NUTRIENT CYCLING BY THROUGHFALL AND STEMFLOW PRECIPITATION IN THREE COASTAL OREGON FOREST TYPES

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PACIFIC NORTHWEST
FOREST AND RANGE EXPERIMENT STATION
U. S. DEPARTMENT OF AGRICULTURE · FOREST SERVICE

U.S.D.A. FOREST SERVICE
RESEARCH PAPER PNW-54
1968

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This study was supported, in part, by the National Science Foundation, Grant No. GB-3214.

INTRODUCTION

In the Pacific Northwest, where annual precipitation ranges from about 40 to 120 inches per year in commercial forest areas, rainfall washing through the forest canopy returns a part of the nutrient capital of the ecosystem to the soil. Nitrogen is of special interest in this connection because it is the only nutrient element thus far found to appreciably stimulate growth of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) when applied as fertilizer (Gessel et al. 1965).

A number of tree species throughout the world have been shown to contribute to the enrichment of throughfall and stemflow,[1] but in most studies of this phenomenon, only nonnitrogenous nutrient ions have been determined. Few investigators have determined N content in throughfall and stemflow (Voigt 1960b; Sviridova 1960; Mina 1965; Maruyama et al. 1965; Carlisle, Brown, and White, 1967; Cole, Gessel, and Dice, 1967), and only one study (Rahman[2]) included red alder (*Alnus rubra* Bong.), a nitrogen-fixing, nodulated woody plant that is also the major hardwood tree in the Pacific Northwest.

In connection with studies of nitrogen cycling, airborne chemical pollutants, and rhizosphere microflora, we wished to determine the significance of alteration of some chemical constituents of rainfall by its passage through the forest canopy. In the study reported here, we asked: What is the nature and magnitude of alteration of total N and dissolved solids content, and how is pH of gross rainfall altered by throughfall and stemflow in stands of (1) red alder; (2) conifer—Douglas-fir, Sitka spruce (*Picea sitchensis* (Bong.) Carr.), and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.); and (3) mixtures of alder and the conifers?

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[1] *Gross rainfall* is rainfall measured in the open. *Throughfall* is that portion of the gross rainfall which directly reaches the forest litter through spaces in the vegetative canopy and as drip from leaves. *Stemflow* is that portion of the gross rainfall which is caught on the canopy and reaches the litter or mineral soil by running down the stems (Helvey and Patric 1965).

[2] Rahman, A. H. A study of the movement of elements from tree crowns by natural litterfall, stem flow and leaf wash. 118 pp. 1964. (Unpublished M.F. thesis on file at Univ. Wash.)

EXPERIMENTAL PROCEDURES

The study was conducted at Cascade Head Experimental Forest about 6 miles inland from the Pacific Ocean at latitude 45°3' N., longitude 123°55' W. Here, a series of three growth measurement plots—pure alder, pure conifer, and a mixture of alder and conifer—were established in 1937. The stands are now about 40 years old and occupy the following basal areas (square feet per acre): alder, 156; conifer, 268; and mixed stand, 221.

Soils beneath all three stands are Astoria-like Sols Bruns Acides developed from deeply weathered tuffaceous siltstone of Eocene epoch. Detailed morphological and chemical characteristics of soils beneath the three stands are reported by Franklin et al. (1968).

Three polyethylene rainfall collectors were randomly located in each stand and in an adjacent opening of about 21 acres. Three polyethylene funnels, having a total top opening area of 1 square foot, were inserted through the lid of each container. Each funnel was fitted with a Pyrex glass wool filter plug and a 10-mesh copper screen to keep coarse debris out of the collector. Two milliliters of toluene were added to each container to inhibit microbial action.

Three trees, selected at random in each stand, were fitted with lead troughs which conducted stemflow through Tygon tubing into a polyethylene container protected against contamination in the same manner as the throughfall collectors.

Collectors were emptied monthly from late spring through fall, then bimonthly during the winter. The volume of precipitation collected was measured to the nearest 1 milliliter. After being passed through Whatman No .5 filter paper, the water was analyzed for nitrite nitrogen with 1-naphthylamine sulfanilic acid and sodium acetate buffer (American Public Health Association 1955). Nitrate nitrogen was determined by the phenoldisulfonic method (Harper 1924) which included special precautions to avoid loss of nitrate. Free ammonium was determined for 50 milliliter samples by distillation with phosphate buffer at pH 7.4 (Nichols and Foote 1931). Organic nitrogen was determined for 50 milliliter samples by a semimicro modification of the standard Kjeldahl procedure; 25 milliliters of distillate were collected in 6 milliliters of saturated boric acid and titrated with N/70 sulfuric acid using methyl red—bromcresol green mixed indicator.

Total dissolved solids were determined by evaporating a filtered 100-milliliter aliquot of water on a steam bath, drying the residue in a desiccator, then weighing. A glass electrode was used to determine pH.

RESULTS AND DISCUSSION

Nitrogen

Average concentration of total N was 0.05 milligram per liter in gross rainfall (table 1). We found no measurable NO_2^- or NH_4^+ and very little NO_3^-. Most of the N brought down in precipitation collected in the open was in the organic form and was attributed to locally generated airborne organic debris, including pollen (Tarrant et al.[3])

For all forms of N determined, the order of magnitude of concentration in relation to kind of precipitation was: stemflow > throughfall > gross rainfall. Concentrations of total N in throughfall and stemflow were increased about 3 to 14 times over that of gross rainfall. In most instances, more than 80 percent of the total N was in organic form. Concentration of NO_3^- in stemflow from conifer trees, both in the pure conifer stand and in the mixed stand, was much greater than in any other precipitation-forest type combinations observed. This finding suggests that rough conifer bark may harbor large numbers of nitrifying bacteria that could aid in altering organic N to more readily available forms.

Although we found no measurable NH_4^+ in gross rainfall, this ion was present in varying amounts in throughfall and stemflow. The concentration of NH_4^+ in alder throughfall was twice that in the conifer or mixed stands. In alder stemflow, NH_4^+ concentration was slightly greater than in the conifer type and 50 percent greater than in the mixed stand. These findings may indicate that alder in some way encourages development of ammonifying bacteria in the phyllosphere and on the tree stem.

Organic N concentration was greatly increased in all stands over that of gross rainfall. As with the other forms of N, concentration of organic N in stemflow was greater than that of throughfall.

[3] Tarrant, R. F., Lu, K.C., Chen, C.S., and Bollen, W. B. Nitrogen content of precipitation in a coastal Oregon forest opening. Tellus. (In press.)

TABLE 1. — *Yearly N concentration by type of precipitation and forest cover — weighted average of three observations over nine sampling periods, Cascade Head, Oregon*

Precipitation and forest cover type	Yearly precipitation	NO_3^-	NH_4^+	Organic	Total
	Million liters per acre	Milligram per liter			
Gross precipitation	11.66	0.01	0	0.04	0.05
Throughfall (net):[1]					
Alder	10.33	.02	.02	.22	.26
Conifer	8.18	.01	.01	.14	.16
Mixed	9.11	.02	.01	.23	.26
Stemflow (net):[1]					
Alder	.01	.04	.06	.59	.69
Conifer	.06	.13	.05	.18	.36
Mixed	.05	.15	.04	.38	.57

[1] All values for throughfall and stemflow expressed as net after deducting amount of N in gross precipitation.

Compared with gross rainfall, total N (pounds per acre per year) in throughfall was nearly five times greater beneath alder; almost four times more beneath the alder-conifer stand; and about three times greater under conifers (table 2). Although the effect of stemflow on N concentration was substantial (table 1), the net effect on a weight-per-area basis was minor (table 2) because of the relatively small amount of stemflow per acre as was pointed out also by Carlisle, Brown, and White (1967).

TABLE 2. — *Precipitation and litterfall compared as sources of total nitrogen in three forest types of coastal Oregon*

Nitrogen source	Total N		
	Alder	Mixed	Conifer
	----Pounds per acre per year---		
1. Throughfall (net)[1]	5.88	5.18	3 44
2. Stemflow (net)	.02	.08	.04
3. (1) + (2)	5.90	5.26	3.48
4. Less N in conifer precipitation	2.42	1.78	0
5. Litterfall[2]	100.30	103.69	31.95
6. Less N in conifer litterfall	68.35	71.74	0
7. N accretion from alder (4) + (6)	70.77	73.52	0

[1] Throughfall and stemflow expressed as net after deducting 1.22 pounds per acre per year N input in gross precipitation.

[2] Tarrant, R. F., Lu., K. C., Bollen, W. B., and Franklin, J. F. Nitrogen enrichment of two forest ecosystems by red alder (*Alnus rubra*).(Unpublished data on file at Forestry Sciences Laboratory, Pacific Northwest Forest & Range Experiment Station, Corvallis, Oreg.)

Gross rainfall at this coastal Oregon location (113 inches during the year sampled) does not provide any significant accretion of N to the nutrient capital of the ecosystem (Tarrant et al.[4]), nor, probably, does the enriched throughfall and stemflow beneath the conifer stand. We deducted the N content of throughfall and stemflow from that for both the alder and mixed stands to obtain a conservative estimate of the N that might be regarded as an addition to nutrient capital through symbiotic fixation of atmospheric N by red alder. On this net basis, N accretions of about 2.4 pounds per acre beneath alder and 1.8 pounds per acre beneath the alder-conifer stand may be attributed to the function of red alder as a nitrogen-fixing woody plant (table 2).

Nitrogen increases to nutrient capital of the ecosystem from precipitation, however, are minor compared with the annual deposition of N in litterfall of red alder and the mixed stand (table 2). For a site of lower productivity than that we observed, Rahman[5] found, over a 9-month period, that, of the total return of N from litterfall and from precipitation passing through the forest canopy, about 78 percent was contained in litterfall beneath Douglas-fir and 86 percent in that beneath red alder. Thus, the role of precipitation in the cycling of N apparently is not great in coastal Pacific Northwest forests, a finding supported also by the work of Cole, Gessel, and Dice (1967) in Washington State.

[4] See footnote 3.

[5] See footnote 2.

Total Dissolved Solids

As with N, total dissolved solids concentration was substantially greater in precipitation influenced by forest cover than in gross rainfall (table 3). On a net-weight-per-area basis, additions of dissolved solids in throughfall were substantial but stemflow contributions were negligible.

TABLE 3. — *Yearly dissolved solids concentration and weight by type of precipitation and forest cover: weighted average of three observations over nine sampling periods, Cascade Head, Oregon*

Precipitation and forest cover type	Yearly precipitation	Dissolved solids	
		Concentration	Total weight
	Million liters per acre	Milligram per liter	Pounds per acre
Gross rainfall:			
Open	11.66	0.15	385
Throughfall (net):[1]			
Alder	10.33	.31	705
Conifer	8.18	.19	342
Mixed	9.11	.34	682
Stemflow (net):[1]			
Alder	.01	.47	1
Conifer	.06	.80	11
Mixed	.05	.85	10

[1] Net = gross throughfall and stemflow less gross rainfall.

"Total dissolved solids" includes a number of ions as well as some dust that fell during dry periods or was washed from the air during rainstorms. Some measure of the constituents of total dissolved solids is available in the findings of Moodie (1964) who sampled nutrient inputs in precipitation at Long Beach on the Washington coast about 100 miles north of our study area. Here, where precipitation for the years 1962-65 averaged about 77 inches per year (in contrast to 113 inches at Cascade Head), average total weight of dissolved constituents of gross rainfall for the 4-year period was 207 pounds per acre per year.[6] Of this total, 82 percent was represented in three forms: Cl, 41 percent; Na, 23 percent; and dustfall, 18 percent.

For the 384 pounds per acre per year of dissolved solids we measured in gross precipitation, Moodie's (1964) data would indicate possible rainfall inputs of nutrient elements (pounds per acre per year) in coastal Oregon forests to be: P, 1.5; K, 6.1; Ca, 8.1; and Mg, 10.4. Phosphorus is apparently adequate for good tree growth in soils beneath the three stands. and K is very high (Franklin et al. 1968). Base content of these soils, however, is low, especially beneath alder. Most of the difference in base status between soils of the three stands is found in amounts of exchangeable Ca and Mg.

Rahman[7] found that at least two-thirds of the K returned to the soil and half the P and Mg was brought down in throughfall and stemflow. On the basis of our present information, we believe that future studies of alteration of ionic content of precipitation by stemflow and throughfall in coastal Oregon forests should be concentrated on the cycling of exchangeable bases.

Acidity of Precipitation

Average yearly pH level of throughfall was not different from that of gross rainfall (table 4), although throughfall variation was greater than that of gross rainfall. Stemflow was always more acid than gross rainfall. Alder stemflow was only slightly less so (pH 5.8 vs. 6.1), but in the mixed and conifer stands, stemflow pH was 0.8 and 1.0 unit lower, respectively, than gross rainfall.

The throughfall process involves a relatively short duration of contact between rainfall and smooth-surfaced needles or leaves. In contrast, stemflow is affected especially by rough, corky conifer bark which provides greater opportunity than smooth-barked alder for water retention and organic matter decomposition which yields acid residues. The ecological significance of stemflow pH being less than that in throughfall or gross rainfall is probably not great, since stemflow affects only a small area about the base of the tree (Voigt 1960a). No difference in pH was found in either the F layer or A11 soil horizon within 2 feet of the base of an alder tree compared with samples taken further from the stem (Bollen et al. 1968).

TABLE 4. — *Acidity of precipitation (pH) collected in open and beneath three forest types — yearly average of three observations in each forest cover type*

Precipitation and forest cover type	Yearly range	Yearly average
Gross rainfall:		
Open	5.7 — 6.3	6.1 (±.02)
Throughfall:		
Alder	5.6 — 6.6	6.0 (±.04)
Conifer	5.9 — 6.8	6.1 (±.03)
Mixed	5.7 — 6.7	6.1 (±.04)
Stemflow:		
Alder	4.8 — 6.4	5.8 (±.11)
Conifer	4.7 — 5.7	5.0 (±.08)
Mixed	3.8 — 6.0	5.3 (±.20)

[6] Unpublished data for 1964-65 were kindly supplied by C. D. Moodie, Washington State University.

[7] See footnote 2.

CONCLUSIONS

The role of precipitation in N-cycling in three coastal Oregon forest types appears to be minor in comparison with the much greater amounts of N cycled in litterfall. Concentration of NO_3^- was much greater in stemflow from conifers than in other precipitation-forest type combinations, and that of NH_4^+ was substantially greater in alder stemflow and throughfall. These observations indicate the need for more information on microbial populations on leaf and needle surfaces and on tree stems to elucidate possible differences between tree species in numbers of nitrifying and ammonifying bacteria.

Substantial differences between forest types in amount of dissolved solids in precipitation indicate that other nutrient elements might be more important subjects of investigation than N. The role of different tree species in influencing throughfall and stemflow content of exchangeable bases, especially, appears to require further investigation. Other factors that appear to require study include metabolites such as carbohydrates, amino acids, and organic acids in general.

Despite the generally greater content of nutrient ions in stemflow than in throughfall, stemflow appears to be of little importance in nutrient cycling by precipitation because of the small volume of stemflow on an area basis. In future studies of ionic content of precipitation in coastal Oregon forests, sampling effort might better be concentrated on throughfall. Likewise, determination of NO_2^--N is not necessary because of its extremely rare occurrence in measurable amounts.

Acidity of throughfall precipitation was not different from that of open-collected rainfall. Stemflow was always more acid than the other two forms of precipitation, but the ecological significance of this difference is not believed to be great.

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Throughfall and stemflow were collected beneath three adjacent forest types — red alder; conifer — Douglas-fir, western hemlock, and Sitka spruce; and a mixture of alder and conifer. Weight of N and dissolved solids in stemflow was insignificant because of small amounts of stemflow and soil area affected. Nutrient cycling rates differ appreciably between the three forest types.

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