2 from six canopy trees representing *Balanops australiana* F.Muell., *Ceratopetalum virchowii* F.Muell., and *Elaeocarpus foveolatus* F.Muell.

Materials and methods

The stemflow collars used in both sites consisted of high quality hose slit longitudinally and sealed to the trunk in an upward spiral with U-shaped staples and silicon sealant. An unslit portion of the hose directed the drainage water into plastic collection bins. The bins were emptied and cleaned prior to the raindays in which stemflow samples were collected for chemical analysis. All water samples were collected within 24 h of stemflow events to protect against secondary chemical changes. Incident rainfall was collected in plastic rain gauges (15 cm diameter) located in clearings near the two study sites. Throughfall was collected beneath the collared trees using similar plastic rain gauges. The water samples were transferred to the laboratory in sterilized Whirl-pak sample bags and filtered through 0.45 µm filter paper. Mg^{2+} and K^{+} were analyzed using a Varian atomic absorption spectrophotometer.

Stemflow inputs were calculated by the equation $S=(PV)/B$, where P is the cation concentration in the stemflow

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Table 1. Magnesium and potassium concentrations and fluxes per unit trunk basal area during heavy rainfall events

		Mean funnelling ratio	Mean concentration		Mean flux	
			Mg^{2+} ($\mu g\,ml^{-1}$)	K^{+} ($\mu g\,ml^{-1}$)	Mg^{2+} ($\mu g\,cm^{-2}$)	K^{+} ($\mu g\,cm^{-2}$)
Site 1[a]	Incident rainfall	–	0.08	0.50	0.8	5.3
	Throughfall	–	0.35	3.1	3.4	30
	Stemflow					
	Aleurites moluccana	2.3	1.31	42.0	30	974
	Argyrodendron peralatum	3.3	3.13	9.6	102	314
	Castanospermum australe	2.0	1.25	9.3	24	178
	Dysoxylum pettigrewianum	2.3	1.33	3.8	30	85
	Toona australis	1.8	1.40	40.9	25	724
Site 2[b]	Incident rainfall	–	0.10	0.65	0.4	2.4
	Throughfall	–	0.30	1.00	1.1	3.7
	Stemflow					
	Balanops australiana	74.1	0.70	0.60	195	167
	Ceratopetalum virchowii	62.2	4.20	7.10	978	1,656
	Elaeocarpus foveolatus	59.7	0.30	0.80	67	179

[a] Unweighted mean values based on measurements on 18 March 1980 (171 mm), 4 January 1981 (55 mm), and 26 February 1981 (71 mm). These three raindays represented an average wet season rainday of 99 mm

[b] Measured on 23 February 1982 (38 mm)

solution, V is the stemflow volume, B is the basal area of the tree, and S is the input per unit basal area (i.e. $\mu g\,cm^{-2}$). This method of expressing of stemflow input allows useful comparisons between trees of different girth, and comparisons with incident rainfall and throughfall fluxes to the same unit areas. The relationship between stemflow volume and basal area indicates the extent of rainwater funnelling, and is given by the equation $F = V/(BG)$, where G is the depth equivalent of rainfall and F is the funnelling ratio. When the volume of stemflow collected is greater than the volume of stemflow expected in a rain gauge occupying the same projected area as the trunk basal area, then F exceeds unity, indicating that rainwater funnelling has occurred.

Results

Stemflow was collected in Site 1 on 55 raindays. Fourteen of these raindays generated a forest-wide funnelling ratio that exceeded unity. Chemical analyses were performed on the stemflow samples collected on three of these 14 raindays. For these three raindays, which represented an average wet season rainday of 99 mm (Table 1), the mean funnelling ratios of the five species ranged from 1.78 to 3.30 which is equivalent to rainfall depths per unit trunk basal area ranging from 177 to 327 mm. The significant differences between species in rainwater funnelling ($P < 0.01$) corresponded to differences in their branching geometry (see Herwitz 1982).

The Mg^{2+} concentrations in the stemflow solutions were not significantly different between species, while the K^{+} concentrations were significantly different ($P < 0.001$). The mean concentrations for each of the five species were greater than incident rainfall by factors ranging from 16 to 39 in the case of Mg^{2+}, and 7 to 79 in the case of K^{+} (Table 1).

The main finding is that a combination of high cation concentrations and rainwater funnelling results in exceptionally large stemflow cation inputs to localized parts of the forest floor. The mean stemflow inputs from each of the five species were greater than rainfall by factors ranging from 30 to 128 for Mg^{2+} and 16 to 184 for K^{+}, and greater than throughfall by factors ranging from 7 to 30 for Mg^{2+} and 3 to 32 for K^{+}. Significant interspecific differences in these stemflow inputs ($P < 0.05$ for Mg^{2+}; $P < 0.001$ for K^{+}) further compounds the spatial heterogeneity of the aqueous deposition of these two cations on the forest floor, and complicates the assessment of mean annual aqueous nutrient transfers by the conventional method of extrapolating stemflow data obtained from individual trees in different size-classes. If tree species exhibit the range of variation in stemflow cation inputs shown in Table 1, then any attempt to derive an accurate forest-wide stemflow input for a species-rich tropical forest would require information on both the composition and frequencies of tree species.

In Fig. 1, the stemflow inputs from all 51 trees at Site 1 are shown in grams per m^2 of basal area to illustrate how stemflow compares with (1) the rainfall input to an equivalent area at the top of the canopy and (2) the throughfall input to an equivalent area on the adjacent forest floor. For the same average day of heavy rainfall, the stemflow inputs exceed the rainfall inputs by two orders of magnitude and the throughfall inputs by one order of magnitude. In fact, the stemflow inputs actually exceed the mean annual rainfall inputs and, in the case of K^{+}, is of the same order of magnitude as the mean annual throughfall input (Fig. 1).

Stemflow data collected under the more extreme rainfall conditions in Site 2 showed even higher stemflow fluxes than in Site 1. On a selected rainday in Site 2 (38 mm) in which the rainfall in the preceding 3-week period was 725 mm, the funnelling ratios averaged >50 for all three species (Table 1). These exceptionally high funnelling ratios were the result of the large amount of antecedent rainfall which had thoroughly wet the branches and trunks of the trees.

The stemflow inputs of Mg^{2+} and K^{+} measured at Site 2 exceeded the throughfall inputs that occurred during the same rainday by three orders of magnitude in the case of Mg^{2+} and two orders of magnitude in the case of K^{+} (Fig. 1). The stemflow inputs from this single rainday were almost equivalent to the mean annual throughfall inputs.

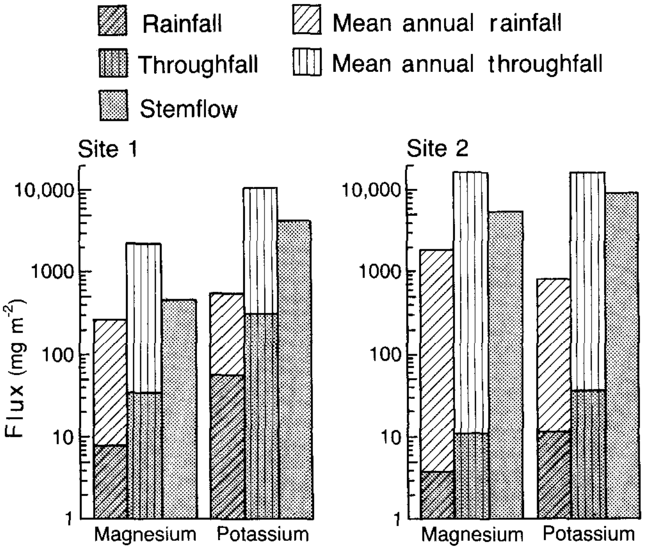

Fig. 1. Rainfall, throughfall and stemflow inputs of Mg^{2+} and K^+ per unit trunk basal area shown on a logarithmic scale. Site 1 inputs for a wet season rainday of 99 mm are unweighted means based on measurements from three separate days of heavy rainfall. Site 2 inputs are from a single wet season rainday. Mean annual rainfall and mean annual throughfall inputs to unit areas equivalent to trunk basal area are based on interpolations of rainfall and throughfall chemistry data collected by Brasell and Gilmour (1980) and Brasell and Sinclair (1983) on the Atherton Tableland and on Mount Bellenden Ker

Discussion

By analyzing stemflow data in relation to basal area, I have shown the extent of the differences between rainfall, throughfall and stemflow inputs of Mg^{2+} and K^+ to areas equal to trunk basal area. Under heavy rainfall conditions, the area around the bases of individual canopy trees receives aqueous inputs of these two cations that may exceed the amounts introduced to other parts of the forest floor by as much as three orders of magnitude. The stemflow contribution is clearly a component of the intrasystem nutrient cycle that cannot be ignored when considering the spatial variation in nutrient availability in forests that experience extreme rainfall events (e.g. forests in the cyclone-prone latitudes).

Episodic stemflow inputs are of particular interest in tropical rainforests where the soil is often low in available nutrients. The influence of stemflow on soil chemistry around the bases of tree species that generate large volumes of stemflow has been documented in a temperate forest context (Gersper and Holowaychuk 1971). However, in tropical rainforest environments where the vegetation efficiently takes up dissolved nutrients from percolating soil water (Stark and Jordan 1978), spatially localized patterns of aqueous nutrient deposition may not persist in the soil. For this reason, soil chemical analyses may not be a reliable guide to the influence of stemflow on nutrient availability at the bases of trees.

Insofar as episodic stemflow nutrient inputs occur in northeast Queensland only during the wet season (the primary period of vegetative growth), the aqueous nutrients introduced at the bases of individual canopy trees may be differentially exploited in comparison with the amounts withdrawn from the less localized throughfall inputs during this period to equivalent areas on the adjacent forest floor. The influence of stemflow on the spatial distribution of soil microorganisms and understory herbs has been demonstrated in temperate forest ecosystems (Bollen et al. 1967; Crozier and Boerner 1984). The extent to which plants and soil microorganisms in tropical rainforests exploit the highly localized cation pulses documented in this short communication remains to be determined.

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