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Effect of stemflow precipitation on chemical and microbiological soil properties beneath a single alder tree[1]

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Abstract

Stemflow from a red alder tree had a substantially greater concentration of nitrogen and dissolved solids and slightly lower pH than gross rainfall. On a weight/area basis, however, the contribution of nutrient ions in stemflow was very small compared to that in gross rainfall or throughfall. No evidence was found to indicate that enriched stemflow affected chemical and microbial properties of soil at a distance of only 2 feet from the stem. Results of this study support previous demonstration of a narrow absorption area about the tree stem as the total soil area affected by stemflow.

The volume of stemflow[2] is of little importance hydrologically, being less than 1 percent of total rainfall in mature stands of Douglas-fir (*Pseudotsuga menziesii*) (Rothacher, 1963), or western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*) (Patric, 1966). On the other hand, Voigt (1960a) showed that stemflow is released to the soil in a narrow band about the tree stem. On the basis of this "absorption area," Voigt estimated that the soil surface within a radius of about 1 foot from the stem of a beech (*Fagus silvatica*) tree received about 2.5 times the amount of water falling on an equal area in the open. In hardwood stands of northeastern United States, Leonard (1961) found, on the basis of Voigt's "absorption area," that stemflow amounting to seven times the depth of gross rainfall was concentrated close to the base of the tree.

Other investigations (Voigt, 1960b; Sviridova, 1960; Mina, 1965; Maruyama et al., 1965) have indicated that stemflow is substantially richer in nutrient ions, including ammonium (NH_4^+-N) and nitrate-nitrogen

[1] *This study was supported, in part, by the National Science Foundation, Grant No. G-21015.*

[2] *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).*

(NO_3^--N), than gross rainfall. Some effect of chemically enriched stemflow might also be involved in findings of Zinke (1962) that the pattern of physical and chemical properties under an individual forest tree is generally developed with radial symmetry to the tree, varying with distance from the stem.

The possibility of stemflow exerting a localized influence on soil properties was of special interest to us in connection with studies of airborne pollutants, rhizosphere microflora, and nitrogen cycling. If chemicals moved by precipitation are concentrated in significant amount near the tree stem, as a synthesis of research findings on stemflow might indicate, sampling techniques and study design would be importantly affected. With these considerations in mind, and as part of a larger study of atmospheric chemistry and localized precipitation enrichment by forest stands, we undertook the study herein described. Our objective was to improve our understanding of the contribution to soil fertility by stemflow and the relationship of some chemical and microbial soil properties to distance from a single red alder *(alnus rubra)* tree.

We asked in this study:

1. Is stemflow from a red alder tree different in chemical composition from gross rainfall?
2. Is any difference between chemical composition of stemflow and that of gross rainfall ecologically significant in the case of a 40-year-old alder tree?
3. Does the pattern of variation in chemical and microbial soil properties appear to be related to stemflow effect?

What We Did

A single, relatively isolated red alder tree, 9.9 inches d.b.h. and about 40 years old, was selected for study on an experimental plot at Cascade Head Experimental Forest on the Oregon coast. Gross rainfall, which averages 90 inches/year at the study site, was sampled from June 1963 through May 1964 in an open area adjacent to the alder stand, and stemflow and throughfall were measured beneath the study tree. A polyethylene container was located midway between the tree stem and outer edge of the canopy to collect throughfall. Three polyethylene funnels, having a total area of 1 ft^2, were inserted through the lid of the 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 ml of toluene were added to the container to inhibit microbial action. The tree was fitted with a lead trough which conducted stemflow through Tygon tubing into a polyethylene container protected against contamination in the same manner as the throughfall collector. In June 1964, 1 ft^2 samples of the F layer and All soil horizon were taken at 2,4, and 6 ft from the tree in each cardinal direction.

Stemflow and throughfall samples were filtered through Whatman No. 5 paper, then analyzed for nitrite nitrogen (NO_2^--N) by the method of the American Public Health Association (1955); NO_3^--N by the phenoldisulfonic

method (Harper, 1924); free and replaceable ammonium (NH_4^+-N) by the method of Nichols and Foote (1931); organic nitrogen by a semimicro modification of the Kjeldahl procedure; and pH by the glass electrode. Total dissolved solids (TDS) were determined by evaporating a 100-ml aliquot of water on a steam bath, drying in a desiccator, then weighing.

Microbial and chemical analyses of -2 mm samples of F layer and All horizon were carried out within 3 days after sampling. After air-drying, part of each sample was further ground to -0.02 mm size for Kjeldahl nitrogen determinations. All chemical analyses were made in duplicate, and microbial determinations in triplicate.

Fifty-gram, ovendry portions of -2 mm samples of the F layer and All horizon samples were made up to 1:5 suspensions by adding distilled water and mechanically shaking for 10 minutes. After coarse particles had settled, pH was measured with a glass electrode. The soil suspension was then treated with cupric acetate and calcium hydroxide to obtain a clear filtrate. Excess calcium hydroxide was removed with ammonium carbonate and the filtrate was analyzed for NO_2^--N using 1-naphthylamine, sulfanilic acid and sodium acetate buffer (American Public Health Association, 1955), and for NO_3^--N by the phenoldisulfonic acid method (Harper, 1924).

Ammonium nitrogen was determined by distilling 10.00-gm samples, ovendry basis, with phosphate buffer solution at pH 7.4. One hundred ml of distillate were collected in 30-ml saturated boric acid solution and titrated with N/14 sulfuric acid, using methyl red-bromcresol green mixed indicator (Nichols and Foote, 1931). Kjeldahl nitrogen was determined by a modified AOAC method (Association of Official Agricultural Chemists, 1960); Hibbard's mixture and a selenized granule were used in the digestion; and steam distillation was employed to drive the ammonia into receivers containing saturated boric acid solution. Titration was then made with N/14 H_2SO_4, using methyl red-bromcresol green as indicator.

Microbial analyses were made by pouring triplicate plates of appropriate dilutions of sieved fresh soil with peptone glucose agar acidified to pH 4.0 for molds, and with sodium albuminate agar for bacteria and *Streptomyces* (Waksman and Fred, 1922). Incubation was at 28 C. Counts were made after 3 days for molds and after 15 days for bacteria and *Streptomyces.*

All data are expressed on the basis of ovendry soil.

What We Learned

Chemical Composition of Precipitation

Total N concentration in stemflow (Table 1) was nearly 11 times greater than that in gross rainfall. Nitrite nitrogen, a very minor component of total N, was little changed by stemflow. Nitrate N concentration was increased in stemflow about 2½ times over that of gross rainfall; that of organic N was increased more than 12 times; and NH_4^+-N concentration was increased from zero in gross rainfall to 0.12 mg/liter in stemflow.

Concentrations of NO_3^--, organic-, and total N in stemflow were about twice those in throughfall. Ammonium N was increased from zero in gross rainfall to 0.08 mg/liter in throughfall, but this concentration was only

TABLE 1. Nitrogen concentration in precipitation; mean yearly values in mg/liter, Cascade Head Experimental Forest, June 1963 through May 1964

Sample source	Nitrogen				
	NO_2^-	NO_3^-	NH_4^+	Organic	Total
Gross rainfall	<0.01	0.02	0.00	0.08	0.10
Throughfall	.01	.04	.08	.48	.53
Stemflow	.01	.09	.12	.97	1.07

two-thirds that found in stemflow. Concentration of NO_2^--N was not different between stemflow and throughfall.

The effect of stemflow on N concentration in precipitation was substantial, but the effect of such enrichment on amount of N per acre was small (Table 2). As pounds per acre per year, N in throughfall was about four times greater than that in gross rainfall, but the amount of N in stemflow was negligible because of the small area (0.05 acre) affected.

Net concentration of total dissolved solids (TDS) in stemflow (Table 3) was more than four times that in gross rainfall. In throughfall, TDS concentration was twice that in gross rainfall. On a net pounds-per-acre-per-year basis, however, throughfall contained about one-third more TDS than gross rainfall, and stemflow contained less than 1 percent of the TDS load found in open-collected precipitation.

TABLE 2. Total nitrogen in 1 year's precipitation, Cascade Head Experimental Forest, June 1963 through May 1964

Sample source	Area affected	[1] Total N per ft^2	Total N
	Ft^2	*Mg*	*Lb/acre*
Gross rainfall	43,560	13.84	1.33
Throughfall outside absorption area[2]	41,480	56.17	5.13
Throughfall onto absorption area	2,080	56.17	.26
Stemflow	2,080	5.46	.03
Total			6.75

[1] *All values are net, after deduction for N in gross rainfall.*

[2] *Radius of absorption area (Voigt 1960a) = 16.4 inches (12 inches plus 4.4-inch radius of average tree).*

Absorption area (ft^2/acre) = 2,080 (5.87 ft^2/tree – 0.41 ft^2 basal area of average tree X 381 trees/acre).

TABLE 3. Total dissolved solids (TDS) in 1 year's precipitation, Cascade Head Experimental Forest, June 1963 through May 1964

Sample source	Area affected	TDS concentration	[1] TDS per ft^2	TDS per acre
	Ft^2	*Mg/liter*	*Mg*	*Lbs*
Gross rainfall	43,560	17	4,190	402
Throughfall outside absorption area[2]	41,480	34	5,635	515
Throughfall onto absorption area	2,080	34	5,635	26
Stemflow	2,080	72	453	2
Total				945

[1] *All values are net, after deduction for TDS in gross rainfall.*

[2] *Radius of absorption area (Voigt 1960a) = 16.4 inches (12 inches plus 4.4-inch radius of average tree).*
Absorption area (ft^2/acre) = 2,080 (5.87 ft^2/ tree–0.41 ft^2 basal area of average tree X 381 trees/acre).

"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. We did not determine ionic content of the various forms of precipitation other than that of nitrogenous components, but Moodie (1964) provided some measure of TDS composition when he sampled nutrient inputs in precipitation on the Washington coast about 100 miles north of our study area. There, where precipitation for 1962-65 averaged about 78 inches (in contrast to 113 inches at our study site), average TDS weight for the 4-year period was 208 lbs/acre.[3] Three forms accounted for 82 percent of this total: chlorine, 41 percent; sodium, 23 percent; and dustfall, 18 percent.

Acidity varied little between the three types of precipitation we collected. Gross rainfall and throughfall had essentially the same pH–6.1 and 6.0, respectively. Stemflow pH was slightly lower, 5.6, which is probably due to organic acids washed from the many bark crevices in the tree stem.

Chemical and Microbial Properties of Soil

No trend is evident in chemical and microbial data for F layer and All horizon samples (Table 4) that would indicate stemflow strongly influences soil even 2 ft from the tree. Nitrite-N and pH were essentially alike at all three distances sampled. Small variations in NH_4^+- and organic N do not indicate any relationship with distance from the tree. Only values for NO_3^--N, molds, and *Streptomyces* in the F layer were higher at 2 ft than at 4 or 6 ft from the tree, and these differences were small. All characteristics measured in the All horizon 2 ft from the tree were either no different or less than those measured at one or both of the other two distances sampled.

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

TABLE 4. Chemical and microbiological soil properties in relation to distance of sample from a red alder tree mean values; Cascade Head Experimental Forest

Distance from tree (feet)	Soil reaction	Nitrogen				Molds	Bacteria	Streptomyces
		NH_4^+	NO_2^-	NO_3^-	Organic			
	pH	*Ppm*	*Ppm*	*Ppm*	*Percent*	*X* 10^{-3}	*X* 10^{-6}	*Percent of total bacteria*
				F layer				
2	4.0	27	3	91	1.18	442	8	17
4	4.1	25	2	69	1.08	399	9	10
6	4.1	31	2	63	1.34	353	18	13
				All horizon				
2	4.3	20	2	43	.76	128	5	6
4	4.3	23	2	36	.73	135	5	6
6	4.3	28	2	50	.84	145	5	20

Conclusions

The first question posed in this study was: "Is stemflow from a red alder tree different in chemical composition from gross rainfall?" We believe, from this small study, that it is. Stemflow collected from a single alder had a substantially greater concentration of nitrogen and total dissolved solids and slightly lower pH than gross rainfall. This finding agrees with a number of published data although none dealt specifically with red alder.

Our second question was: "Is any difference between chemical composition of stemflow and that of gross rainfall ecologically significant in the case of a 40-year-old red alder tree?" We found that when stemflow data for nitrogen and total dissolved solids were projected to a weight/area basis, the contribution of nutrient ions was very small compared to those from gross rainfall or throughfall. Further, we do not believe the small reduction in pH of stemflow over that of gross rainfall (5.6 vs. 6.1) has any significance, even within the small absorption area (Table 4).

Our answer to the third question: "Does the pattern of variation in chemical and microbial soil properties appear to be related to stemflow effect?" is "Probably not." We found no evidence that the levels of some important chemical and microbial soil properties were associated with distance up to 6 ft from a tree stem. Results of this part of the study convince us that Voigt's (1960a) demonstration of a narrow absorption area about the tree stem is valid as an estimate of the total soil area affected by enriched stemflow.

Findings from this study have several practical applications. Rothacher (1963) and Patric (1966) have shown the volume of stemflow from western conifers to be of little hydrological significance. We would add that ions circulated in red alder stemflow are probably of little importance in substantially enriching the nutrient capital.

In future studies of the influence of red alder stands on chemical composition of precipitation, we would probably omit stemflow measurements. Stemflow is difficult to measure and is subject to various interpretations, according to the areal basis selected by the observer on which to calculate amounts. Sampling effort might better be spent in more thoroughly measuring and evaluating the much greater amounts of nutrient ions added by chemical alteration of gross rainfall in the throughfall process.

In future studies involving soil sampling in red alder stands, we would avoid taking samples from the narrow stemflow absorption area at the base of the tree. Outside this area, we would continue to rely on random sampling without concern about distance of the sample from an individual tree.

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