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Nutrient and particulate matter balances were established for five ecosystems dominated by Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco] in the western Cascades, Oregon. Carriers of N and P were particulate matter (dust in precipitation and sediment in streams) and dissolved matter in both precipitation and stream water. The input and outflow of these materials (particulates, N and P) are interpreted in relation to atmospheric and forest ecosystem processes. Drainage basin sites are FC-2 (north), HJA-7, 9 and 10 (central), and CC-4 (south). Climate at all sites is maritime with cool-wet falls, winters, and springs and warm-dry summers. Soils, from igneous parent materials (Tuff, andesite, basalt), are porous, deep and of loam to silty clay texture. The basins are steep (12-70% slope) and completely covered by natural forest vegetation.

varied by a factor of 2 or 3 over the range of runoff among the sites. The N outflow is explained by environmental factors, chemical composition of forest litter and the flushing efficiency of the annual runoff. Organic P may be controlled by litter quality, but ortho-P outflow was greatest where parent materials were dominantly tuff and declined according to the increasing proportions of less easily weathered basalt andesite.

Dust depositions were 14.3% of suspended sediment (SS) outflows, but varied according to the geologic erosion rate among sites. At FC-2, dust deposition exceeded SS by 177%, but deposition was only 5.0% of SS at CC-4. Dust deposition was an important source of soil material and partly offset geologic erosion. Mean N inputs, 1.6-3.2 times the outflows, were considered important in relation to known inputs by symbiotic fixation. Mean P inputs were 51% of outflows, but were considered relatively unimportant because of the abundant supply in igneous bedrock.

Nitrogen, Phosphorus and Particulate Matter Budgets of Five Coniferous Forest Ecosystems in the Western Cascades Range, Oregon

by

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TABLE OF CONTENTS

LIST OF FIGURES

NITROGEN, PHOSPHORUS AND PARTICULATE MATTER BUDGETS OF FIVE CONIFEROUS FOREST ECOSYSTEMS IN THE WESTERN CASCADE RANGE, OREGON

INTRODUCTION

The conservation of nutrients and soil is essential for the continued maintenance of the productivity of forest ecosystems. The present status of these materials in natural forests is the net result of accumulation during periods of stable forest cover and loss by 1) leaching, 2) natural geologic erosion by creep, high velocity landslides, bank erosion, and 3) volatilization of nitrogen by fire.

Processes of soil formation and accumulation of nutrient capital during Pleistocene and Recent times have contributed to the present soil and nutrient capital of these forest ecosystems. Now that these natural ecosystems are being managed for timber production, it is necessary that we understand more clearly the relationship between processes of accumulation and loss that determine the supply of essential materials.

Studies are currently in progress on five forest ecosystems in the coniferous forests of western Oregon. This thesis will summarize current knowledge concerning these undisturbed natural ecosystems.

Soil depth and the levels of soil N and P are known to influence the productivity of these conifer forests, and losses of these materials

REVIEW OF LITERATURE

The evolution of soil-plant ecosystems probably begins with major episodes of geological revolution from volcanism, uplift, and glaciation. The relationships between processes of landscape evolution including removal in solution following mineral weathering, removal of the products of weathering by erosion, retention of the products of erosion and formation of soil as influenced by climate and vegetation, periodic tectonic disturbances causing changes in base level, and addition of fresh minerals by ash falls have been debated for nearly a century (Davis, 1899; Clements, 1905; Penck, 1953; Hack, 1960). But it is well understood that C, N, S, and O are supplied from the atmosphere by biological fixation or in precipitation and that the cations and P are released from soil parent materials by mineral weathering.

The retention of soil and essential nutrients is a property of biological systems necessary for their survival. In the western Cascades of Oregon, the capital of these essential materials has undergone wide fluctuations in the last 100,000 years due to the effects of glaciation, climatic change and destruction of the forest by wildfire. Swanson and James (1975) have described erosion processes and landform development at the H. J. Andrews Experimental Forest in the western Cascades since glaciation prior sized particles from electrostatic discharge. From 2.4 to 5.3 kg/ha of NH_4-N and 0.02 - 0.07 kg/ha of P were deposited by impaction in fog drip on the northern coast of California during 15 days in the summer (Azevedo and Morgan, 1974).

Measurements of N and P in precipitation at Vancouver (Moodie, 1964), the Cedar River Watershed in Washington (Cole et al., 1967) and the Cascade Head Experimental Forest in Oregon (Tarrant et al., 1968) are summarized below.

	Year	NH_4-N	NO_3-N	Org. N	All N	ortho-P
				- kg/ha -		
Moodie	1962	1.47	0.29	Not	1.76	0.019
Moodie	1963	1.33	0.24	measured	1.57	0.060
Cole	--	--	--	"	1.1	trace
Tarrant	1963-64	trace	0.19	1.30	1.49	--

Biological fixation of N occurs at all stages of stand development in Douglas-fir. Ceanothus velutinus seed germinate following wildfire that destroyed Douglas-fir forests before modern fire protection measures were adopted. Youngberg and Wollum (1975) report 1030 kg/ha of N accretion in soil, litter and Ceanothus biomass ten years after clearcutting and burning of logging residues at a site near the Andrews Experimental Forest.

Older age classes of Douglas-fir exhibit a conspicuous epiphyte flora in the upper canopy. Pike et al. (1972) measured 18.3 kg of epiphytes

The production of soluble nutrients from organic matter occurs in all strata of the forest. In the canopy, needle parasitism before abcission, excretions by canopy grazers, decomposition of lodged litter, diffusion of ions through the cuticle of foliage, and the solution of impacted nutrients are known sources for nutrients and DOM in canopy drip and stemflow. Cole et al. (1967) reported 1.7 and 0.4 kg/ha of N and P respectively in annual canopy drip and stemflow and leaching losses were 0.6 and 0.02 kg/ha of N and P from below the root zone; the losses of N and P were 35 and 5% respectively of returns in canopy drip and stemflow. Decomposition of forest floor materials contributed an additional 3.1 and 0.55 kg/ha of N and P to the soluble flux of nutrients entering the rooting zone. Leaching losses based on soluble N and P from both sources were 3.6 and 3.3% respectively and attest to the retention efficiency of Douglas-fir ecosystems for these nutrients. Similar data for HJA-10 have shown outflows of dissolved N and P in streamflow (0.38 and 0.52 kg/ha respectively) to be 19 and 21% of amounts in canopy drip (2.0 and 2.5 kg/ha respectively) (Grier et al., 1974).

Data comparable to that developed at the Cedar River Watershed by Cole and associates for N and P contributed to soil solution from stemflow and litter decomposition will soon be available for HJA-10. Differences in production and outflow of soluble N and P for these two sites can be expected because of vast differences in biomass, for the difference in TP loss. The above figures did not include N and P in particulate matter.

Precipitation is the driving force for the soil erosion which occurs incrementally year by year from streambanks and periodically by landslide erosion when severe stresses are generated in the soil mantle. Precipitation is deposited by long duration, low intensity storms that come from the Pacific Ocean. Shear stresses in the mantle are often further intensified by rapid snow melting thought to be caused by the condensation of water vapor on snow surfaces during these Pacific storms. One such event which covered most of the Northwest USA in 1964 caused soil erosion at a rate of 32 m^3/ha from undisturbed areas of the H. J. Andrews Experimental Forest (Dyrness, 1967). These catastrophic events have caused extensive flooding in western Oregon at intervals of 17 years since 1861, but erosion from more localized events is noted more frequently (Fredriksen, 1965). At the Andrews Experimental Forest, they have occurred at intervals of three to four years. Helley and LaMarche (1973) found abundant evidence of flooding equal to the 1964 flood in northwestern California from radiocarbon dating and tree ring chronology of terrace remnants of these floods. Evidence was found for a much larger flood about 1600 A. D.

Streambank erosion is undoubtedly the predominant source of suspended sediment in streams of undisturbed forests of the western

METHODOLOGY

Study Watersheds

The drainage basins in this study are located in two major forested regions of the Western Cascade province in Oregon described by Franklin and Dyrness (1973). The Tsuga heterophylla Zone (Fig. 1) covers the northern two-thirds of the province. This zone was originally covered by old growth Douglas-fir forests and derives its name from western hemlock (Tsuga heterophylla)--a shade tolerant tree that grows in the secondary tree layer of these stands and eventually replaces them in the absence of wildfire. The Abies amabilis zone occupies cooler and higher elevation sites dominated by Douglas-fir and Pacific silver fir (Abies amabilis). Winter snow packs often remain on these sites from December through April. Mixed forests of Douglas-fir, sugar pine (Pinus lambertiana), ponderosa pine (Pinus ponderosa), incense cedar (Libocedrus decurrens) and white or grand fir (Abies concolor or grandis) in the Mixed Conifer Zone are typical of the warmer and drier sites in the southern portion of the Western Cascades province.

Measurements of temperature and moisture stress of forest associations were taken on reference stands on or adjacent to the drainage basin sites.

Bull Run Watershed

Fox Creek, the northernmost site, is tributary to the Bull Run River. The Bull Run River, the water supply stream for Portland, Oregon, is 35 km west of Fox Creek (Table 1). This linear and gently sloping basin is only slightly incised in a broad crested, west-tending ridge composed of basalt and andesite of Pliocene age (Beaulieu, 1974). A shallow lake covering about 7 ha contains water during the winter months.

Soils are developed in coarse textured colluvium and till from glaciation that probably occurred during mid-Wisconsin times about 125,000 years b. p. Two soil series, the Damsite, a Typic Haplumbrept, and Sisi, a Typic Haplorthod, were mapped in the basin as stony or gravely loams (Stevens et al., 1966). Occasional rock outcrops and rubble land break the continuity of the overmature stand of 500-year-old Douglas-fir and western hemlock.

Pacific silver fir (Abies amabilis) is present on the more cool and moist portions of the basin. Dyrness[3] described a mosaic of two-plant associations depending on the presence of a huckleberry (Vaccinium alaskense) shrub layer or a well developed herb layer of Cornus canadensis or Oxalis oregona). These associations are

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[3] File report, Forestry Sciences Laboratory, Corvallis, Oregon.

Abies amabilis/Vaccinium alaskense and Abies amabilis/Oxalis oregona (Franklin, 1966).

Fox Creek-2 (FC-2) is a cool-moist site that receives much of its precipitation as snow (Table 2). Although the temperature environment may not be optimum for timber production, the moistness of the site from late melting snow and moderate amounts of summer rain, together with fog-drip, may account for the large standing volume (650-700 m^3/ha) observed on this site.[4]

H. J. Andrews Experimental Forest

The H. J. Andrews Experimental Forest is a 6,100 ha area about 190 km south of Fox Creek and centrally located within the Western Cascades province (Fig. 1). Old growth Douglas-fir, approximately 450 years old, covers roughly 60% of the area below 1,220 m elevation. The climate at the H. J. Andrews differs markedly from the Fox Creek site. Precipitation is somewhat lower, but the growing season is 20 to 100 days longer depending on elevation (Table 2). The combination of a longer growing season, lower summer precipitation and warmer air temperature explain the larger moisture stress observed on the reference stands at the H. J. Andrews.

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[4] From records of the Columbia Gorge District, Mount Hood National Forest, Troutdale, Oregon.

Two elevation zones are included in the study. Two small basins, HJA-9 and HJA-10, comprise one set at low elevation (435-725 m). These basins are deeply incised in bedrock of the Little Butte series consisting of andesitic and dactitic tuff (Peck et al., 1964). Two soil series were described on the Little Butte series by Stephens (1964). The Frissel series, a Typic Dystrochrept, is a stony, loamy textured soil, commonly noted on the steep side slopes and head walls. The McKenzie River series, a Typic Haploxerult, is deeper, finer textured, and generally less stony than the Frissel series. The McKenzie River soil occupies ridge top and gentle side slopes off of these ridges comprising less than 10% of the area in HJA-10 and probably less than 2% of the area of HJA-9. Soils are less than 1 m deep and often overlie porous saprolite to maximum depths of 6 m below the soil surface in HJA-10; saprolite probably does not exceed 3 m depth in HJA-9. Both soils have a particularly high erosion potential due to steepness of slope. The present low erosion rate observed for these sites is in large part due to the protection and strength given the porous mantle by the forest and the roots of the forest vegetation. The erosion rate was observed to increase 3.3 times above the natural rate following clearcutting of an entire drainage basin adjacent to HJA-9 (Fredriksen, 1970).

Douglas-fir dominates the tree layer on both HJA-9 and 10. Western hemlock forms a secondary canopy layer on moist, lower shorter than the lower elevation watersheds, HJA-9 and 10, by 60 to 100 days (Table 2). Although the temperature environment is less than optimum for growth, moisture stress is much lower than the low elevation sites and probably at least partially compensates for the effect of the cooler and shorter growing season on stand growth.

Parent materials of soils in HJA-6, 7 and 8 are tuff and hypersthene andesite flows of the Sardine Formation (Peck _et_ _al_., 1964). Four soil series described by Stephens (1964) were mapped by Dyrness and Hawk (1972). The Carpenter series, from deep andesitic landslide material, occupies nearly three quarters of the area. The Tidbits and Blue River series, higher on the ridge and developed in andesite residuum, each cover about 10% of the area. The stone content of these soils ranges from 5 to 30% volume. The texture of all three soils ranges from gravelly sandy loam to loam. The Budworm series, developed in tuff, is finer textured--ranging from silt loam to clay loam. The Carpenter and Budworm are deep; 2 to 3 m of porous, unstructured, clayey subsoil may exist between the developed profile and the bedrock. The Tidbits and Budworm, although more shallow, generally have a rooting depth greater than 1 meter All soils are Typic Haplorthods with the exception of the Tidbits which is an Andic Cryumbrept. All soils are stable on 20 to 30% slopes. A steep 4 to 5 ha area on the headwall of HJA-8, although presently stable with forest vegetation, undoubtedly has a higher erosion potential.

The environment for timber growth is comparable to HJA-6, 7 and 8 in terms of optimum temperature days, night moisture stress and length of growing season, but the annual precipitation is about 100 cm less and the summer precipitation half of that at HJA-6, 7 and 8 (Table 2).

Soil parent materials are weathered from massive deposits of dactitic and rhyodactic tuff belonging to the Little Butte Series (Peck _et al._, 1964). They are similar to parent materials at HJA-9 and 10. These tuffs and breccias in the South Umpqua drainage are intercalated with lenses of basalt. These layers have been extensively faulted and subjected to metamorphism. Four soils were mapped in CC-4 on basalt and tuff breccia (Richlen, 1973). Two soil series differentiated on tuff-breccia are the Dumont, classified as a Typic Haploxerult, and the Strait--a Dystric Xerochrept. The two series mapped on basalt are Freezener, an Ultic Haploxeralf and Coyata, a Typic Xerumbrept.

The Coyata is a shallow, droughty soil occupying ridge top and upper slope positions in CC-4. Only small areas of Freezener occur on broad crested ridges. The Strait and Dumont are observed most frequently in the basin. The Dumont is a clayey soil that probably reaches depths of 3 to 4 m on toe slope positions. A high natural geologic erosion rate of the Dumont series in this basin is maintained by rapid mantle creep. The Strait is a shallow soil on measurements of soil and air were taken to characterize habitats and the N outflow behavior of the sites.

Routine servicing of instruments and sample collection at stream gaging stations, stream and precipitation samplers, and thermographs at all sites were normally performed at intervals of 3 weeks; more frequent visits were occasionally necessary owing to equipment failures caused by large runoff events.

Stream Gaging

Conventional stream gaging was used on all drainage basins. To minimize leakage, all structures were anchored to bedrock with concrete cutoff walls except for HJA-7 which was placed on weathered bedrock. Depth of water through artificial cross sections was continuously measured by float operated stage recorders employing stilling wells. Volume flow was calculated from depth measurements by an equation developed from model studies in hydraulic laboratories for weirs and H flumes. Trapezoidal flumes were field rated by determination of the cross section and velocity over the full range of streamflow and a series of linear equations fitted to the data. Velocity was measured with the velocity head rod (Wilm and Storey, 1944). Trapezoidal flumes at FC-2, H flumes at the HJA-6, 7, 8, 9 and 10, and a 120° V notch weir at CC-4 were designed to measure peak flows of 1.6 to 2.2 $m^3/s/km^2$ with a 50-year return period.

wind-blown organic matter (needles, insects, etc.). These funnels were replaced the fall of 1971 with stainless steel funnels (25 cm diameter) with integral bird guards. Stainless steel screen with 0.4 mm openings was cemented in the neck with silicone cement.

These funnels were used at FC-2, CC-4, and HJA-6, 7 and 8. At HJA-9 and 10, samples were taken in a funnel (25 cm diameter, 60 cm deep) fitted with a stainless steel screen. The funnel was placed on top of a tower 18 m tall in the center of a clearcut. A removable stainless steel bird guard was removed from December through March to facilitate snow collection. Precipitation was stored in a closed water-tight container buried in the soil at the base of the tower. All precipitation sample storage containers were of 20 l~~iter~~ capacity. Precipitation was collected at roughly 3-week intervals at all sites except HJA-9 and 10 where samples were taken soon after precipitation in the warm seasons.

Stream Samples

Because of the large range of streamflows and variable sediment and dissolved chemical concentration of streams, a proportional water sampler was designed and tested in 1967 and 1968 (Fredriksen, 1969). The sampler pumps at a rate proportional to streamflow and the samples are composited in a 20 liter carboy. Proportionality is achieved by sampling at rates from one to twenty samples per unit

Laboratory Analysis of Water and Sediment and Compilation of Data

Water Samples

The stream water samplers were operated during the cool seasons beginning in October at all sites and ending approximately in May at CC-4, June at HJA 6-10, and about July 1 at FC-2. Grab samples taken during the warm low flow seasons in 2-liter polyethylene containers were refrigerated for transportation to the laboratory. All containers were acid washed when new and as necessary thereafter. While in storage, the containers were capped and rinsed with double distilled, deionized water (DDW) before they were taken to the field. Care was taken that the inside surfaces of the bottles and caps were not handled.

Stream sample bottles were enclosed in a cool, dark environment in the soil beneath the gage houses. Soil did not come in contact with the bottles. The chamber was covered to reduce variation of ambient temperatures.

Upon arrival at the laboratory, sets of water samples (precipitation and stream water) were immediately placed in storage at 0°C for stream samples from CC-4; freezing of these latter samples at -18°C was necessary for flocculation of amorphous silica. All samples were thawed if frozen, wiped free of condensed moisture in the laboratory because of its effect on N and P analyses.

Glassware could only be kept as clean as the water supply. Special measures to provide clean water were filtration of laboratory distilled water through beds of activated charcoal, anion and cation exchange resins, and a final redistillation. The water (DDW) was stored in pyrex glass. Daily checks of quality were made by Nesslerization reaction and conductivity. DDW that equaled or exceeded 97% transmittance with 2 ml of Nessler's reagent per 100 mls of DDW produced no indication of N or P in standard blanks. Glassware was washed with hot water only, and rinsed with DDW. Glassware for P analysis was soaked in dilute HCl overnight. A special set of pyrex glassware was used for each analysis, and when not in use, the glassware was stored in a dust free environment. High solution blanks were evidence of dirty glassware, bad water or poor technique, and cause for reanalysis of samples.

Analysis for organic nitrogen and free ammonia was done by macro-Kjeldahl on half liter samples.[5] The distillation system was equipped with pyrex tubing, and the flexible joints were of rubber tubing. Flushing the distillation system with DDW previous to each day's operation was necessary to remove substances deposited in

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[5] Holcombe, E. E., D. G. Moore, and R. L. Fredriksen. A macro-Kjeldahl method with improved sensitivity in the routine analysis of ultra-low levels of nitrogen in natural waters. Manuscript in preparation.

and histidine. Ten samples corrected by two blanks were compared to ten standards of the same concentration. The mean distilled ammonia sample optical density (0.167) was equal to the standards and recovery was 100%. A sample containing 0.230 mg/l organic nitrogen was spiked with 0.442 mg histidine and 0.650-0.230 = 0.420 mg recovered for 95% recovery. Recovery of histidine in DDW was 98.8%.

Nitrite was determined by the sulfanilamide method and nitrate after reduction by cadmium-copper columns was detected as nitrite (Strickland and Parsons, 1965). The detection limit of nitrite was less than 0.001 mg/l and the optical density of standard solutions varied by ± 0.003 units among ten columns over 0.001-0.050 mg/l.

Orthophosphorus (ortho-P) concentration was determined by the molybdate blue method and total P after persulfate-sulfuric acid digestion in the autoclave and detection as orthophosphate (FWPCA, 1969). The standard deviation of 12 replicate determinations of one sample (0.0038 mg/l) was 8.3% of the mean concentration (0.0459 mg/l) of the sample.

Particulate Matter

The sediment collected on glass fiber papers was grouped by season of the year for each sampling site (stream or rain collector) and subdivided after being homogenized in a Waring blender following

All organic fractions were ground in Wiley mills and the material < 2 mm (soil) was pulverized. Air dry weights of organic and soil fractions were corrected to oven dry weights at a drying temperature of 105°C.

Both suspended and bedload sediment fractions were analyzed for organic nitrogen by a macro-Kjeldahl method using 1 gram of pulverized sediment, 0.5 g of organic matter from bedload samples, or 1 aliquot of the suspended sediment sample. One gram of digestion mix (2.5 g selenium metal, 10 g anhydrous $CuSO_4$, 590 g anhydrous Na_2SO_4) and 10 ml concentrated H_2SO_4 were added and a small quantity of water was used to wash the sediment to the bottom of the flask. The sample was digested for 1 hour after clearing. Distillation and analysis for ammonia was the same as for water samples.

Analyses of suspended sediment samples for P followed digestion of organic matter with H_2O_2. Ten milliliters of analytical grade H_2O_2 added to aliquots of sediment and glass fiber paper in covered Erlenmeyer flasks were warmed on top of a drying oven to accelerate digestion. Double distilled water was added so that the solution covered the slurry. One to three weeks of digestion was required before the solution cleared. Samples containing more than a gram of sediment required more H_2O_2 to complete the digestion. Only traces of P were found in blanks containing only filter discs. The

RESULTS

Inputs in Precipitation

Dust

Early in the study, when substantial amounts of particulate matter (dust) were found in precipitation, analytical methods were developed to measure N and P carried by dust so that the nutrient content of both the dust and wash-out of soluble nutrients could be evaluated. In addition to transporting nutrients, dust could also be beneficial by adding to the soil mass.

The annual pattern of dust deposition varied greatly by year and site (Fig. 2). Total deposition was most variable during the years with the heaviest precipitation (1971 and 1972). The deposition was more uniform in 1973--one of the driest years on record. At FC-2, the deposition was heaviest in the fall-winter-spring wet season and least during the summer dry season. The pattern of deposition was similar at HJA-10 except for a greater summer season deposition. At the southern site (CC-4), the annual deposition pattern was uniform throughout the year except for 1972 when deposition in the summer was much lower. Timber harvest in an adjacent basin occurred during the period of rapid dust accumulation in the summer of 1971. Heavy deposition in 1973 came during a long dry season.

No general trend is apparent for the annual wash-out of dust from the atmosphere by precipitation (Fig. 3), but dust deposition at FC-2 shows a different pattern and larger variability in deposition between years compared to the other sites. In 1971, 1973, and 1974, deposition at FC-2 was greater than at the other sites, and was unrelated to the amount of precipitation. Deposition in 1972 was the lowest of all sites and similar to the deposition at HJA-10 (Fig. 2). The close proximity to Portland, Oregon, the Columbia River Gorge, and variability of storm paths from the east and west flow of air through the gorge may explain the differences observed at the FC-2 site. When the three high deposition years at FC-2 were excluded, annual deposition declined with increasing precipitation according to the relationship shown on Figure 3.

Nutrients in Dust

The chemical analysis of dust samples (Table 3) gives reasonable values in most cases even though sample sizes are small. Except at FC-2 in 1972, N and C values are fairly well correlated. Values for small samples probably overestimate C. The P content of dust is more uniform than that of the other nutrients, and increases in the summer dust depositions are paralleled by rising C percentage.

The nutrient content of the dust on an annual basis was more variable for N than P (Fig. 4). For N, the data clustered in two

Table 3 . Nutrient composition of particulate matter in precipitation by season.

		Fox Creek 2				H. J. Andrews 7				H. J. Andrews 10				Coyote Creek 4			
Year	Season	C	N	P	Sample size	C	N	P	Sample size	C	N	P	Sample size	C	N	P	Sample size
		------	%	------	- g-	-----	%	-----	--g--	-----	%	-----	--g--	-----	%	-----	--g--
1972																	
	Fall, Winter	13.1	1.68	.08	.041[1]					19.4	3.14	.21	.024	15.1	3.06	.28	.017
	Spring	4.6	3.09	.20	.057					4.5	2.01	.11	.078	1.8	.42	.05	.291
	Summer	25.1	2.90	.27	.014					8.7	4.34	.37	.026	17.6	4.31	.53	.047
1973																	
	Fall	--	.90	.10	.041	--	.40	.15	.027	14.0	2.00	.50	.095	--	.62	.50	.025
	Winter	--	.95	.08	.083	--	.35	.12	.033	10.4	2.49	.71	.027	--	.35	.22	.042
	Spring	--	2.43	.26	.076	--	.90	.36	.012	11.0	2.07	.66	.024	--	.63	.53	.022
	Summer	--	2.07	.21	.055	--	.17	.10	.078	16.2	3.19	1.33	.015	--	.46	1.12	.036

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[1] Values reported for samples smaller than 0.02 g are qualitative. In 1973, C analyses were dropped for samples except those from HJA-10 to improve the accuracy of N and P analyses.

strata; HJA-7 and CC-4 in 1973 contained less than 0.6% N and the remaining sites and years suggest a decline in N% from 2.8 to 1.4% over a range in dust deposition from 16 to 56 kg/ha. These differences are again indicative of wide variation in atmospheric dust quality due to the annual variation in dust transport by global air circulation and local sources of dust.

Stratification of particulates with elevation may account for the lower concentration of dust and N in the dust at the HJA-7 and CC-4 sites in 1973. These sites are at high elevation and are also the farthest removed from human habitation (Table 1).

By segregating the annual deposition of N by dust into the two populations according to N content, N input via dust declined by 0.34 kg/ha/100 cm precipitation over the range shown in Figure 5, and this was similar to the form of the annual dust input (Fig. 3). No relationship was found between P deposition in dust and precipitation.

Dissolved Nutrient Input

Forms of N and P in dissolved organic matter (DOM) predominate over inorganic forms in precipitation (Table 4). Ammonia and NO_3 occur as cloud condensation nuclei in the atmosphere, but these forms may also result from decomposition of DOM where decomposition is not prevented in sample bottles. The larger proportions of inorganic forms occur at all sites except at HJA-10 where special

Table 4. Form of N and P in filtered precipitation and in dust. Percentages are in parentheses.

Site	Year	Nitrogen					Phosphorus			Precipitation
		"Dissolved"				In Dust				
		NH_3	NO_3	Org. N	All N	N	P	Total P	Ortho P	
		kg/ha					kg/ha			cm
FC-2	1971	1.12	1.06	1.88	4.06	.71	--	--	--	282
	1972	.94	1.40	1.56	3.90	.40	.02	.23	.02	332
	1973	.38	1.01	.73	2.12	.79	.08	.22	.03	166
	Ave.	.81 (24.1)	1.16 (34.5)	1.39 (41.4)	3.36	.63	.05	.22	.02	260
HJA-7	1973	.54 (39.1)	.40 (29.0)	.44 (31.9)	1.38	.06	.03	.26	.05	162
HJA-10	1969	1.05	.07	.96	2.08	--	--	--	--	253
	1970	.55	.22	.73	1.50	--	--	--	--	216
	1971	--	.55	1.25	--	.51	--	--	--	272
	1972	.06	.37	1.08	1.51	.51	.04	.06	.02	286
	1973	.17	.33	.79	1.29	.80	.23	.18	.08	168
	Ave.	.46 (28.8)	.25 (15.6)	.89 (55.6)	1.60	.61	.14	.12	.05	239
CC-4	1971	.63	.32	1.15	2.10	1.04	--	--	--	156
	1972	.58	.30	1.32	2.20	1.29	.15	.37	.25	159
	1973	.23	.55	.62	1.40	.19	.11	.14	.05	89.5
	Ave.	.48 (25.3)	.39 (20.5)	1.03 (54.2)	1.90	.84	.13	.25	.15	135

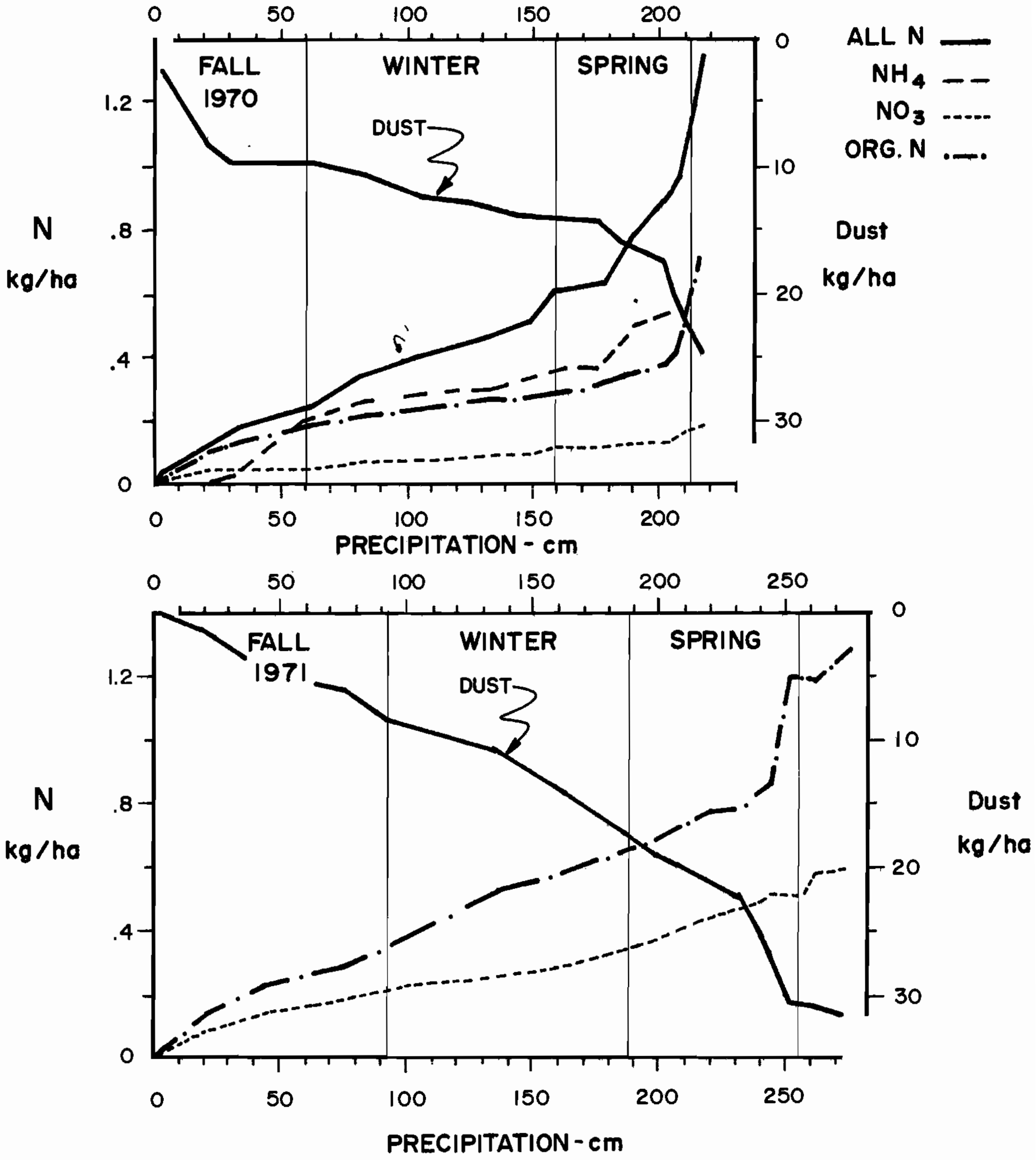

Figure 6. Annual cumulative dust depostion and N input in precipitation at HJA-10 from October 1 to September 30 of 1969-1970, 1970-71, 1971-72, and 1972-73.

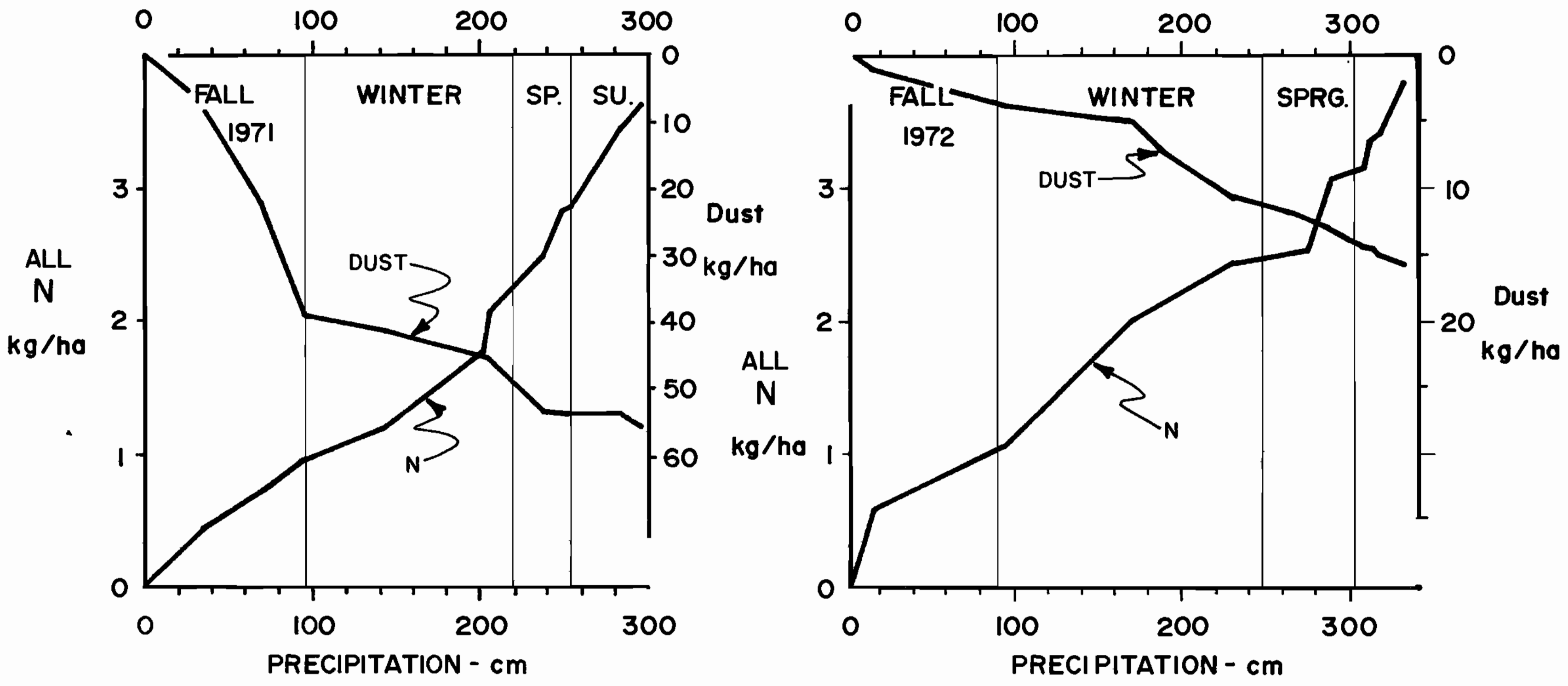

Figure 7. Annual cumulative dust deposition and N input in precipitation at FC-2 from October 1 to September 30 of 1970-71, 1971-72, and 1972-73.

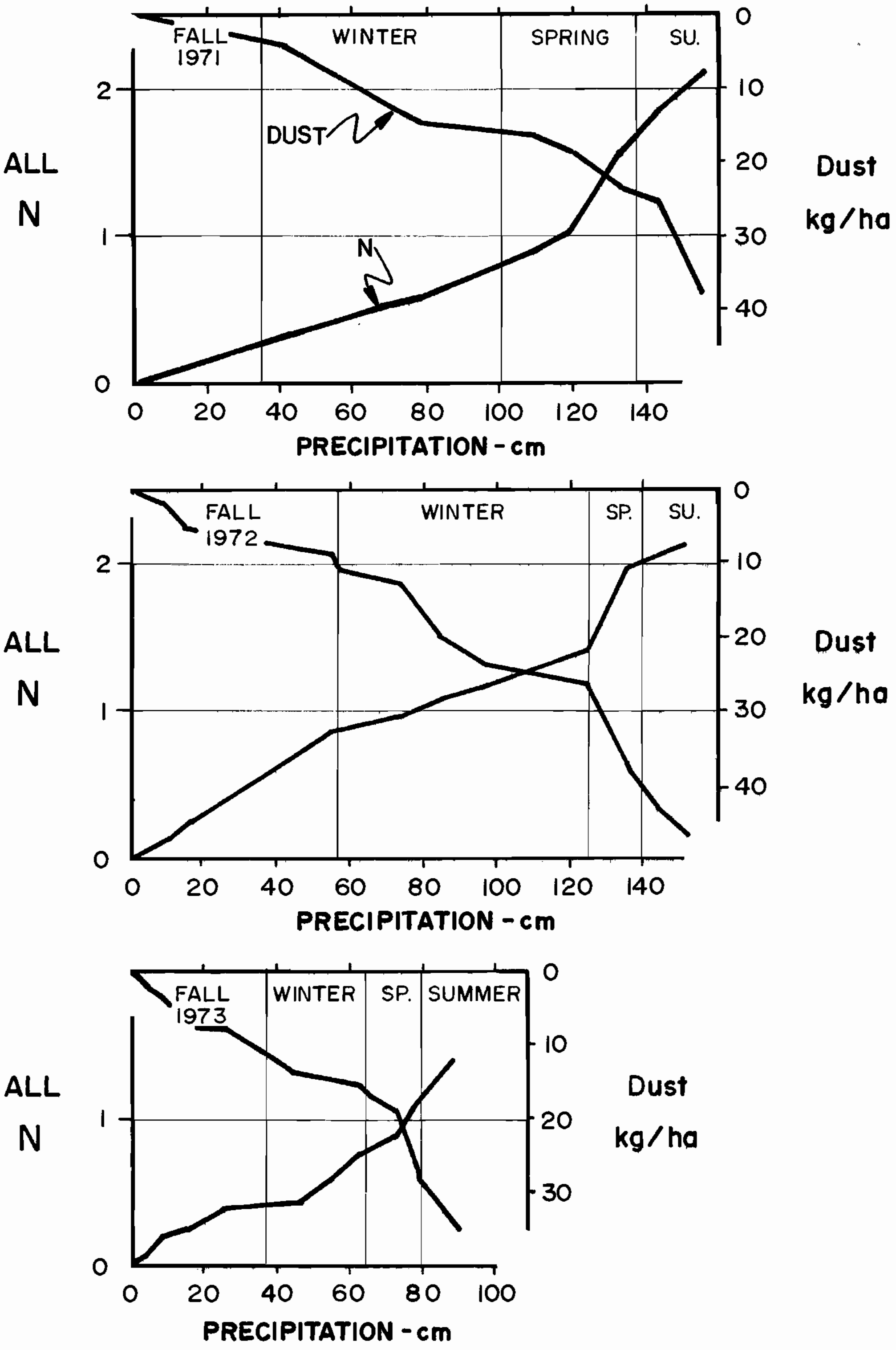

Figure 8. Annual cumulative dust deposition and N input in precipitation at CC-4 from October 1 to September 30 of 1970-71, 1971-72, and 1972-73.

in 1973 (1.30 and 1.38 kg/ha) but nearly double the dust deposition at HJA-10, the low elevation site (Figs. 6 and 9).

The pattern for P input (Fig. 10) was similar to N except for a pronounced leveling-off in fall or winter. The input of dust closely approximated the shape of the nutrient traces, but plottings (not shown) of P or N on dust were curvilinear--suggesting that the size fractions vary greatly with time of year.

Annual Input

The annual input of N in relation to precipitation is described by three linear equations (Fig. 11). The input for FC-2 and CC-4 increased at 1.11 and 1.12 kg/ha/100 cm precipitation respectively; the increase is much lower at HJA-7, 9, and 10 and rises at 0.36 kg/ha/100 cm precipitation. The standard error (tsd) was 1.07 kg/ha for FC-2, 0.43 kg/ha for CC-4 and 0.12 kg/ha at the HJA sites. The intercepts for these equations do not pass through the origin and this suggests that some mechanism other than precipitation wash-out carries N to the gages or that the relationship is curvilinear for smaller values of precipitation.

Phosphorus data suggest very different relationships (Fig. 12). Based on 1972 and 1973 data, P input rose sharply with precipitation at CC-4, and appears to be unrelated to precipitation at FC-2. Based

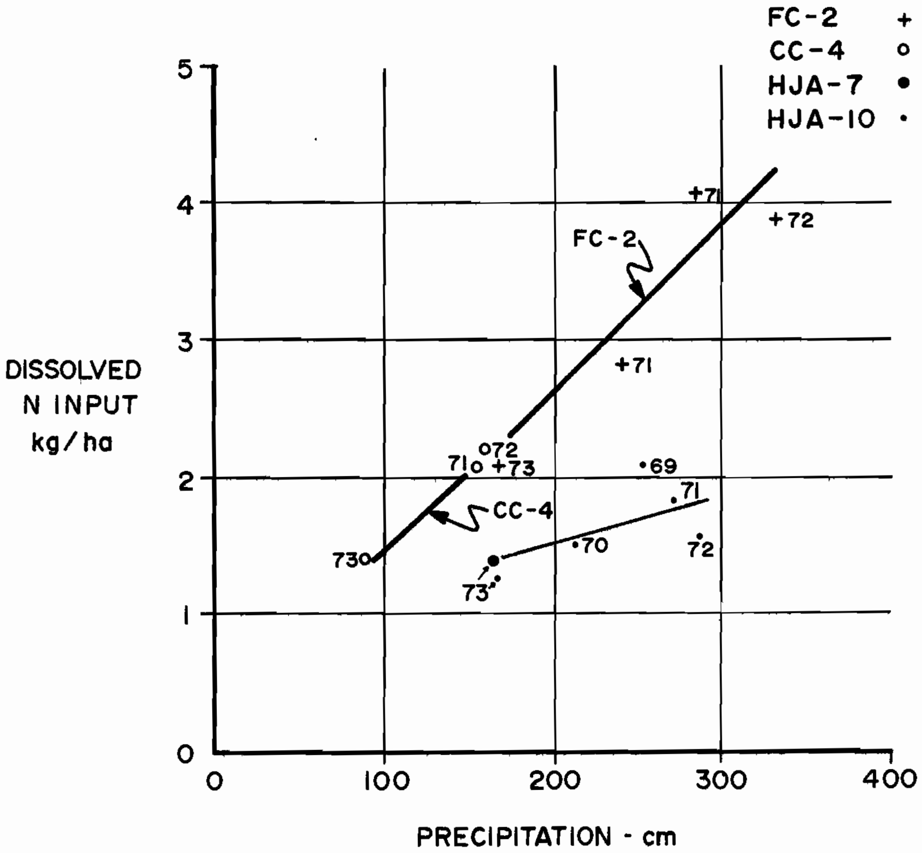

Figure 11. Input of "dissolved" forms of N (NH$_3$, NO$_3$, and Org. N in precipitation.

For FC-2 -- N kg/ha = .30 + .0118 ppt cm -- r = .93
For CC-4 -- N kg/ha = .41 + .0111 ppt cm -- r = .997
For HJA sites -- N kg/ha = .78 + .0036 ppt cm -- r = .64

on 3 years data at HJA-10, "dissolved" P input declined at 0.1 kg/ha/100 cm precipitation.

Outflow in Streams

The outflow of N, P, and sediment are described in this section. N and P are transported in stream water as components of sediment and as dissolved substances. Both nutrients may be carried in dissolved form either as ions or as part of dissolved organic matter (DOM).

Nutrient and sediment outflows are transported in proportion to peak streamflows from storms and soil erosion, and nutrient leaching rates are established for each ecosystem on each drainage basin. Relationships are drawn between nutrient leaching rates and nutrient pools as they are depleted by leaching and recharged by decomposition of readily decomposable organic matter. Organic decomposition and DOM recharge is hypothesized from soil temperature during 2 wet years (1971 and 1972) with distinct differences in temperature environment and a very dry year (1973).

Peak flows from rainstorms and snowmelt occur from as early as October and as late as May, depending upon the year and general regional climate. General relationships between annual outflow of nutrients and sediment are shown for a broad range of annual runoff.

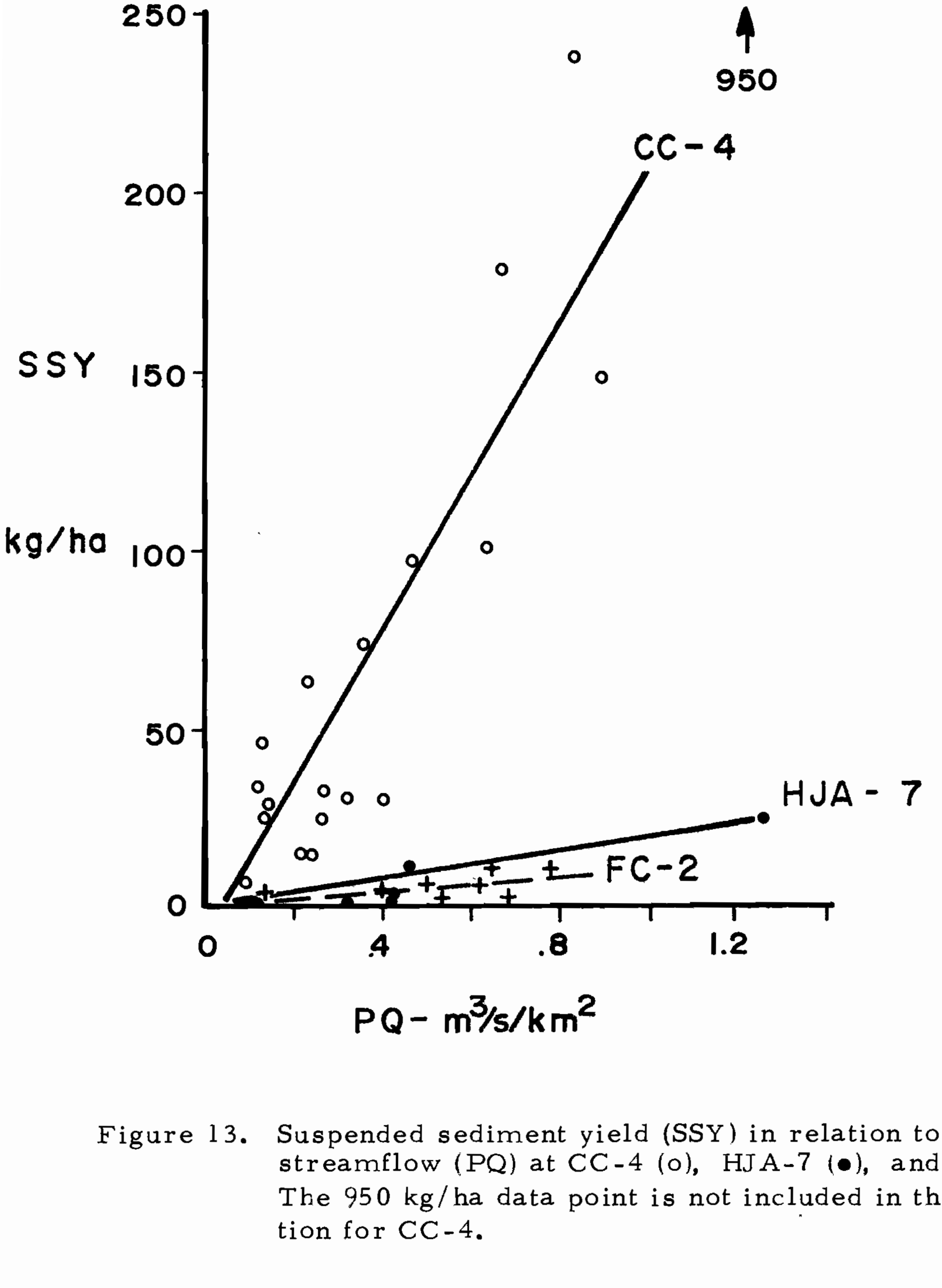

Figure 13. Suspended sediment yield (SSY) in relation to peak streamflow (PQ) at CC-4 (o), HJA-7 (●), and FC-2 (+). The 950 kg/ha data point is not included in the equation for CC-4.

Table 5. Equations for contemporary soil erosion rates (kg/ha) measured by the suspended sediment yield (SSY) in relation to storm peak flow in $m^3/s/km^2$ (PQ). Sample size (n), correlation coefficient (r) and standard error of regression (tsd) are given for each equation.

Site	n	r	tsd	Equation
CC-4	18	.89	64.3	$SSY = 226\ PQ - 13.9$
HJA-7	5	.94	10.9	$SSY = 18.1\ PQ$
HJA-9	19	.58	6.0	$SSY = 8.6\ PQ$
HJA-10	18	.34	13.6	$SSY = 13.3\ PQ$
FC-2	9	.38	4.0	$SSY = 10.0\ PQ$

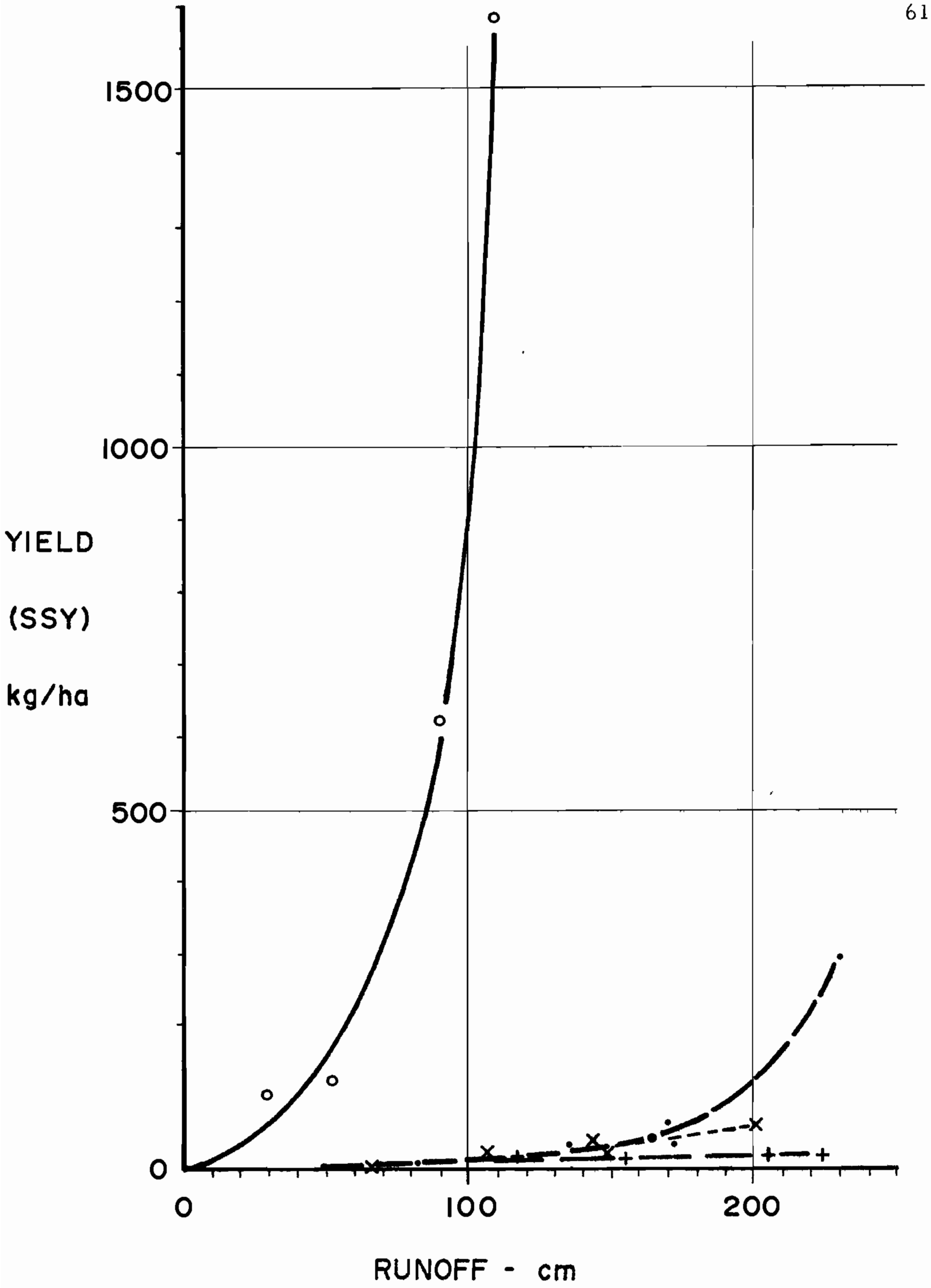

Figure 15. Annual suspended sediment yield (SSY) in annual runoff at FC-2 (+), HJA-7 (●), HJA-9 (x), HJA-10 (.), and CC-4 (o).

Table 7. Seasonal nutrient yield by suspended sediment (SSY) from the study basins in 1972 and 1973.

		H. J. Andrews 9				H. J. Andrews 10			
Year	Season	SSY	C	N	P	SSY	C	N	P
		kg/ha							
1972	Fall	8.0	1.0	.07	.0056	62.7	1.8	.42	.020
	Winter	55.8	10.3	.58	.022	230	17.2	.91	.039
	Spring	2.0	.26	.011	.0002	3.9	.3	.05	.008
	Summer	.07	--	--	--	.03	--	--	--
1973	Fall	.7	.09	.009	.003	.39	.05	.004	.001
	Winter	4.0	.52	.054	.019	8.4	.80	.14	.022
	Spring	.6	.03	.007	.002	.46	--	--	--
	Summer	.16	.006	.001	.000	.53	.05	.001	.001

		Coyote Creek 4				Fox Creek 2			
Year	Season	SSY	C	N	P	SSY	C	N	P
		kg/ha							
1972	Fall	291	3.9	.44	.029	3.4	1.5	.06	.006
	Winter	1237	17.8	1.24	.124	10.8	3.2	.18	.006
	Spring	52	.7	.09	.021	7.4	1.4	.10	.008
	Summer	13.9	.1	.02	.001	1.5	.2	.04	.002
1973	Fall	39	2.2	.02	.014	16.6	-	.15	.010
	Winter	48	2.3	.03	.016	7.3	-	.04	.006
	Spring	19	.6	.01	.004	1.0	-	--	--
	Summer	1.2	.1	.00	.001	1.7	-	.01	.001

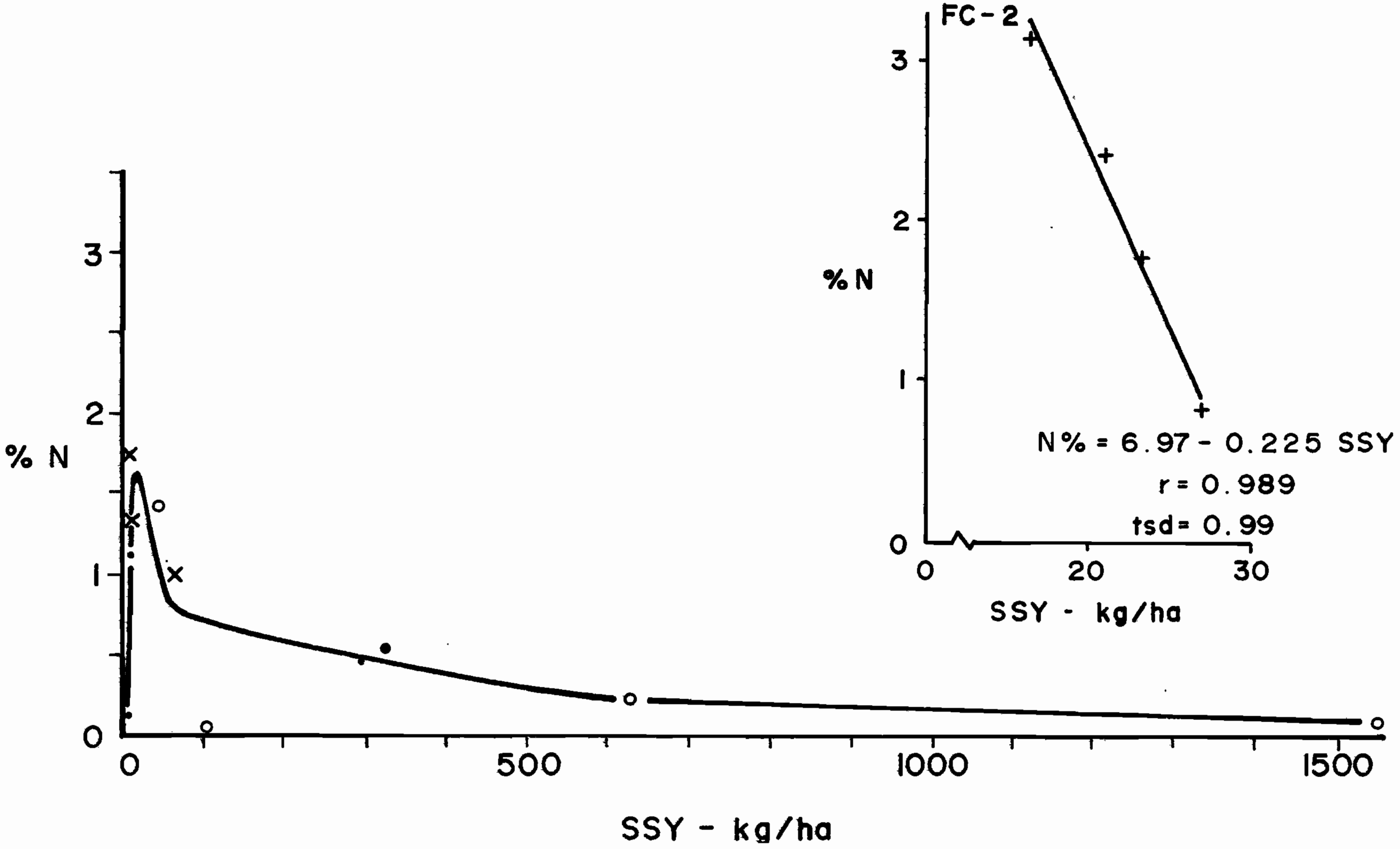

Figure 16. Nitrogen concentration of suspended sediment in relation to annual suspended sediment yield (SSY), FC-2 (+) (inset figure), HJA-7 and 8 (●), HJA-9 (x), HJA-10 (.), and CC-4 (o).

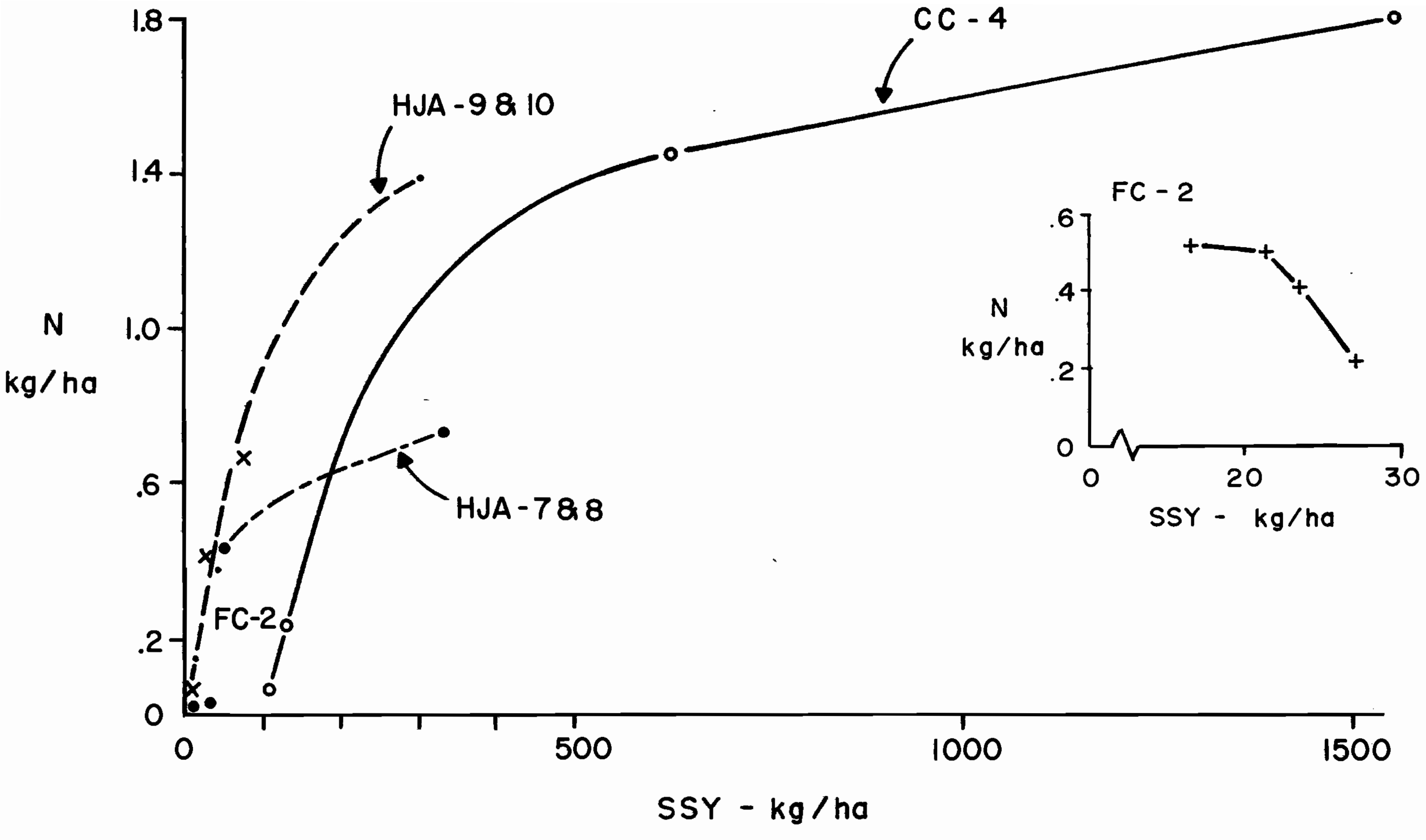

Figure 18. Nitrogen outflow in suspended sediment in relation to annual suspended sediment yield (SSY), FC-2 (+) (inset graph), HJA 7 and 8 (●), HJA-9 (x), HJA-10 (.) and CC-4 (o).

a limiting condition of N outflow is observed as sediment sources shift to bank erosion. The steeper rate of P outflow for SSY's > 100 kg/ha may be due to breakdown of minerals in the sediment. At FC-2, N outflow declined with increasing SSY's possibly because of depletion of organic matter in the gravel with greater gravel movement and a shift to mineral sediment with higher flows.

Dissolved Nutrient Outflow

Total N and P (TN and TP) outflows are dominantly controlled by the flushing of water through the drainage basins which is expressed as annual runoff (RO). Volume of RO accounts for between 90 and 98% of the TN outflow for the five sites (Fig. 20).

The equations (Table 8) fall into two groups by slope, with CC-4 and HJA-9 outflow increasing at rates of .0065 and .0056 kg/ha/cm of RO respectively; at FC-2, HJA-7, and HJA-10, outflow rises from .0032 to .0037 kg/ha/cm RO. The equation shown for HJA-7 was fitted to data from two drainage basins (HJA-6 and 7) for 1972 and 1973. The soils and vegetation of these sites were similar as were their TN/RO relationships.

No simple relationships to precipitation, temperature, elevation, aspect, optimum temperature days, moisture stress or length of growing season appear to control TN outflow observed from the basins (Tables 1 and 2, Fig. 20). Reduction in nutrient uptake could

Table 8. Equations for total dissolved nitrogen (TN) in kg/ha and nitrogen concentration (NC) in relation to runoff (RO) in cm. Sample size (n), correlation coefficient (r) and standard error of regression (tsd) are given for the equations.

Site	n	r	tsd	Equation
A. <u>N Yield</u>				
FC-2	4	.96	.20	$TN = .202 + .0037\ RO$
HJA-6 & 7	4	.99	.28	$TN = .0034\ RO - .023$
HJA-9	5	.97	.29	$TN = .0056\ RO - .029$
HJA-10	5	.97	.18	$TN = .112 + .0032\ RO$
CC-4	4	.95	.24	$TN = .136 + .0065\ RO$
B. <u>N Concentration</u>				
FC-2	4	.83	.0039	$NC = .060 - .000064\ RO$
HJA-9	5	.50	.0065	$NC = .044 + .000065\ RO$
HJA-10	5	.73	.0037	$NC = .048 - .000049\ RO$
CC-4	4	.76	.0161	$NC = .114 - .00035\ RO$

Table 9. Nitrogen and phosphorus in filtered stream water and suspended sediment.

			Nitrogen						Phosphorus		
			Dissolved				Sediment	Total	Sediment	Dissolved	
Site	Year	Runoff	NH_3	NO_3	Org. N	All N		N		Total P	ortho P
		- cm -					kg/ha				
FC-2	1970	155.1	.070	.018	.704	.774	--	--	--	--	--
	1971	205.3	.081	.072[2]	.874	1.027	.51	1.54	--	--[1]	--
	1972	231.5	.044	.117[2]	.837	.998	.41	1.41	.02	.314	.018
	1973	118.1	.020	.156	.443	.618	.22	.84	.01	.279	.042
						(.854)	(.38)	(1.26)	(.015)	(.296)	
HJA-7	1972	161.2	.074	.012	.464	.550	.43	.98	.03	.646	.309
	1973	55.5	.005	.014	.185	.204	.01	.21	.01	.336	.126
						(.377)		(.55)	(.02)	(.491)	
HJA-9	1969	144.1	.143	.008	.738	.889	--	--	--	--[1]	--
	1970	105.6	.051	.001	.479	.532	--	--	--	--	--
	1971	148.2	--[1]	.001	.839	.840	.40	1.24	--	--	--
	1972	198.8	.023	.017	.974	1.014	.67	1.68	.03	.764	.454
	1973	63.4	.002	.006	.278	.286	.07	.36	.02	.321	.137
						(.712)	(.38)	(1.07)	(.025)	(.542)	
HJA-10	1969	169.3	.042	.003[1]	.616	.662	--	--	--	--	--
	1970	134.6	.042	.093[2]	.375	.510	--	--	--	--	--
	1971	172.3	--	.001	.738	.739	.31	1.05	--	--	--
	1972	228.5	.002	.037	.768	.806	1.38	2.19	.07	1.105	.851
	1973	80.2	.003	.014	.338	.355	.14	.50	.03	.418	.309
						(.614)	(.61)	(1.21)	(.05)	(.762)	
CC-4	1970	51.5	.004	.006	.541	.551	--	--	--	--	--
	1971	88.8	.024	.090[2]	.519	.634	1.44	2.07	--	--	--
	1972	107.0	.020	.032	.831	.883	1.79	2.67	.18	.663	.577
	1973	28.9	.040	.083	.164	.287	.06	.35	.04	.289	.184
						(.589)	(1.10)	(1.70)	(.11)	(.476)	

---

[1] $HgCl_2$ used as a preservative in summer 1970 and 1971 complexed P analyses at all sites and ammonia at HJA 9 and 10.

[2] Includes NO_2.

materials. Outflows from CC-4, HJA-10, HJA-7, and HJA-9 on tuff parent materials are clustered at a higher range of outflows than those for FC-2 on basalt and andesite parent materials.

When sources of P are subdivided into organic and inorganic forms, rates of organic P outflow have a smaller range of outflow compared to TP outflows, and the rates decline from HJA-7 and FC-2 (cool, moist sites) to HJA-9 and 10 (warm, moist sites) and CC-4 with long, warm summers and a short flushing season (Table 10). Rates of ortho P outflow probably reflect rates of mineral weathering and are least for basalt and andesite (FC-2), intermediate for HJA-7 and 9 where parent materials are of mixed parentage from basalt and tuff, and highest where parent materials are predominantly tuff (CC-4 and HJA-10).

The outflow of TN and TP can be thought of as the result of two processes--1) the production of soluble forms of N and P in soil solution, and 2) the flushing of these materials from the soil. The change in annual concentration of TN and TP with increasing runoff is an indication of the relationship between production and flushing of these materials. Negative slopes will result when rates of flushing with increasing runoff exceed production of soluble materials and conversely, positive slopes indicate increased production during wetter years.

Reduced production of TN with increasing runoff is evident only at CC-4 (Fig. 22). The other sites exhibit a nearly flat response of TN concentration to runoff. It is doubtful that these slopes are different statistically, and that as a group the slopes differ from zero (Table 8). These relationships suggest that TN production is closely correlated with flushing at the HJA sites and FC-2. It is noteworthy that the outflow of TN became increasingly organic with rising runoff at CC-4 and FC-2 (Table 9), and equations for these sites have the largest negative slopes (Table 8).

TP concentration shows a declining dilution effect from CC-4 in the south to FC-2 at the northern end of the transect of study sites (Fig. 23). The "dilution effect" was apparently the result of lower organic P during 1972 which was cooler and wetter than in 1973. The effect was more pronounced at CC-4 than at the other sites.

Ortho P concentrations remained nearly constant at all sites except CC-4 where the concentration was .01 mg/l less in 1972 than in 1973. These results show that the outflow of ortho P is the result of 1) increased production of soluble P with increasing runoff (interaction effect) and 2) flushing of the soluble material. Note that the slopes of ortho-P outflow increase with increasing runoff in the series from HJA-7, 9, and 10 (Fig. 21). Organic P levels increased only slightly with runoff in these 2 years, and these fluctuations can be expected according to variations in climate and the biological control on decomposition.

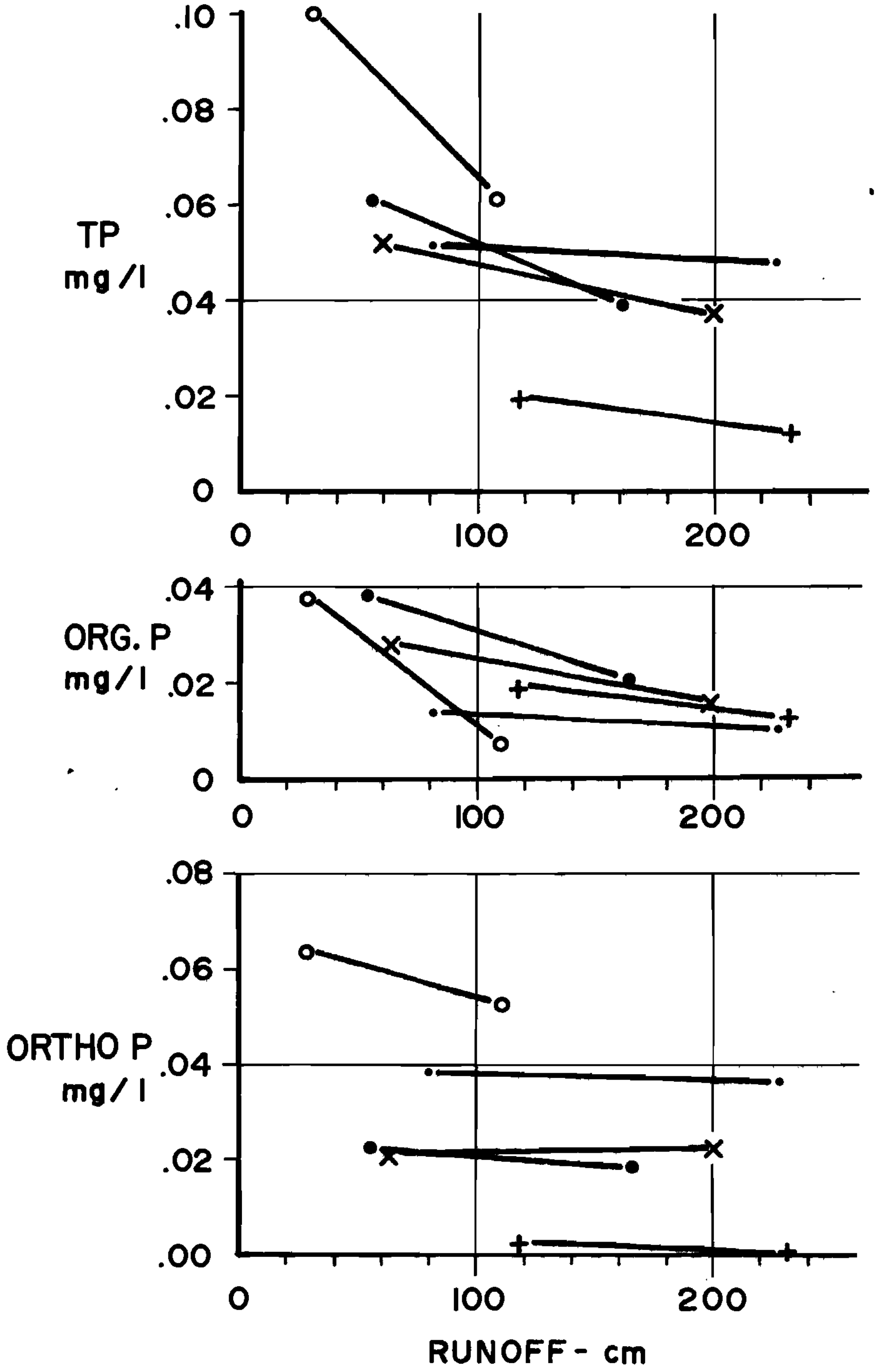

Figure 23. Annual concentration of "dissolved" total P (TP), organic P (Org. P) and ortho P in runoff at FC-2 (+), HJA-7 (●), HJA-9 (x), HJA-10 (.), and CC-4 (o).

temporarily above 3.3°C, particularly during the winter of 1973. Spring ended when soil mantle flushing stopped. This was determined as the date of the sampling period when runoff was less than 0.2 cm. Soil temperature data were only available from 1971 through 1973 (Table 10).

The large scale differences between the sites at the Bull Run Watershed in the north (FC-2), the H. J. Andrews Experimental Forest mid-way along the north-south transect (HJA-10), and the South Umpqua Experimental Forest in the south (CC-4) are evident from Figures 24, 25, and 26. The coincidence of maximum precipitation with minimum soil temperatures in the winter and maximum soil temperature with minimum precipitation in summer is a striking characteristic of all three sites. Mean growing season soil temperatures were similar at CC-4 (9.8°C) and the HJA sites (9.8-11.6°C), but the temperature was somewhat lower at FC-2 (9.1°C) (Table 10). Annual precipitation was lowest at CC-4 and highest at FC-2 (Table 4). Summer precipitation and the number of rainless months indicate a short-moist summer at FC-2 and progressively longer and drier summers from HJA-10 to CC-4 (Tables 2 and 10).

Nitrogen and P outflows (Figs. 24-26) follow the precipitation cycle, but there is a much greater lag time in the fall between the beginning of heavy precipitation and the outflow of nutrients from HJA-10 and CC-4 than at FC-2. In fact, flushing occurs almost

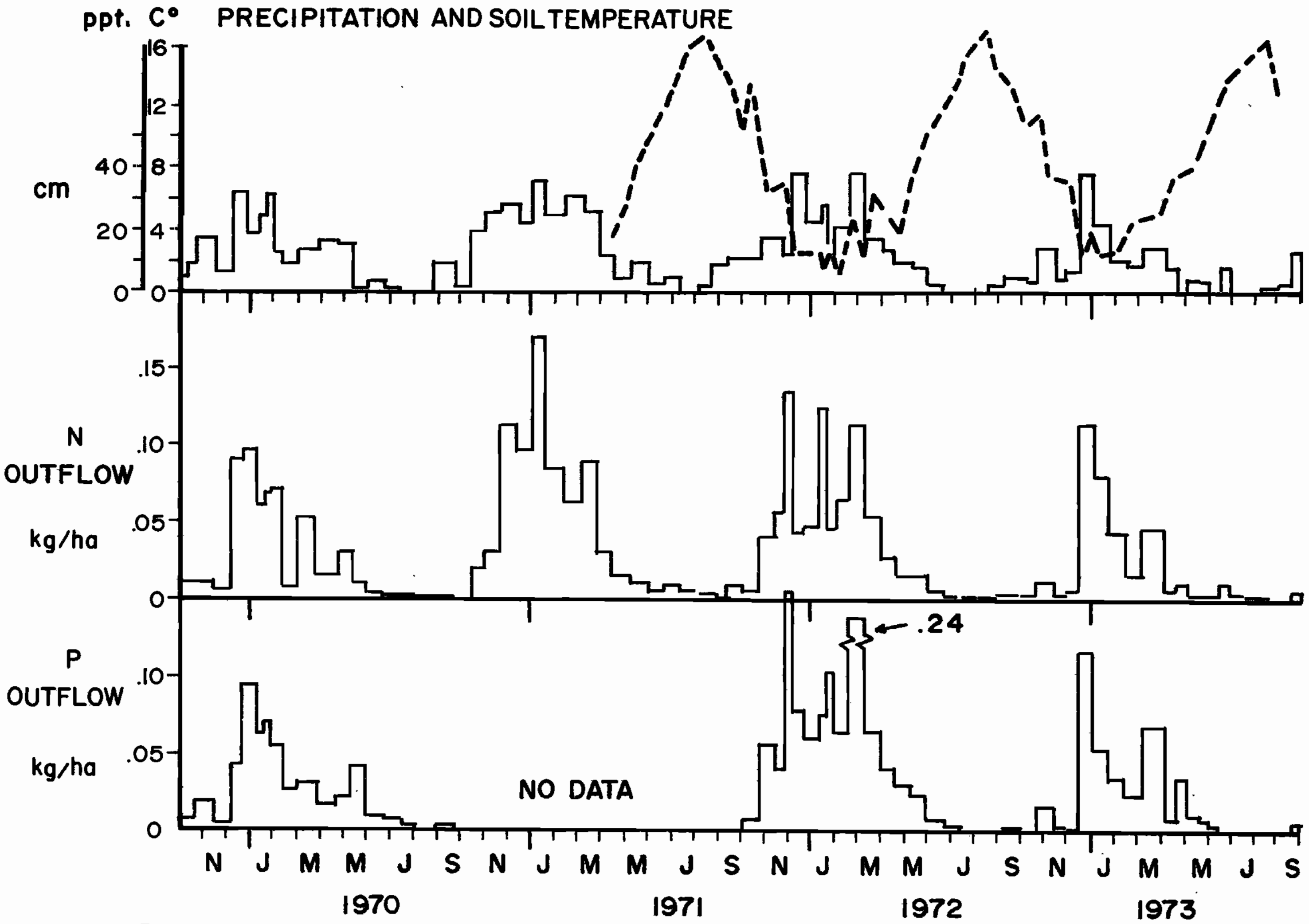

Figure 25. Annual cycles of precipitation (ppt) and soil temperature (C°) in relation to "dissolved" N and P outflows at HJA-10--H. J. Andrews Experimental Forest.

immediately with the beginning of fall precipitation at FC-2. The bimodal flushing peaks at FC-2 from precipitation in the fall and snowmelt in the late winter and spring are not apparent at HJA-10 or CC-4 because most of the precipitation comes as rain there. Note that peak N outflows are greatest at CC-4 and least at HJA-10, and that peak P outflows are greatest at HJA-10 and lowest at FC-2.

The periodicity of the total dissolved nitrogen (TN) outflow can be explained by comparing TN outflow to the peak streamflow of the flushing event causing the outflow. Soil temperature presumably regulates the production of dissolved organic matter (DOM) and the source of the TN (Fig. 27). The amount and chemical quality of organic detritus, source for the DOM, can also change from year to year determining the pool size and the rate that the pool is replenished after prolonged flushing. Peak flows from storm events decrease with increasing size of basin, and are lowest on FC-2 and highest on HJA-10. Rapid snowmelt may augment these flows. Figures 28-31(A) show TN in streamflow in relation to the peak flow of flushing events. Curves are hand fitted through the highest data points over the range of peak flows to indicate the outflow under "full pool" conditions. Peak TN outflows appear to be independent and unrelated to preceding peaks except at HJA-9 where a "carry-over" effect was noted. The time trace of these flows (B on the figures) is shown below for years when soil temperature information is available.

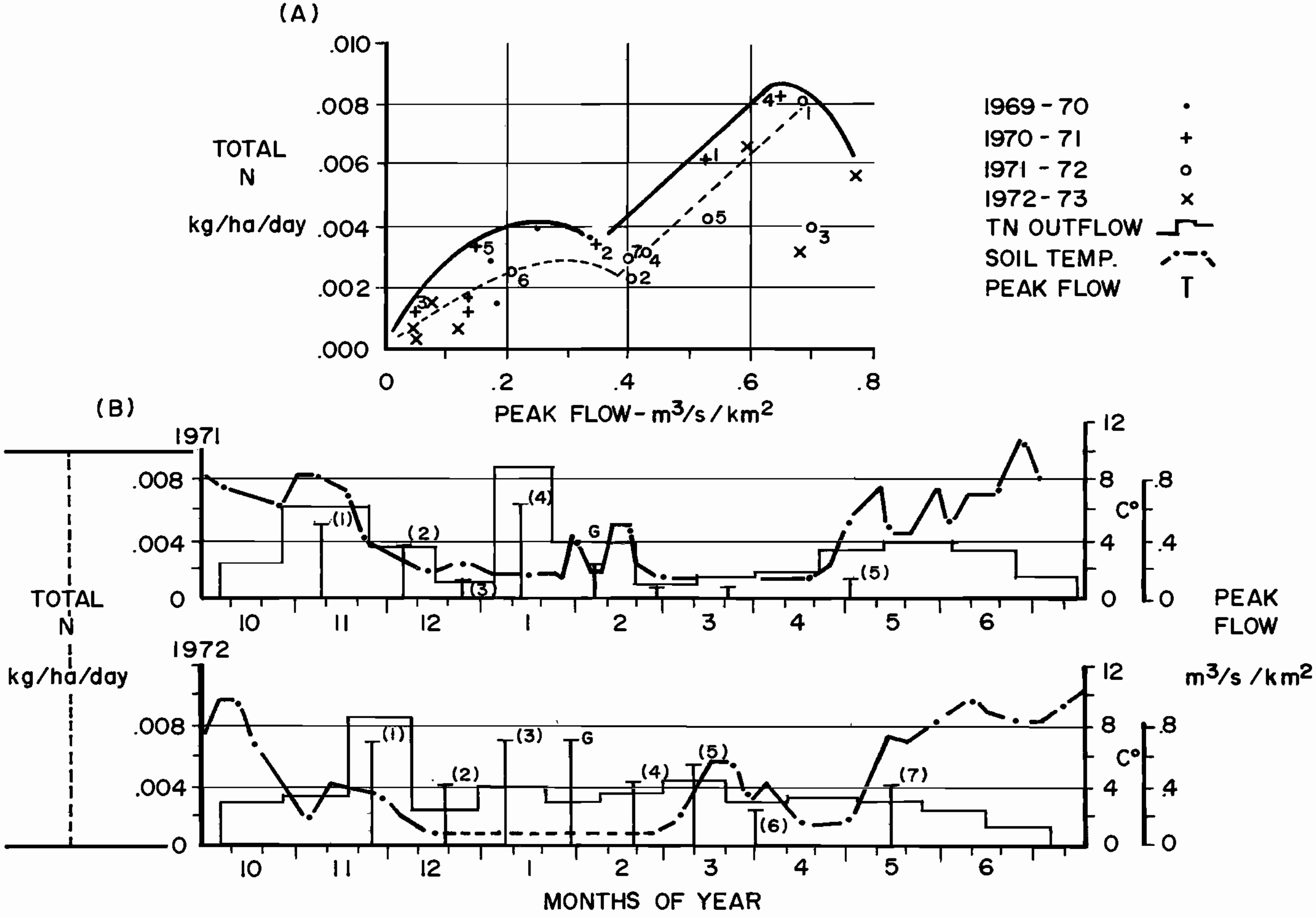

Figure 28. Total N outflow in relation to flushing by peak flows of storms and snowmelt and soil temperature during the cool-wet seasons of the year at FC-2. (A) Total N outflows in relation to peak flows 1970-73. (B) Total N outflows in relation to peak flows and soil temperature regimes. G indicates that a garb sample was taken because of sampler breakdown.

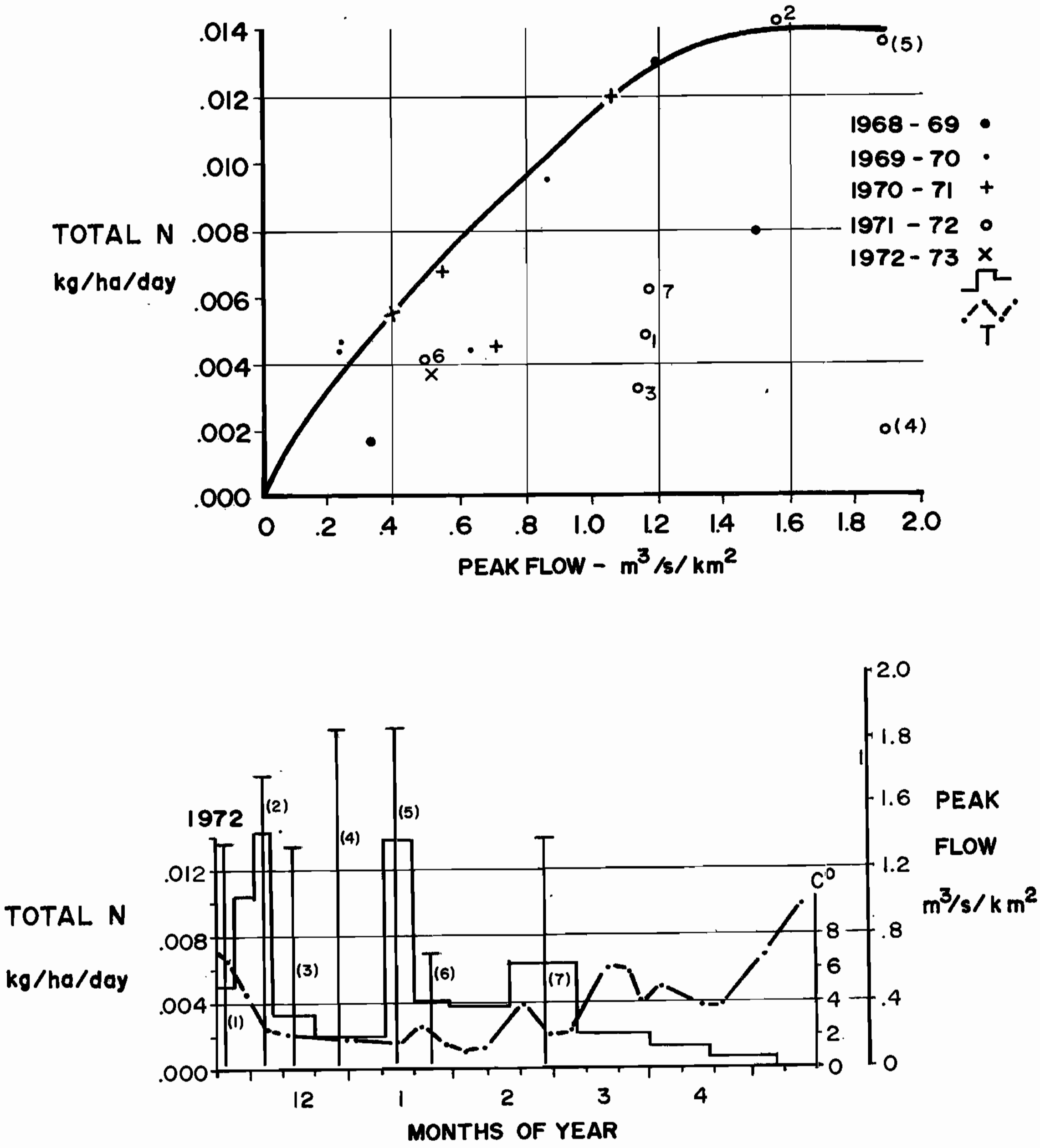

Figure 30. Total N outflow in relation to flushing by peak flows of storms and snowmelt and soil temperature during the cool-wet seasons of the year at HJA-10. (A) Total N outflows in relation to peak flows 1969-73. (B) Total N outflows in relation to peak flows and soil temperature regimes.

The rejuvenation of DOM pools is interpreted in relation to the effect of the soil temperature cycle on TN outflows by comparison to the hand fitted "full pool" curves for each site.

At FC-2, TN outflow suggests a complex form of N outflow with the runoff process as indicated by the hand fitted curves from 0-0.35 $m^3/s/km^2$ and the linear portion of the curve to 0.63 $m^3/s/km^2$ (Fig. 28). The data from 4 years indicates that DOM pools are depleted by flows greater than 0.63 $m^3/s/km^2$ at a rate in excess of the rate of replenishment as suggested by rapid decrease in outflow at the end of the curve. The solid line described above is drawn to fit the 1971 data. A similarly shaped dashed curve is shown for the 1972 data which produced lower values of TN outflow over nearly the same range of peak flows as in 1971.

FC-2 is a moist site with a climate unlike the areas further south in the western Cascades. Although precipitation does decrease in the summer, it is unusual to have a rainless month (Fig. 24) and drip of cloud water from vegetation supplies moisture which is not measured in precipitation gages. Therefore, decomposition is probably continuous through the summer season.

Points on Figure 28B (FC-2) are distributed through the high runoff season. In 1971, the point marked (1) came from a series of storms in late October and November. The next peak flow shown on December 5 produced the TN outflow marked (2). The other peaks closely following peak flows as shown by the dashed line. The first peak flow (1) in 1972 (Fig. 29B) shows reduced TN outflow from the hypothesized relationship--possibly because of uptake in the fall while soil temperatures were still warm. Increased outflow of peak (2) is indicative of full pool level, but progressive reduction in pool size occurred for peaks (3) and (4) which took place during the period of low soil temperature. Peak (4) was the lowest TN outflow recorded for this site. Peaks (5) and (6) followed the warming trend toward the end of January and produced nearly the same TN outflow (0. 0136 and 0. 0138 kg/ha/day respectively). Peak (6) is a secondary peak flow showing the "carry-over effect" from a larger peak (5) after pool replenishment. The other peaks in 1969 and 1970 positioned above the solid line also closely followed earlier and often larger peak flows and this suggests that the TN pool replenishment was continuous during the recession flow period of storm runoff events on HJA-9. This process maintained high "dissolved" N concentrations in the stream during periods of high runoff. The depression of peak (7) following the rise in soil temperature in late February may be due to the depletion of soluble N from the pool by uptake.

The pattern for HJA-10 (Fig. 30) was nearly identical to that described for HJA-9 except for the depression of peak (6) after soil warming in late January of 1972. There was no evidence for the "carry-over effect" of dissolved N outflow as observed at HJA-9.

and CC-4, whereas on the HJA sites, there is a closer coupling between production and uptake.

Relationship Between Input and Outflow

In this section, nutrient inputs and outflows by particulate and dissolved matter are compared to show the relative importance of nutrient transport by these mechanisms. Special attention is given to the conditions that cause negative N budgets. All flows are compared to precipitation to put them on a common base.

One notable finding of the study was that annual dustfall often exceeded the annual suspended sediment outflow (Fig. 32). Dust deposition at FC-2 exceeded sediment yield except in 1972. At the H. J. Andrews, dustfall exceeded sediment outflow at the following sites and years: HJA-7 1973, HJA-9 1971 and 1973, and HJA-10 1973. Suspended sediment yield at CC-4 exceeded dust deposition for all 3 years.

Nitrogen inputs are compared to outflows at the sites in Figures 33-36. The line below the shaded area on each figure is the "dissolved" N flow from the given linear equations. The upper line bounding the shaded areas is "dissolved" N plus N in particulate matter, and equations are given for these inputs at all sites. "Dissolved" and suspended sediment N outflows were curvilinear and are represented by hand-fitted curves except at FC-2 where the

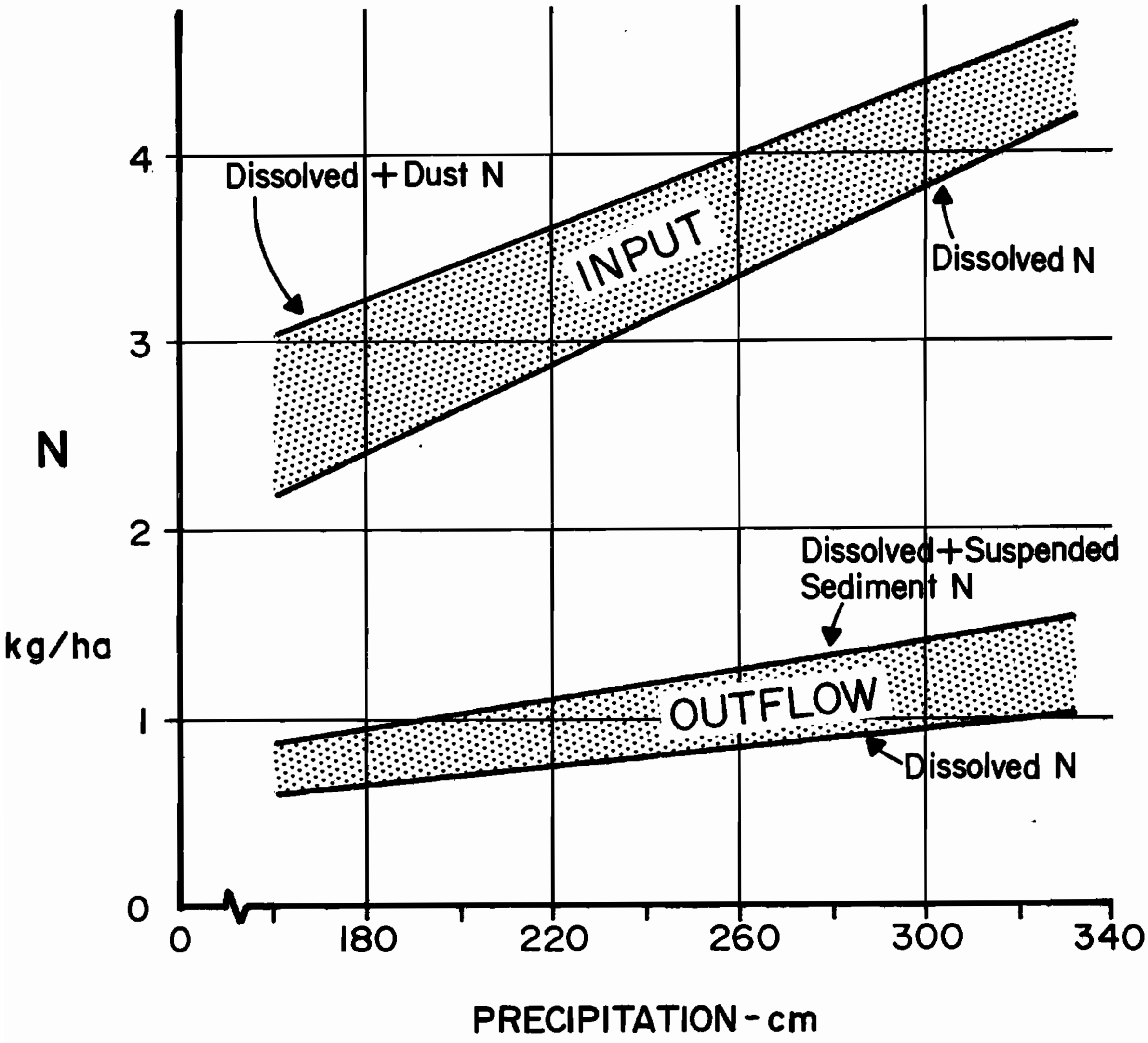

Figure 33. N input by "dissolved" matter and dust in precipitation and outflow by "dissolved" matter and suspended sediment in streamflow at FC-2.

<u>Equations</u>

Input	(tsd)	r	n
N (diss. + dust) = 1.46 + .0098 ppt	.97	.86	3
N (diss.) = .29 + .0118 ppt	1.08	.93	3
Outflow			
N (diss. + susp. sed.) = .26 + .0038 ppt	.30	.89	4
N (diss.) = .20 + .0025 ppt	.20	.90	4

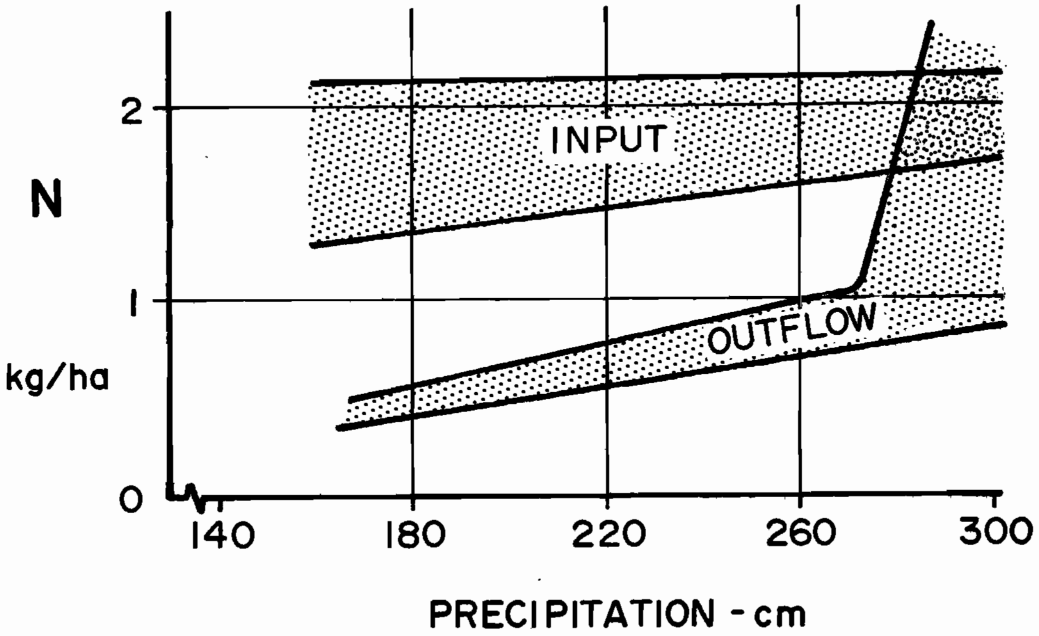

Figure 35. N input by "dissolved" matter and dust in precipitation and outflow by "dissolved" matter and suspended sediment in streamflow at HJA - 10.

Equations

	(tsd)	4	n
Input			
N (diss. + dust) = 2.03 + .00046 ppt	.16	.19	3
N (diss.) = .80 + .0030 ppt	.26	.75	3
Outflow			
N (diss. + susp. sed.) = hand fitted curve			3
N (diss.) = .0038 ppt -.28	.18	.997	5

relationship was linear. The linear equation accounted for a large proportion of the total variation in N flow as indicated by comparing the standard error of regression (tsd) to the range of the outflows. Extrapolations of the flows for estimating conditions causing negative N budgets are shown by dashed lines on the figures.

Nitrogen input increased with increasing precipitation, but the inputs by dust declined (Figs. 33-36) except at CC-4 where N input via dust increased by 1 kg/ha over the range of precipitation (Fig. 36). Nitrogen outflows by suspended sediment increased with increasing precipitation at all sites with high peak flows carrying the largest yields of suspended sediment in years of heavy precipitation.

At FC-2, N inputs exceeded outflow by a wide margin. Peak flows from heavy precipitation in the years reported here did not cause accelerated soil erosion, and therefore N inputs and outflows diverge.

Relationships of input to outflow were different at the other sites. In 1972, increasing N outflows by suspended sediment decreased the margin between input and outflow to -0. 17 kg/ha (Appendix II) at HJA-10 (Fig. 35) and to +0. 08 kg/ha at HJA-9 (Fig. 34) and +0. 70 at CC-4 (Fig. 36). The large sediment yields at the HJA sites resulted from a peak flow in early January caused by the combined effects of precipitation and rapid snowmelting. At CC-4, the largest measured yield from all sites (1,594 kg/ha) was the result of four

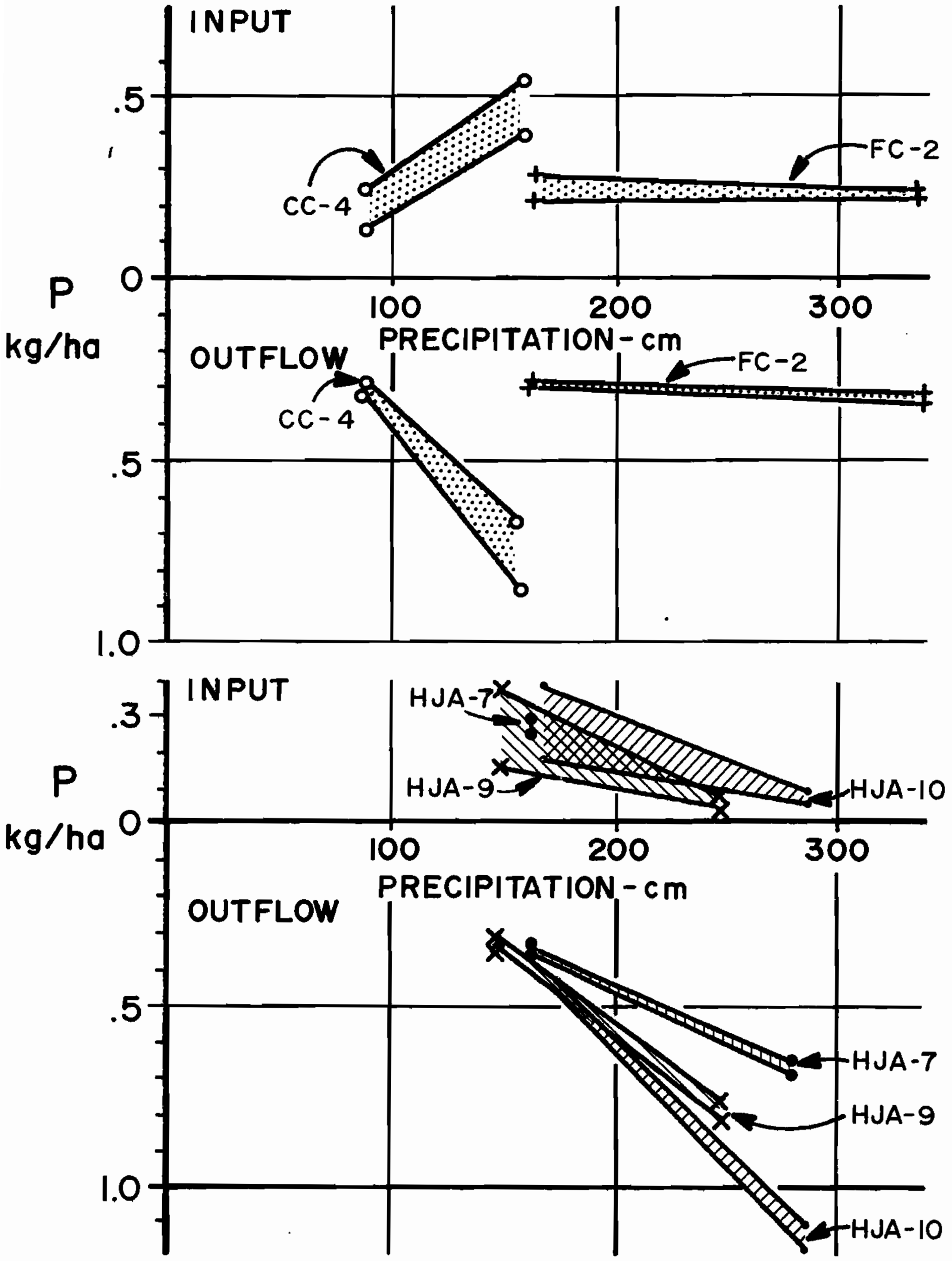

Figure 37. P input "dissolved" matter and dust in precipitation and outflow by "dissolved" matter and suspended sediment vs. streamflow for 1972 and 1973. The lesser precipitation values were for 1973.

heavy precipitation seasons rather than during the dry summer months. At CC-4 where the flushing season averaged 152 days (Table 10), 69% of the dust was measured in the moist seasons and at FC-2 81% came in the moist seasons. All sites have nearly complete vegetation cover, and traffic on logging roads is probably the main source of the summer deposition. Roads are a negligible source in the fall, winter, and spring months when the soil is wet most of the time and road traffic is greatly reduced. Dust deposition in the wet seasons is undoubtedly from the upper air circulation system of the earth and minor amounts come from local sources. The reduction in dust deposition with increasing annual precipitation may be the result of rain-out before the air mass carrying the dust arrived over the study sites. The concentration of aerosols and dust predominantly from auto exhausts, field burning and industry are trapped in the Willamette Valley by air inversions in the late summer and fall months. At FC-2 heavy dust deposition was evident in the fall precipitation of 1971 and 1973 (Fig. 7), but there was no evidence for increased nutrient input by the dust. The concentration of N and P in the dust at FC-2 (Table 3) in the fall and winter of those years was lowest among all of the sites except for HJA-7 in 1973 where the N and P concentration of dust was also low. Both sites occupy the highest elevation range among the study sites (Table 1) and may be in the path of air currents that carry lower concentrations of dust compared years (Youngberg and Wollum, 1975). The timing of the input may be as important as the amount of N contributed to the forest. Inputs in precipitation are continuous regardless of the successional stage of the vegetation. Symbiotic fixation is probably more periodic judging from the information available. It would appear from visual evidence that the epiphyte flora reaches full growth in mature stands and that the effect of these inputs would require rotation ages of more than 100 years. Nitrogen fixed by Ceanothus velutinus during the regeneration stage of Douglas-fir is undoubtedly of paramount importance to young stands to meet the N requirements during the period of juvenile growth. Inputs in fog drip (Azevedo, 1974) have not been confirmed for locations removed from the ocean. Work now underway by Dennison and Carroll (personal communication) may soon provide comparative information for N input by organisms in the canopy including epiphytes and free living organisms on the surface of conifer needles.

Soil erosion rates are closely related to peak streamflow from catastrophic storms. Soil losses from an undisturbed basin (HJA-2) located within 1 km of HJA-9 and 10 included stream bank erosion from catastrophic storm runoff in late December, 1964 (Fredriksen, 1970). Suspended sediment outflow was 860 kg/ha[5] for the year including this storm, and the average annual suspended

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[5] Data on file, Forest Science Laboratory, Corvallis, Oregon.

(Sedell et al., 1974); high concentrations of C, N, and P are evident during years with low to moderately high peak flows (1973, Table 6). During large peak flows (1972), stream bank erosion was the main source of sediment resulting in lower nutrient concentrations in the suspended sediment. Nitrogen outflow from HJA-2 was 0.16 kg/ha in 1967 and again in 1968; suspended sediment outflows were 21 and 30 kg/ha (Fredriksen, 1971). These data complement the relationships shown in Figures 16 and 18. The relationships of N and P transport by suspended sediment (Figs. 18 and 19) are a composite of all sites with bedrock stream channels with no terrace development. A different relationship was observed for FC-2 with well developed terraces and a gravel stream bed. While minor differences in the curve form may emerge among the sites as more data are available, the general form of the relationships (Figs. 16-19) should not change.

The bedload erosion at CC-4 in 1971 and 1972, was about half of the suspended sediment outflow. Only 2.4-4.3% of the N outflow was carried by the bedload and most of this was contained in the "soil" fraction (see methodology). Essentially no P was found in the bedload fractions. At another drainage basin study in New Hampshire, N transport by bedload sediment was 5.9% of the total N outflow for 1 year, but dissolved organic N and the N carried in suspended sediment was not analyzed (Bormann et al., 1969).

Gaultheria shallon and Acer macrophyllum which covered 40% of the drainage basin area (Grier et al., 1974). Fogel and Cromack (1973) found a relationship between the lignin content and the decomposition rate of the litter ($R^2 = 0.63$). The decomposition rate of Pacific rhododendron and Acer macrophyllum litter was about half that of the needles of Douglas-fir and the leaves of Acer circinatum. The litterfall on HJA-10 has a large component of branch and bark litter from standing dead trees and branches and bark had the lowest decomposition rate of all categories of forest litter. Based on vegetation cover measurements, litterfall in HJA-9 should be predominantly tree needles of Douglas-fir and leaves of Acer circinatum, and Corylus cornuta var. californica. Therefore a greater rate of litter decomposition would be expected on HJA-9 than HJA-10 based on the chemical composition of the litter. Also, winter and spring temperatures may be warmer on HJA-9 than on HJA-10. The peak streamflow from snowmelt is observed about 1 month earlier at HJA-9 than at HJA-10, but soil temperatures (Table 10), warmer on HJA-10 than HJA-9 in 1972, may be the result of one thermograph location high on the ridgetop while at HJA-9, thermographs are installed at low elevations in the basin. Snowmelt occurs earlier on ridgetop sites than lower slopes that are protected from direct solar radiation. Both temperature and litter composition on HJA-9 may enhance the outflow of soluble N and partly explain the observed replenishment could be explained by a greater level of soluble N production at these sites than is required by organisms of the forest. Excess ammonium, where production exceeded requirements would be available for nitrification. A much closer margin between production and uptake at HJA-9 and 10 would explain the much lower level of NO_3 found in drainage from these sites. A narrower margin between TN input and TN outflow was observed on the HJA sites compared to FC-2. Repression of nitrification may also be involved (Rice and Pancholy, 1972). Aqueous solutions of litter extracts have been found to repress nitrification (Boquel and Suavin, 1972).

Total P outflows were in the same general range as those for N. Temperature and composition of parent materials appeared to be factors controlling total P outflows. Organic P concentrations were lower in 1972 than in 1973 and soil temperatures at the study sites were also lower in 1972 than 1973. Ortho P concentrations remained relatively constant for the 2 years, but outflows of ortho P were accelerated in 1972 from the solubilization of ortho P and flushing from greater runoff. The levels of ortho P appeared to decline according to increasing proportions of basalt and andesite and decreasing proportions of tuff-breccia parent materials. Mineral weathering of tuff-breccia is undoubtedly more rapid than that of basalt and andesite.

increase the supply of organic matter and the mobilization of N in streamflow during years with higher rainfall. At the second site, N pulses from storm runoff were of longer duration than those observed from other sites. This may have been caused by a supply of readily decomposible leaf litter and a warmer winter environment compared to the other sites.

Three sites had less steeply sloped N/stream runoff relationships. One site, where the greatest level of N outflow was observed, there was a long period of flushing which encompassed the fall, winter and spring seasons. At the second site, the lignin content of leaf litter from the shrub layer on nearly half the area of the site was thought to depress the decomposition rate and N mobilization. At the last site, decomposition was thought to be depressed by cold winter soil temperatures and short fall and spring seasons when the soil temperature and moisture was conducive for decomposition.

3. Phosphorus outflow was apparently controlled by decomposition of organic matter and mineral weathering of soil parent materials. Ortho P outflow declined according to the increasing proportions of andesite and basalt rock at the sites. Organic P outflow was similar among the sites and lower organic P outflows were observed where the lowest soil temperatures were measured.

4. Soil erosion was predominantly from stream banks. The rates of soil erosion were low except where mantle creep caused stream

BIBLIOGRAPHY

Azevedo, J. and D. L. Morgan. 1974. Fog precipitation in coastal California forests. Ecology 55:1135-1141.

Beaulieu, J. D. 1974. Geologic hazards of the Bull Run Watershed, Multnomah and Clackamas Counties, Oregon. State of Oreg. Dept. of Geol. and Mineral Indust., Bull. 82, 77 p. plus maps.

Boquel, G., and L. Suavin. 1972. Inhibition of nitrification by aqueous extracts of litter of Tectona grandis and Melaleuca leucadendron. Revue d'Ecologie et de Biologie du Sol. p. 641-654.

Bormann, F. H., G. E. Likens and J. S. Eaton. 1969. Biotic regulation of particulate and solution losses from a forest ecosystem. BioScience 19:600-610.

Cleary, B. D. and R. H. Waring. 1969. Temperature: collection of data and its analysis for the interpretation of plant growth and distribution. Can. J. Bot. 47:167-173.

Clements, F. E. 1905. Research methods in Ecology. Univ. Publishing, Lincoln, Neb.

Cole, D. W., S. P. Gessel, and S. F. Dice. 1967. Distribution and cycling of nitrogen, phosphorus, potassium, and calcium in a second-growth Douglas-fir ecosystem. In: Symposium, Primary Productivity and Mineral Cycling in Natural Ecosystems. U. of Maine Press, p. 198-232.

Davis, W. M. 1899. Geographical essays, reprinted in D. W. Johnson, Ed. (Dover, New York, 1954). 777 p.

Denison, B., S. Anderson, B. Bormann, B. Caldwell, L. Eldred and C. Swanberg. 1974. The effects of acid rain on nitrogen fixation in western Washington coniferous forests. Evergreen State College, Olympia, Wn. 98505, 38 p.

Dyrness, C. T. 1967. Mass soil movements at the H. J. Andrews Experimental Forest. USFS, Res. Pap. PNW-42. 12 p., illus.

Helley, E. J. and V. C. LaMarche, Jr. 1973. Historic flood information for Northern California streams from geological and botanical evidence. Geol. Surv. Pap. 485-E, 16 p., illus.

Jackson, M. L. 1960. Soil chemical analysis. Prentice-Hall, Inc. 485 p., illus.

Jones, K. 1970. Nitrogen fixation in the phyllosphere of the Douglas-fir, *Pseudotsuga douglasii* Am. Bot. 34:239-44.

Kawahara, T., T. Tsutsumi. 1972. Studies on the circulation of carbon and nitrogen in forest ecosystems. Bulletin of the Kyoto University Forests No. 44:141-158.

McBirney, A. R., J. F. Sutter, H. R. Naslund, H. G. Sutton and C. M. White. 1974. Episodic volcanism in the central Oregon Cascade Range. Geology, Dec. 1974. p. 585-589.

Minore, Don. 1972. A classification of forest environments in the South Umpqua Basin. USDA For. Serv. Res. Pap. PNW-129, 12 p. plus appendices.

Moodie, C. D. 1964. Nutrient inputs in rainfall at nine selected sites in Washington 1962-1963. Wash. Agric. Exp. Stn. Wash. State Univ. 8 p. illus.

Peck, D. L., A. B. Griggs, H. G. Schlicker, F. G. Wells and H. M. Dole. 1964. Geology of the central and Northern parts of the Western Cascade Range in Oregon. Geol. Surv. Prof. Pap. 449, 56 p. plus maps.

Penck, W. 1953. Morphological analysis of landforms. Transl. by H. Czech and K. C. Boswell, MacMillan and Co., St. Martin, New York.

Pike, L. H., D. M. Tracey, M. A. Sherwood, and D. Nielsen. 1972. Estimates of biomass and fixed nitrogen of epiphytes from old-growth Douglas-fir. In: J. F. Franklin, L. J. Demster, and R. H. Waring (eds.), Proc.--Res. on Conif. For. Ecosystems, p. 177-187.

Pruppacher, H. R. 1973. The role of natural and anthropogenic pollutants in cloud and precipitation formation. In Chemistry of the Lower Atmosphere Ed. by S. I. Rasool, Plenum Press, N. Y. London 1973 p. 1-60.

Thompson, P., H. P. Schwarcz, and F. C. Derek. 1974. Continental pleistocene climatic variations from speleotherm age and isotope data. Science 184:893-895.

Walkley, A. and I. A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci. 37:29-38.

Water Resources Council. 1966. A study of methods used in measurement and analysis of sediment loads in streams. Report T, Progress Rep. Lab. Invest. Pumping Sampler Intakes, Fed. Interag. Sed. Proj., Minneapolis, Minn., 48 p., illus.

Wilm, H. G. and H. C. Storey. 1944. Velocity-head rod calibrated for measuring streamflow. Civil Eng. 14:475-476.

Wilson, A. T. 1959. Surface of the ocean as a source of air borne nitrogenous material and other plant nutrients. Nature 184:99-101.

Wood, E. D., F. A. J. Armstrong and F. A. Richards. 1967. Determination of nitrate in sea water by cadmium copper reduction to nitrite. J. Marine Biol. Assn. U. K. 47:23-31.

Wright, H. E., Jr. 1974. Landscape development, forest fires and wilderness management. Science 186:487-495.

Youngberg, C. T. and A. G. Wollum. 1975. Nitrogen accretion in developing Ceanothus stands. Soil Sci. Soc. Amer. Proc. 39 (in press)

APPENDICES

APPENDIX I

List of Plant Species

Abies amabilis (Dougl.) Forbes	Pacific silver fir
Abies concolor (Gord. & Glend.) Lindl.	white fir
Abies grandis (Dougl.) Lindl.	grand fir
Acer circinatum Pursh.	vine maple
Acer macrophyllum Pursh.	bigleaf maple
Berberis nervosa Pursh.	Oregon grape
Bromus orcuttianus Vasey	Orcutt's brome
Castanopsis chrysophylla (Dougl.) A. D C.	golden chinkapin
Cornus nuttallii Aud. ex T. & G.	Pacific dogwood
Corylus cornuta var. *californica* (D. C.) Sharp	California hazel
Gaultheria shallon Pursh.	salal
Holodiscus discolor (Pursh.) Maxim.	creambush oceanspray
Libocedrus decurrens Torr.	incense-cedar
Lobaria oregana (Tuck.) Mall. Arg.	
Oxalis oregana Nutt. ex T. & G.	Oregon oxalis
Pinus lambertiana Dougl.	sugar pine
Pinus ponderosa Dougl. ex Loud.	ponderosa pine
Polystichum munitum (Kaulf.) Presl.	swordfern
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir
Rhododendron macrophyllum G. Don	Pacific rhododendron
Tsuga heterophylla (Raf.) Sarg.	western hemlock
Vaccinium alaskense How.	Alaska huckleberry
Whipplea modesta Torr.	whipple vine
Xerophyllum tenax (Pursh.) Nutt.	common beargrass

APPENDIX (Continued)

Site	Year	Water Flow	Input or Outflow	Method of Transport[1/]	Material Flows		
					Particulate Matter	N	P
		cm			kg/ha		
H. J. Andrews 7	1972	161.9	out	Diss		.55	.65
				SSed	46.0	.43	.03
						.98	.68
	1973	162.2	in	Diss		1.38	.26
				Dust	17.5	.06	.03
						1.44	.29
		55.5	out	Diss		.20	.34
				SSed	8.7	.01	.01
						.21	.35
H. J. Andrews 9	1969	207.0	in	Diss		1.68	.09
				Dust	21.7		
	1969	144.1	out	Diss		.89	
				SSed	40.6		
	1970	177.1	in	Diss		1.23	
				Dust	19.9		
	1970	105.6	out	Diss		.53	
				S sed	22.3		
	1971	223.0	in	Diss		1.48	
				Dust	25.5	.43	
						1.91	
	1971	148.2	out	Diss		.84	
				SSed	23.0	.40	
						1.24	
	1972	247.6	in	Diss		1.32	.05
				Dust	15.8	.44	.03
						1.76	.08
	1972	198.8	out	Diss		1.01	.76
				SSed	65.9	.67	.03
						1.68	.79
	1973	148.8	in	Diss		1.13	.16
				Dust	31.7	.70	.24
						1.83	.40
	1973	63.4	out	Diss		.29	.32
				SSed	5.5	.07	.02
						.36	.34

APPENDIX (Continued)

Site	Year	Water Flow	Input or Outflow	Method of Transport[1/]	Particulate Matter	N	P
		cm			-------------	kg/ha	-----------
Coyote Creek 4	1970	51.5	out	Diss.		.55	.16
				SSed	122.2	.23	.14
						.78	.30
	1971	156.0	in	Diss		2.10	
				Dust	37.	1.04	
						3.14	
	1971	88.9	out	Diss		.63	
				SSed	624	1.44	
				Bedl	373	.05	
					997	2.12	
	1972	153.0	in	Diss		2.20	.37
				Dust	46	1.29	.15
						3.49	.62
	1972	107.0	out	Diss		.88	.66
				SSed	1594	1.79	.18
				Bedl	635	.12	.01
					2229	2.79	.85
	1973	89.5	in	Diss		1.40	.14
				Dust	34	.19	.11
						1.59	.25
	1973	28.9	out	Diss		.29	.29
				SSed	107	.06	.04
						.35	.33

[1/] Transport by dissolved (Diss), suspended sediment (SSed), dust, and bedload (Bedl).