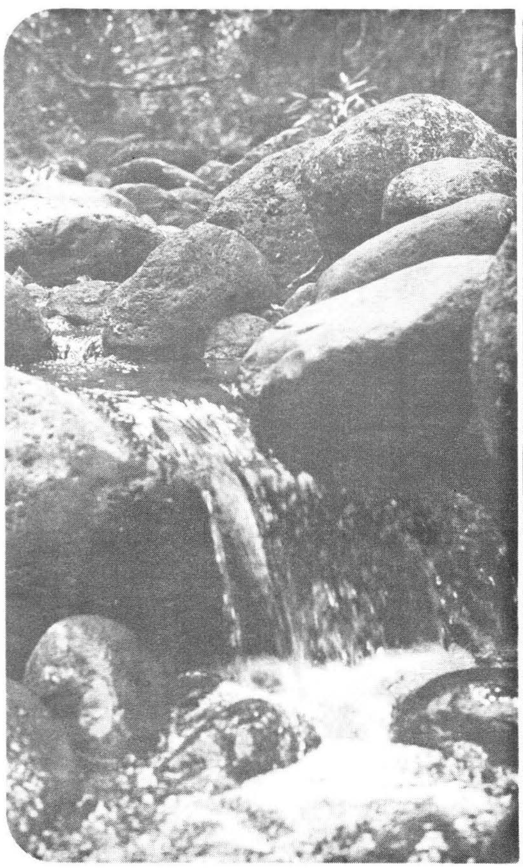
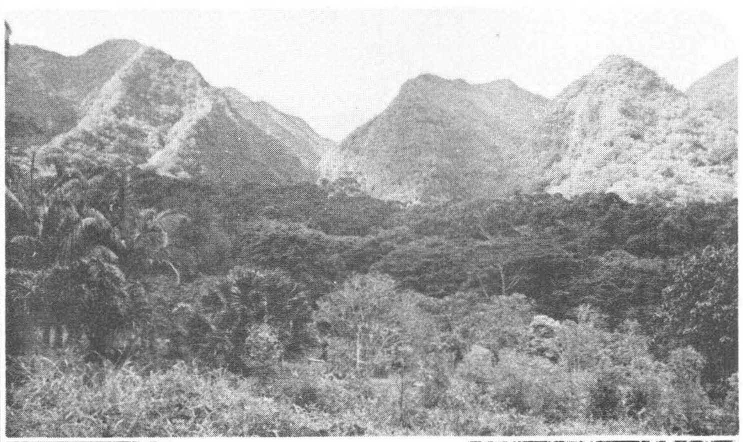
Quality Trends for Waters Harold L. Lyon Arboretum, 1974

S. A. El-Swaify and L. R. Ahuja





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ABSTRACT

Quality trends for rainfall, throughfall, runoff, and extracted soil-water samples from the Harold L. Lyon Arboretum, University of Hawaii, were established for the 1974 calendar year. It was found that seasonal variations occur in pH, electrical conductivity, and nitrate contents of the waters, some of which may be due to rainfall fluctuations. Consistent differences in these properties were noted among collected samples, which indicated that canopy contributions to water composition were appreciable. Of particular interest was the very high NO_3^- *concentration, reaching as much as 11 ppm in certain samples, measured in the soil solution on a site in a eucalyptus grove with ground cover of palm grass. Whether eucalyptus or palm grass is responsible for high nitrate levels has not been definitely established. It is important to note, however, that despite the high content of* NO_3^- *noted in some soil-water samples, the measured levels remain safely under those that are permissable for human consumption. Runoff waters seldom contained more than 1 to 2 ppm of this constituent.*

ACKNOWLEDGMENTS

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CONTENTS

Figures

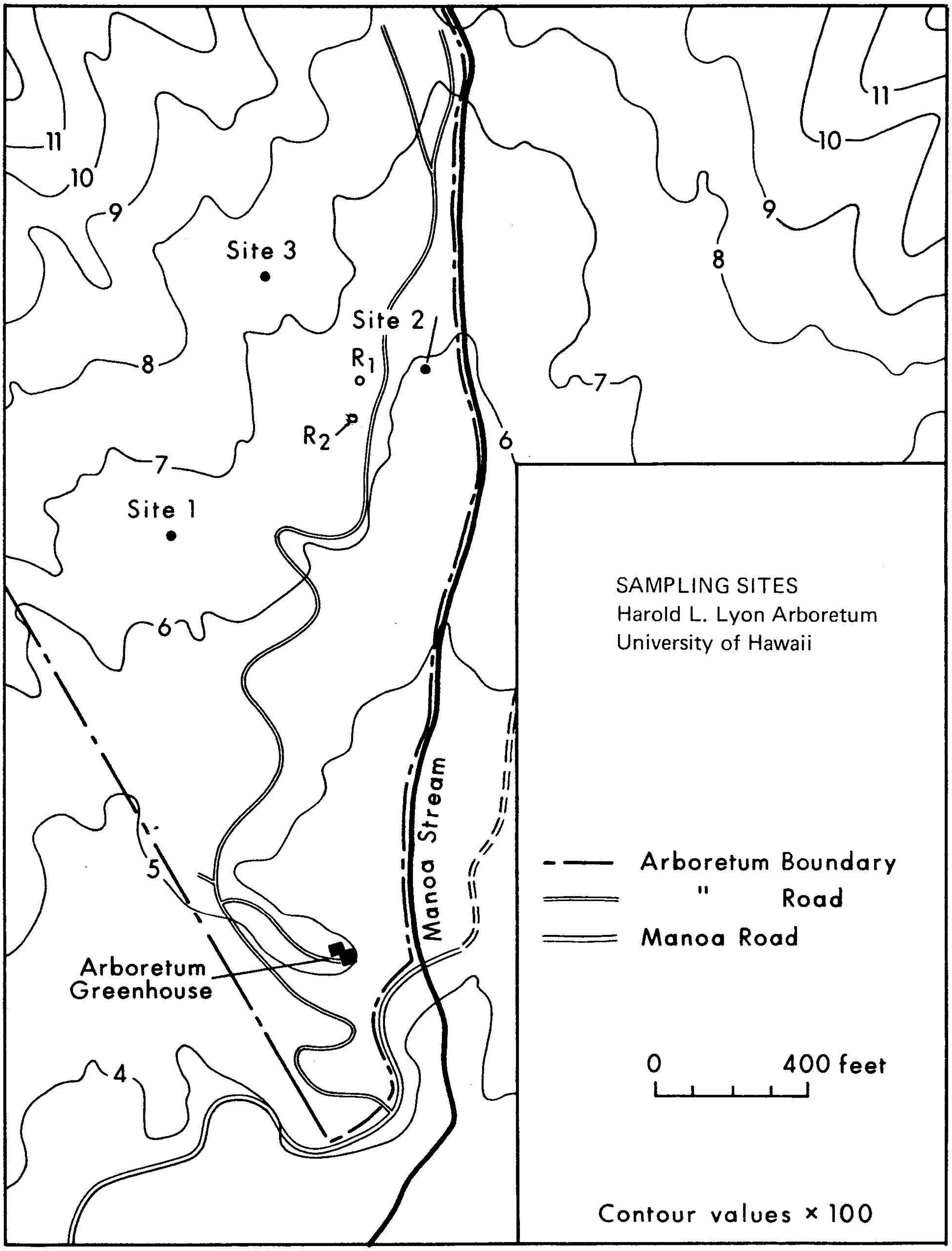

Figure 1. Map of the Harold L. Lyon Arboretum showing water sampling locations. R_1 was the site for rainfall collection, R_2 for throughfall collection, and Sites 1, 2, and 3 for soil solution collections.

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INTRODUCTION

Water yielded by undisturbed forest watershed is subject to the least possible interference from humans; its characteristics and composition reflect only the contributions of rain, vegetation, and soil or rock under a natural, steady-state balance. The quality of such water, therefore, provides a feasible baseline for judging whether or not changes in water characteristics resulting from management practices imposed along the watershed basin are detrimental. Realistic criteria may then be adopted for the purpose of establishing acceptable water quality standards in various regions.

Forest lands in temperate areas have been subjected to many studies involving the cycles of nutrients and their distributions among various components, including soil and water, of the forest system (for example, Duvigneand and Denaeyer-de Smet, 1970). Some such information is also available for tropical forests (Greenland and Kowal, 1960; Nye, 1961). Recently, in an intensive study of irradiation and ecology at El Verde, Puerto Rico, Odum and Pigeon (1970) presented some detailed information on mineral cycling in a tropical rain forest. Their study included investigations of the three parameters examined in this report: namely, acidity, electrical conductivities, and nitrates.

In Hawaii, despite the availability of annual water quality records (U.S. Geological Survey, 1967-present), little is known on the composition of waters of forest watersheds. The objective of this study was to establish trends for pH, electrical conductivity, and nitrate content in soil solutions under various vegetative types and in the rainfall and runoff waters in selected locations at the Harold L. Lyon Arboretum, University of Hawaii, Manoa Valley, Oahu, Hawaii.

MATERIALS AND METHODS

Water Collection Sites

Water samples were collected at biweekly intervals from the sites marked on the map of the Arboretum (Figure 1). Rainfall samples were collected from raingages located on two sites: the first (R-1) on an open *Canna* lily field and the second (R-2) under a closed canopy of Chinese banyon (*Fiscus retusa*) on a plot that was delineated for rainfall-runoff experiments. Runoff samples were collected from barrels installed under the above plot to collect runoff water. Soil solution samples were collected by suction extraction from 15 and 120 cm depths from three locations. Samplers used for this purpose consisted of ceramic cups installed on PVC tubing. Vegetative covers at the three locations were dominated by a full canopy of *Eucalyptus* sp. on Site 1, a full canopy of mixed *Cecropia* sp. and *Citharexylum* sp. on Site 2, and a partial canopy of *Terminalia* sp. on Site 3.

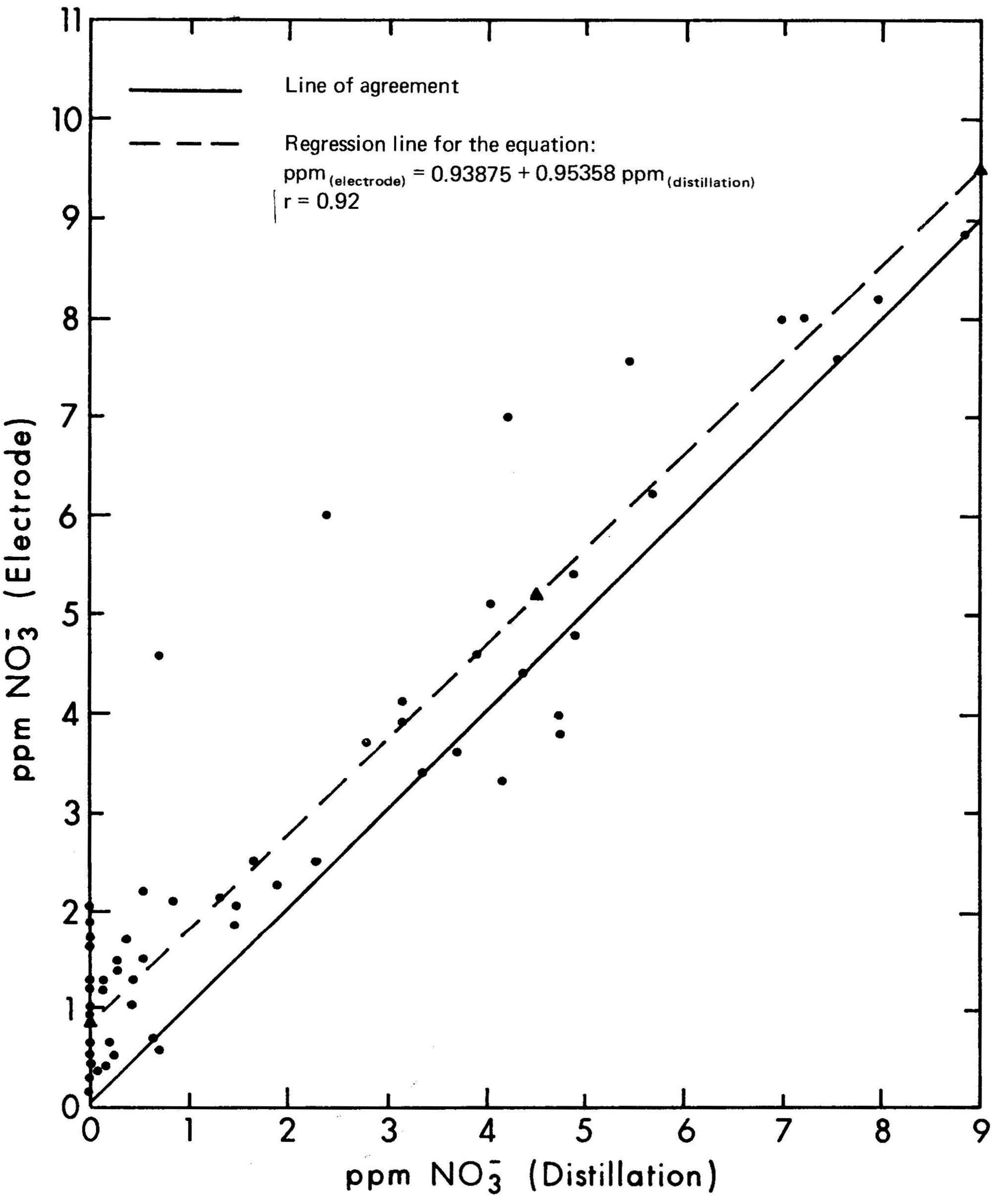

Figure 2. Comparison between NO_3 concentrations measured by nitrate electrode and by Kjeldahl distillation.

Samples were collected in polyethylene bottles, returned immediately to the laboratory, and analyzed soon thereafter.

Analysis of Water Samples

Acidity was evaluated using pH measurements with a Beckman Expandomatic or an Orion Model 8000 digital pH meter. Electrical conductivities, reported as mmhos/cm, were measured using an Industrial Instruments solu-bridge and a conductivity cell with a constant of 5. Nitrates were always determined potentiometrically, using an Orion Nitrate electrode attached to the above pH meters, and occasionally determined by reduction and subsequent distillation in a micro Kjeldahl unit followed by titration of boric acid-trapped NH_3 by standardized H_2SO_4. Values obtained by the two methods were generally comparable, although slightly higher values were obtained by electrode measurements (Figure 2), particularly in the low range of NO_3^- concentration. It would appear, therefore, that interference errors during electrode measurements exceeded errors due to the recovery of forms other than NO_3^- during NH_4 distillation. A regression equation relating both measurement methods is presented in Figure 2.

RESULTS

Quality Characteristics of Rainfall Water

The acidity of water collected from the open field (sample R-1) remained rather steady as indicated in Figure 3 by the pH values, which generally ranged from 6.0 to 6.8. Excessive acidity, occasionally reported and suspected during certain times of volcanic activity on the Island of Hawaii, was noted only on September 26 when the pH of the sample fell to 4.5. As expected, the electrical conductances were the lowest among the samples investigated, ranging from 0.02 to 0.06 mmhos/cm and indicating a low content of soluble material (10-30 ppm). These values closely corresponded to others previously reported for tropical rainfall (Duvigneand and Denaeyer-de Smet, 1970). Nitrate contents were also extremely low, generally ranging from 0.4 to 0.8 ppm most of the year. It would be reasonable to assume, therefore, that this sample provides a natural reference for discussion of effects of various forest components on water quality.

The second rainfall (sample R-2) was collected from a relatively closed canopy and represents the effect of throughfall and contact with overlying tree leaves and branches on water quality. Figure 4 shows that pH values for this sample were slightly higher than those for sample R-1 from the beginning of collection until mid-July; close agreement between the samples is shown thereafter. It is of interest to note, however, that on September 26, the R-2 sample pH fell only to 5.2 in contrast to the value of 4.5 measured for the R-1 sample. It would appear, therefore, that throughfall is subject to a considerable decrease of acidity, compared to original rainfall, due to contact with overlying segments of the canopy. It must also be emphasized that rainfall waters are expected to be weakly buffered and that their pH values are, therefore, easily changed by contact. Electrical conductances of the R-2 sample exceeded their counterparts for the R-1 sample early in the year, a trend previously noted in a Puerto Rico forest by Sollins and Drewery (1970). After the collection of August 10, however, the trend was reversed for a while and then a progressively closer agreement was noted between the two samples toward the year's end. It would be difficult to explain the reduction of soluble ion concentration noted occasionally in throughfall except by the possibility of nutrient absorption from rainfall during contact with vegetation. If this absorption did occur, it apparently did not involve NO_3^- since a comparison between Figures 3 and 4 reveals nitrate contents to be nearly identical for rainfall and throughfall.

Quality Characteristics of Runoff Water

The composition of water collected from a runoff plot represents the contribution of brief contact with the forest to changes in the quality of throughfall. This is because, as stated in the section on Methods and Materials, throughfall sample R-2 was collected from raingages placed on that plot. Figure 5 shows that the pH of runoff water ranged only between 6.1 and 6.6 and thus varied less with time than the pH of either of the rainfall samples. This indicates that the brief contact between rainfall and forest floor (litter and the uppermost mineral soil layer) resulted in sufficient stabilization of water acidity levels. It also clearly indicates that litter contributes only slight acidity to runoff water.

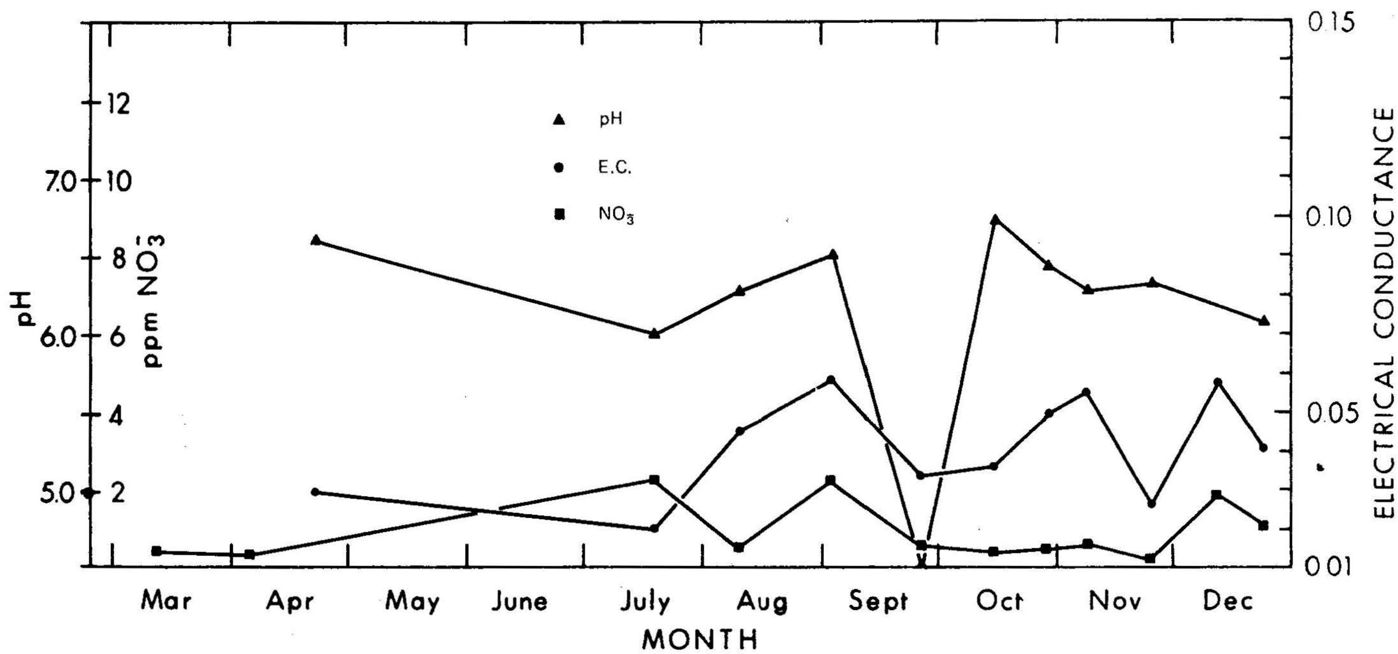

Figure 3. Trends of pH, E.C. (electrical conductivity), and NO_3 concentration in rainfall samples collected from an open area.

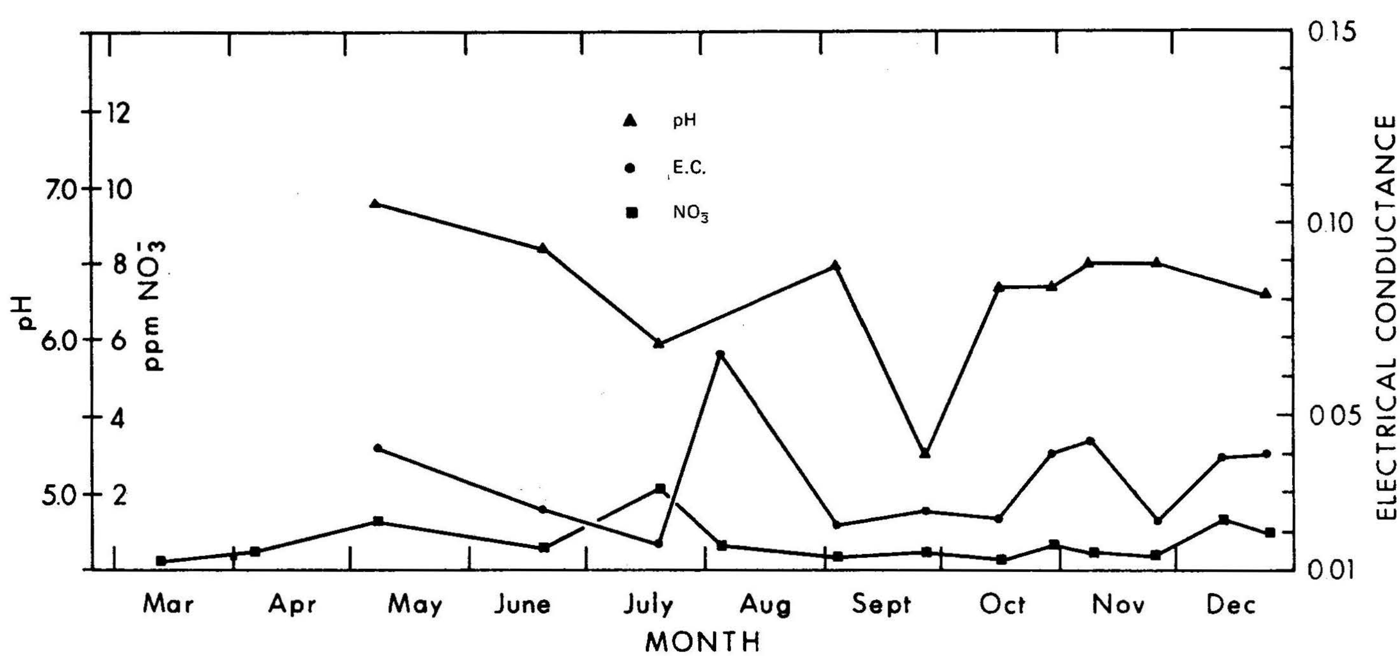

Figure 4. Trends of pH, E.C. (electrical conductivity), and NO_3 concentration in throughfall samples collected under a relatively closed canopy.

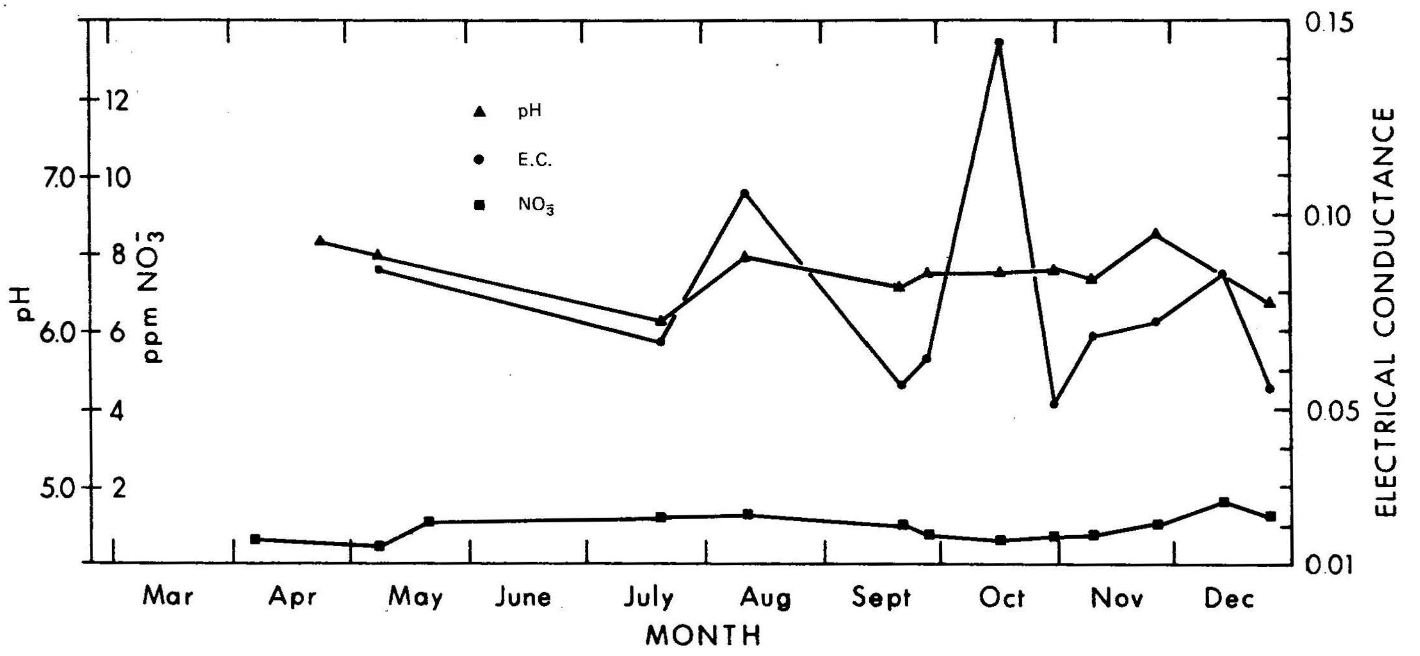

Figure 5. Trends of pH, E.C. (electrical conductivity), and NO_3 concentration in runoff samples.

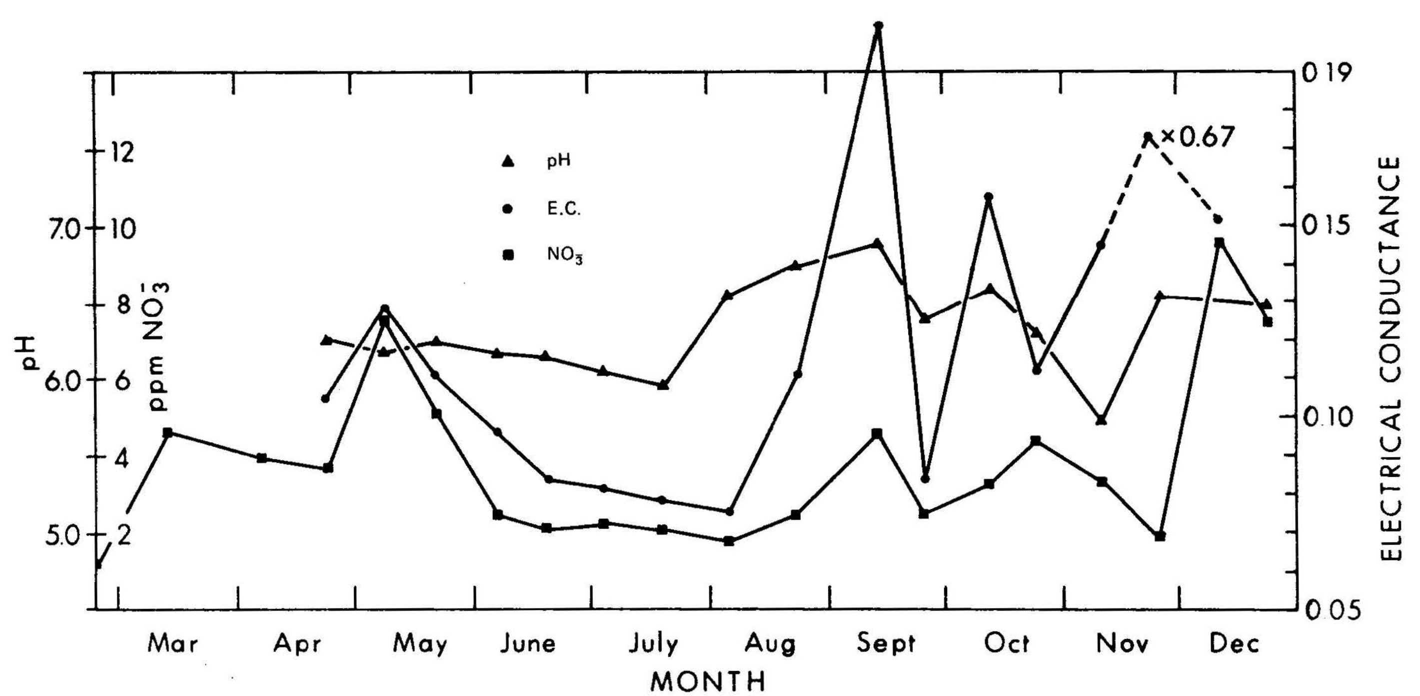

Figure 6. Trends of pH, E.C. (electrical conductivity), and NO_3 concentration in soil solution extracted from a depth of 15 cm under a vegetation dominated by *Eucalyptus* sp. and palm grass.

Markedly higher total soluble ion contents are observed in runoff water than in either of the two rainfall water samples. The contact of rainfall with decomposing forest litter and uppermost soil layer during overland flow approximately doubled electrical conductivities. Sollins and Drewery (1970) recorded appreciably higher electrical conductivities for stemflow than for rainfall, but no information is available in the literature on the contribution of overland contact to changes in electrical conductivities of water. Interestingly, the NO_3^- content of runoff water, as shown in Figure 4, was not appreciably different from that of either of the rainfall samples. Because NO_3^- salts are highly soluble, this may be explained by the tendency of any NO_3^- resulting from organic litter decomposition to be carried with the very first increments of rainfall. These increments enter the soil and by the time runoff is initiated, little NO_3^- is left in the litter. It is clear that insufficient amounts of NO_3^- are consistently produced by the litter to result in significant enrichment of runoff water within rainstorms. Only on a few occasions did its concentration in this water exceed 1 ppm.

Quality Characteristics of Extracted Soil Water

Samples collected from 15 and 120 cm depths at three locations will be referred to as top and bottom samples, respectively. Results of analysis of these samples are presented in Figures 6 to 11.

Some differences in water acidity are noted in the top sample of Site 1 (*Eucalyptus* sp.) when compared to rainfall samples (Figures 3 and 4). Values of pH were generally lower from extracted water than from rainfall until August, at which time they began to be higher. In October, and for the remainder of the year, pH values of extracted water samples were nearly equal to those of rainfall samples. In contrast, a very appreciable increase was noted in the electrical conductivities of these soil samples. As shown in Figure 6, electrical conductivity values generally ranged from 0.08 to 0.2 mmhos/cm, representing a three- to fourfold increase in soluble ion content in extracted samples over rainfall samples. This is a clear indication that appreciable mineralization of organic matter occurs continually in this site, which was confirmed by the very high NO_3^- concentrations, generally ranging from 2 to 7 ppm, in these waters. These concentrations in extracted solutions are five to nine times as much as those in rainfall. It is estimated, therefore, that nitrogen mineralization contributes twice as much soluble material as mineralization of other elements on this site.

Figure 7 shows that pH values were generally lower and E.C. and NO_3^- higher in the bottom sample on Site 1 than the top sample. Values for pH were generally below 5 and, throughout the year, ranged between 5.5 and 6.2, representing the highest levels of acidity noted among sites used in this study. Electrical conductivities in the bottom sample significantly exceeded those in the top sample early in the year but had almost equal values after August. Similarly, NO_3^- concentrations in the bottom exceeded those on the top until the month of October, after which time the samples had nearly the same concentrations for a short period before the trend was reversed for the latter part of the year. The NO_3^- levels in this sample reached as high as 12 ppm and were the highest observed in this study. The little data available in the literature (Viets and Hageman, 1971) indicate that these levels exceed expectations. The possible roles of *Eucalyptus* sp. and ground cover (palm grass) in this phenomenon needs further investigation. The palm grass genus is known to accumulate large quantities of nitrates in the plant body. As high as 2000 ppm nitrate concentration has been measured in a composite sample (personal communication, Dr. Y. Kanehiro, Department of Agronomy and Soil Science, University of Hawaii).

Top samples from Site 2, where prevailing vegetation was composed of *Cecropia* sp. and *Citharexylum* sp., show no unexpected trends in their contents of acidity, total soluble constituents, or NO_3^- (Figure 8). The pH ranged between 5.6 and 7.0--the low values prevailing during the summer months and the high during the winter. Similar observations were previously made by Kanehiro, Matsusaka, and Sherman (1951) regarding seasonal variations of soil pH in Hawaii. Electrical conductivities generally remained below 0.10 mmhos/cm and NO_3^- below 2.0 ppm. Except for the September interval, little fluctuations were noted in these two parameters throughout the year.

The quality of bottom samples from Site 2 (Figure 9) was generally comparable to that of top samples; however, pH and electrical conductivity values were consistently higher in the first than in the latter. Nitrate concentrations were almost equal for both throughout the year, remaining in the range of 0.5 and 2.0 ppm.

Top samples from Site 3 (Figure 10) exhibited higher pH values than samples from other sites, ranging from 6.0 to 7.0; however, electrical conductivities for this site, dominated by *Terminalia* sp., were comparable in value to those observed for the *Eucalyptus* sp. site.

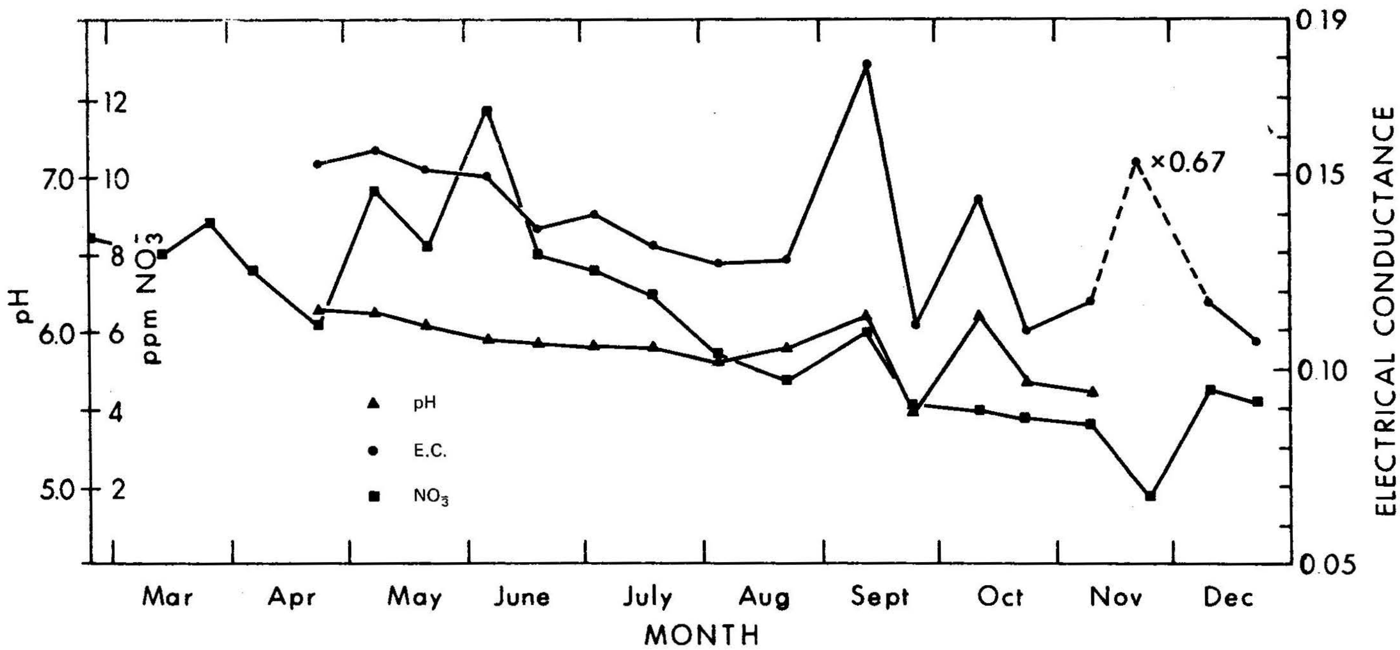

Figure 7. Trends of pH, E.C. (electrical conductivity), and NO_3 concentration in soil solution extracted from a depth of 120 cm under a vegetation dominated by *Eucalyptus* sp. and palm grass.

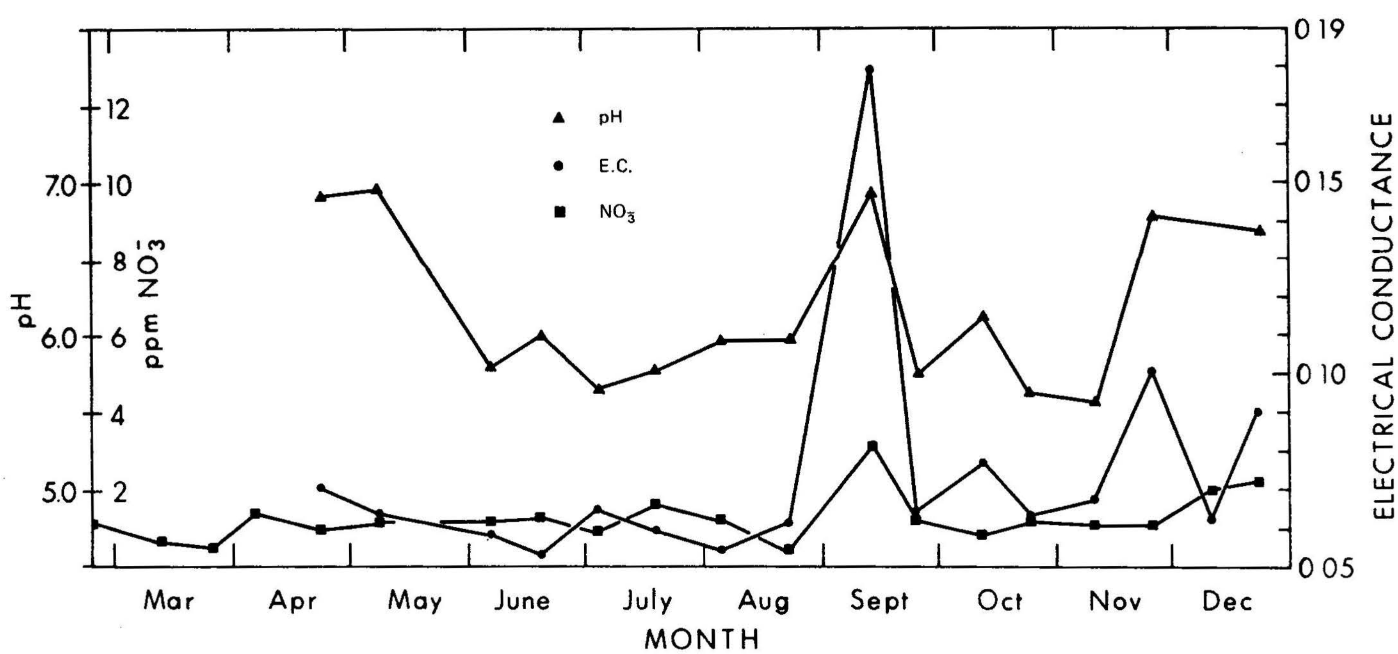

Figure 8. Trends of pH, E.C. (electrical conductivity), and NO_3 concentration in soil solution extracted from a depth of 15 cm under a vegetation dominated by *Cecropia* sp. and *Citharexylum* sp.

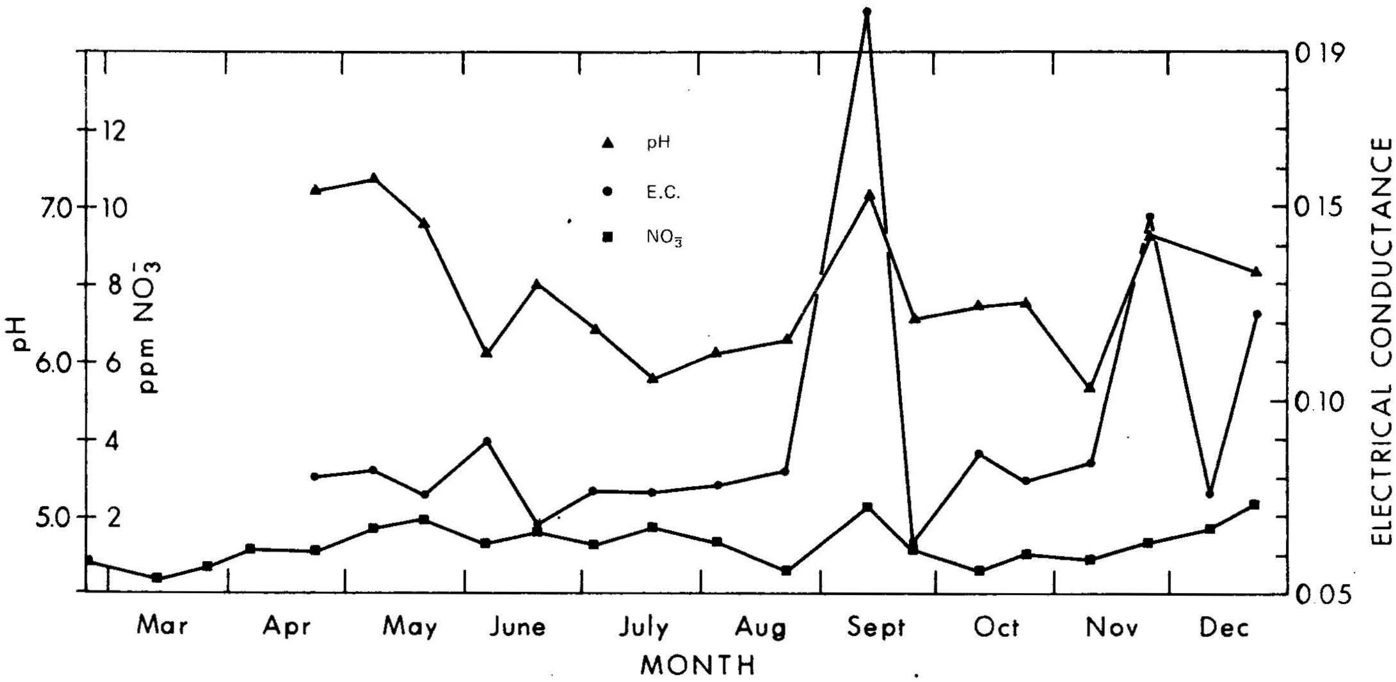

Figure 9. Trends of pH, E.C. (electrical conductivity), and NO_3 concentration in soil solution extracted from a depth of 120 cm under a vegetation dominated by *Cecropia* sp. and *Citharexylum* sp.

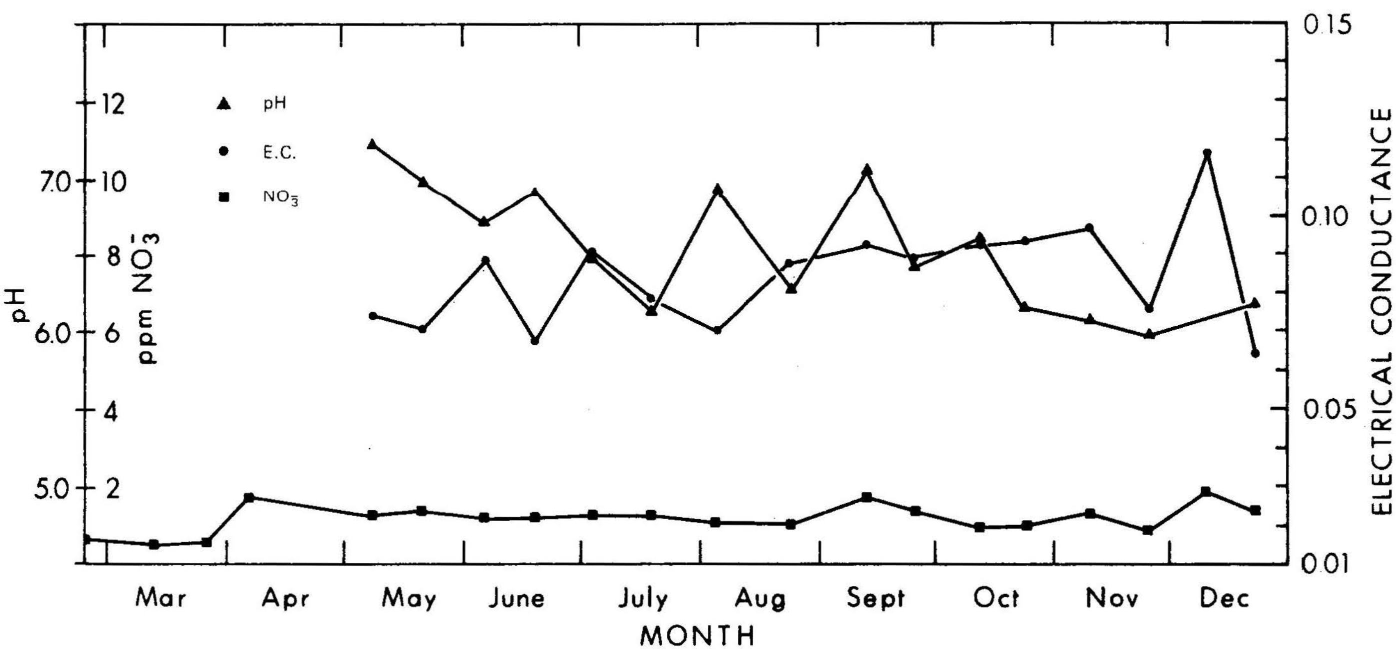

Figure 10. Trends of pH, E.C. (electrical conductivity), and NO_3 concentration in soil solution extracted from a depth of 15 cm under a vegetation dominated by *Terminalia* sp.

Nitrate levels, on the other hand, remained closer to those observed for Site 2, generally ranging from 0.5 to 2.0 ppm. It would appear, therefore, that NO_3^- mineralization at this site relative to other elements is not as appreciable as was the case under Eucalyptus sp.

In the bottom samples of Site 3 (Figure 11), the trends were similar to those of the top samples. Thus, pH values generally ranged between 6.0 and 8.0. Electrical conductivities ranged between 0.08 and 0.13 slightly higher than the top samples and also very high in comparison to the other sites. NO_3^- concentrations were only slightly higher in the bottom than in the top samples, but they were still in the range of 0.5 to 2.3 ppm.

DISCUSSION AND CONCLUSIONS

Variations of the amount of precipitation, as shown in Figure 12, offer some explanation for the variations of water composition throughout the year. This relationship results from dilution of water constituents when rainfall is more abundant and from concentration of the constituents when rainfall is less. Examples of the first case include lower observed electrical conductivities and NO_3^- concentrations in the collections of June 13, July 3, September 26, and November 11 when preceding 24-hour precipitation was very high. Examples of the second case include the higher observed electrical conductivity values and NO_3^- concentrations in the collections of September 12, October 23, and November 26. Seasonal variations in mineral contents of plants are normal (Reichle, 1970), however, and can account for some of the seasonal variations in water composition. The possible role of mineral inputs into the forest system from outside sources is also an important factor. Ocean spray, although not well-documented in the Hawaiian Islands, is expected to contribute soluble salts as noted by the relatively high values of electrical conductivities in certain rainfall samples (Figures 2 and 3). This would be particularly true during the days of southwestern (Kona) winds or of strong northeastern (common trade) winds. After sufficient time has elapsed, runoff and soil-solution samples reflect such abnormally high electrical conductivities as noted in Figures 5 to 11.

On the other hand, differences in composition among collected water samples are generally so consistent that water qualities on various locations are considered inherent to these locations. Additional supporting data, however, is needed to verify why these differences occur--the most obvious is the mass and composition of organic litter contributed by the prevailing vegetations. Also, further delineations are needed to establish the roles of various forest components--for example, stem flow, throughfall from different vegetations, and proximity of sampling site from trees--in the effect on water composition. Finally, definite possibility exists that some of the soil nutrients are in adsorbed form and, therefore, soluble nutrient contents in water, as reported above, only represent a fraction of the total nutrient reservoir in the soils. This would be true even for anions (for example, NO_3^-) since at prevailing pH values in these locations, which ranged from 5.0 to 6.2 in dilute soil dispersions, considerable positive charges would be expected at surfaces of soil constituents.

The differences in soluble NO_3^- concentration among the three soil locations, with the Eucalyptus sp. providing the highest levels, are worthy of elaboration. Edmisten (1970) reported wide differences in NO_3^- concentrations from 4.0 to 21.0 ppm under six different vegetative types in soils of one rain forest. His values are rather high, as they comprise total soil nitrate contents (not just the content of soil solution) of the upper 5 cm only. It is now well-established that different plants, even within one species, tend to accumulate nitrates to different degrees in their tissues (Viets and Hageman, 1971) and thus would be expected to affect soil NO_3^- levels differently. Indeed, it is also well-established (for example by Ovington and Olson, 1970) that different plant organs within one species contain different levels of nitrogen and that these vary with plant age. For a representative of Cecropia sp. on Site 2 (Cecropia peltata), Ovington and Olson showed nitrogen contents to be 0.53-0.96 percent for small roots, 0.19-0.38 percent for butt roots, 0.12-0.40 percent for boles, 0.55-0.62 percent for branches, and 1.66-1.85 percent for leaves. Unfortunately, no such data are available for Eucalyptus sp. or any of the underlying ground covers at the various collection sites. However, even if nitrogen levels in Eucalyptus sp. tissues are not abnormally high, these trees have been shown by some workers to enhance salt storage in forest catchments as indicated from chloride balance estimates (Peck and Hurle, 1973). It may be assumed, therefore, that the very high NO_3^- concentration in the soil solution around these trees is enhanced, at least in part, by their tendency to use excessively large amounts of water and to thus cause large water and nutrient movement gradients toward their roots. The effect of depth on NO_3^- concentration in soil solution--that is, the increased concentration in relation to depth--was most clearly noted for the Eucalyptus

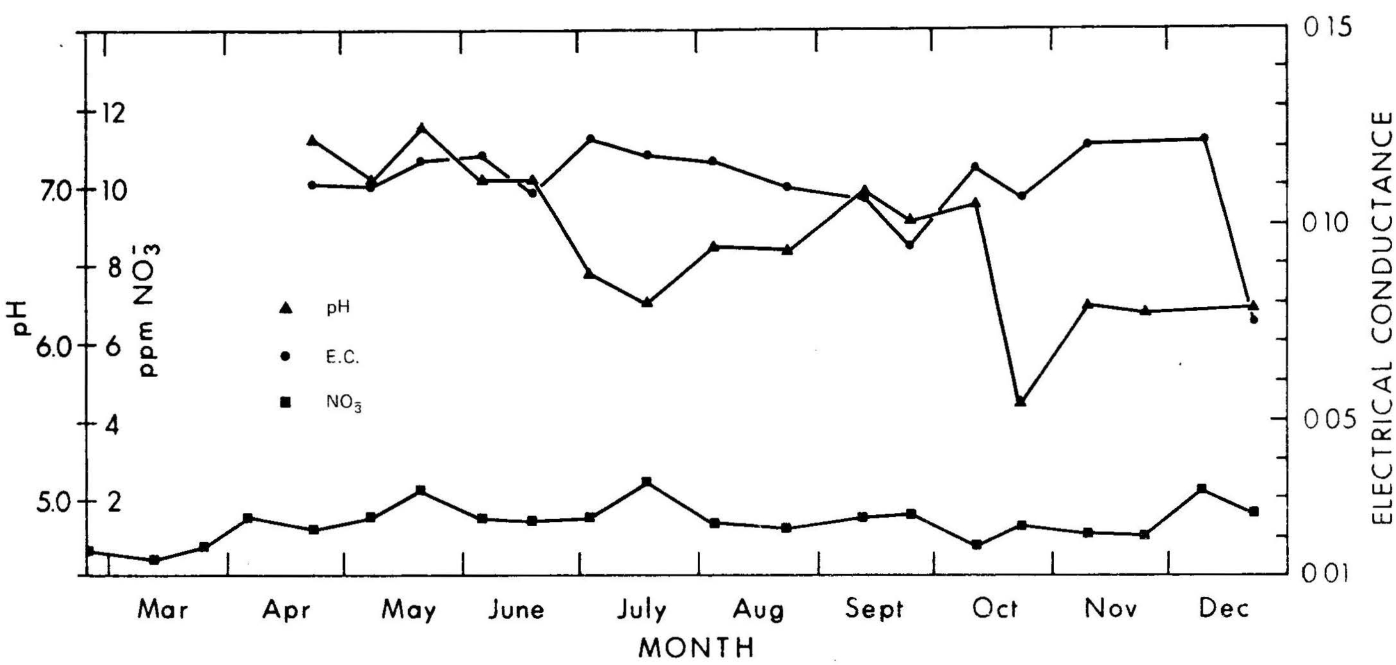

Figure 11. Trends of pH, E.C. (electrical conductivity), and NO_3^- concentration in soil solution extracted from a depth of 120 cm under a vegetation dominated by *Terminalia* sp.

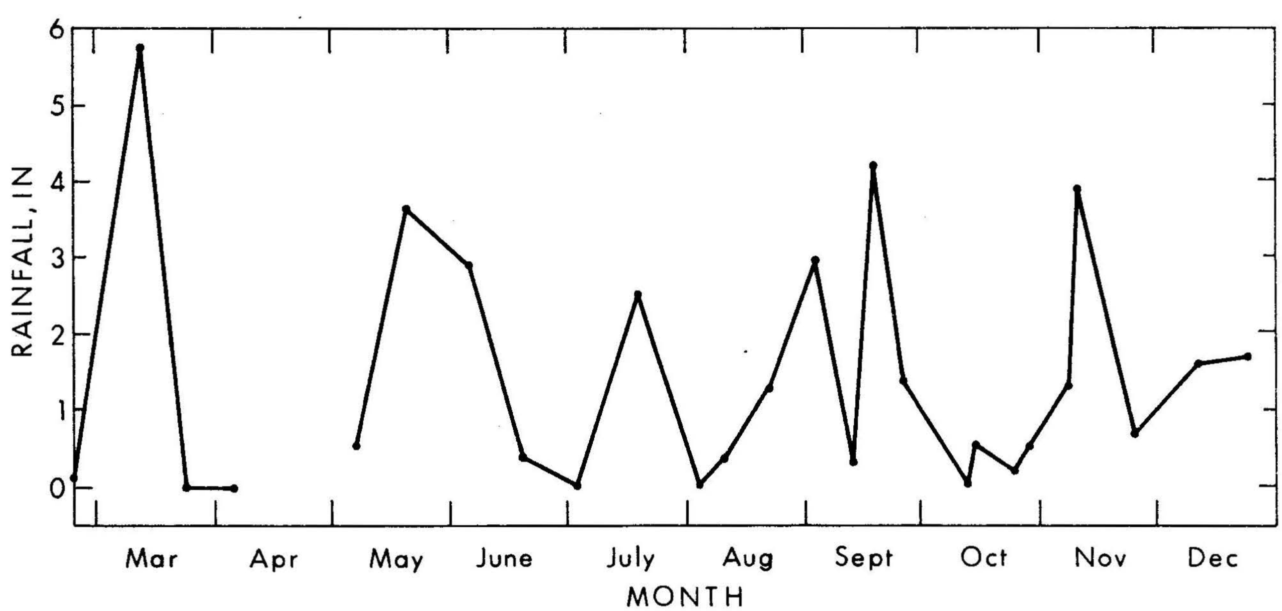

Figure 12. Total rainfall during the 24 hours preceding the collections of water quality samples.

sp. site and may either reflect the nature of gradients surrounding tree roots or result from continuous flushing of the soil surface by rainfall. Difference in soil properties in the upper and lower layers may also be responsible; these would include the nature of adsorptive surfaces that determine affinity for NO_3^-, such as the content of organic matter.

Although some of the NO_3^- levels detected in soil solutions exceeded the limits normally considered desirable for human water consumption, (10 ppm as N or 44 ppm as NO_3^-, Federal Water Pollution Control Administration, 1968), they remain safely under those that are permissable. It is difficult, however, to estimate from the data presented here the extent to which NO_3^- may be allowed to percolate with ground water recharge. It may be safely assumed that the vigorously growing vegetation will act as a very effective sink for NO_3^- and other nutrients, resulting in much less concentration in ground water than in the waters measured here. It is important also to emphasize that the majority of the soil solution samples contained extremely low NO_3^- concentration, as did all runoff waters.

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