Nitrogen and Phosphorus Leaching in Zero-tension Drainage From a Humid Tropical Soil

Ricardo Radulovich; Phillip Sollins

Biotropica, Vol. 23, No. 1 (Mar., 1991), 84-87.

Stable URL:
http://links.jstor.org/sici?sici=0006-3606%28199103%2923%3A1%3C84%3ANAPLIZ%3E2.0.CO%3B2-3

Biotropica is currently published by The Association for Tropical Biology and Conservation.

BIOTROPICA 23(1): 84–87 1991

NOTES

Nitrogen and Phosphorus Leaching in Zero-tension Drainage from a Humid Tropical Soil

Leaching of nutrients from soils is an important component of ecosystem biogeochemical cycles, especially in the humid, warm tropics, where abundant rainfall and high temperatures promote rapid decomposition and weathering year-round. As part of a larger study of water and solute flow through a well aggregated tropical Inceptisol, we designed and installed large zero-tension lysimeters (Radulovich & Sollins 1987). We report here on the concentrations of inorganic nitrogen and phosphorus in the water collected by those lysimeters.

Work was conducted from August through December 1985 on the La Guaria Annex of the La Selva Biological Station, Costa Rica, on the uppermost of several terraces along the Sarapiqui River. Annual precipitation averages 4015 mm, with a poorly defined dry season from January to April, and mean monthly temperature is 26.2°C (La Selva Meteorological Station, 1957–1983). Potential evapotranspiration has been calculated at 1425 mm yr^{-1} (Rojas 1985).

The soil is a well aggregated, freely draining Oxic Dystropept (Helechal Series) developed in volcanic alluvium. The A horizon has a pH of 4.3 (in water), organic matter (OM) content of 9.15 percent, and a sum of base cations of only 1.0 cmol kg^{-1} out of a total effective cation exchange capacity of 3.7 cmol kg^{-1}. Nitrogen (N) content to 0.7 m depth is of 3.7 kg m^{-2}. Extractable phosphorus (P) (by acid ammonium fluoride), though not measured in these particular sites, ranged from 4 to 10 ppm (weight basis) on surrounding upper terrace soils. Thus, in general, the soil is acid, base-poor, but OM-rich (and so N-rich), and has intermediate levels of available P (Sollins *et al.,* in press). It has low bulk density (<0.9 Mg m^{-3} to 1.0-m depth). Initial water infiltration at field capacity is extremely fast (>1000 mm hr^{-1}) and, after saturation, internal drainage rates approach zero in <1 hr. Volumetric water content is 49.2 percent at −33 kPa and 37.2 percent at −1500 kPa of soil matric potential. The soil is of high clay content and high degree of aggregation (Radulovich & Sollins 1985, 1987; Sollins & Radulovich 1988; Radulovich *et al.* 1989; Sollins *et al.* in press). Because of these physical characteristics, the soil behaves like sand at high water content, in that it has a high infiltration rate and drains rapidly, and like clay, in that it retains large amounts of water after it reaches field capacity.

Two sites were used, both cleared of primary forest in the early 1950s. One was an abandoned pasture that was initially lightly grazed, now dominated by grasses (*Ischaemum, Panicum,* and *Brachyaria* spp.) interspersed with ferns (*Nephrolepis* and *Hypolepis* spp.). The other site, 120 m distant, was in 15 yr old, mixed secondary forest.

Three large, galvanized iron lysimeters, 0.5 m on each side and 0.1 m deep, with a catchment area of 0.25 m^2 were installed at each of the two sites (Radulovich & Sollins 1987). Lysimeters were installed in tunnels from pit faces at 0.5-m depth, at least 0.25 m in from the pit face. The rim of the lysimeters was pressed about 10 mm into the tunnel ceiling, in order to improve collection efficiency. A metal screen was placed close to the bottom of the lysimeters to prevent any fallen soil from clogging the outflow tube. The profile above the lysimeters, including surface litter and vegetation, was not disturbed (Radulovich & Sollins 1987).

Two rain gauges were placed at the grass site, and five throughfall troughs (25 mm wide × 1 m long opening) were placed at the forested site. Collection efficiency of the lysimeters, defined as volume of water collected by lysimeters during rainfall events divided by volume of percolating water as calculated from a daily water balance, averaged 36.2 percent under grass and 17.3 percent under forest (high values in comparison to those usually reported in the literature). The dependability of these lysimeters was very high, with 78.3 percent of all collections yielding >500 ml (Radulovich & Sollins 1987). Results presented here are not based on percolation as calculated from the daily water balance because, during some rainfall events, the lysimeters collected substantial amounts of water even though the model predicted no percolation (Radulovich & Sollins 1987). This indicates that zero-tension water flow occurred in these soils during unsaturated conditions (see below).

Lysimeter solutions were collected within a day of each rainfall event. If available, 250 ml were saved for analysis. Samples were taken immediately to the laboratory, filtered through paper, and refrigerated

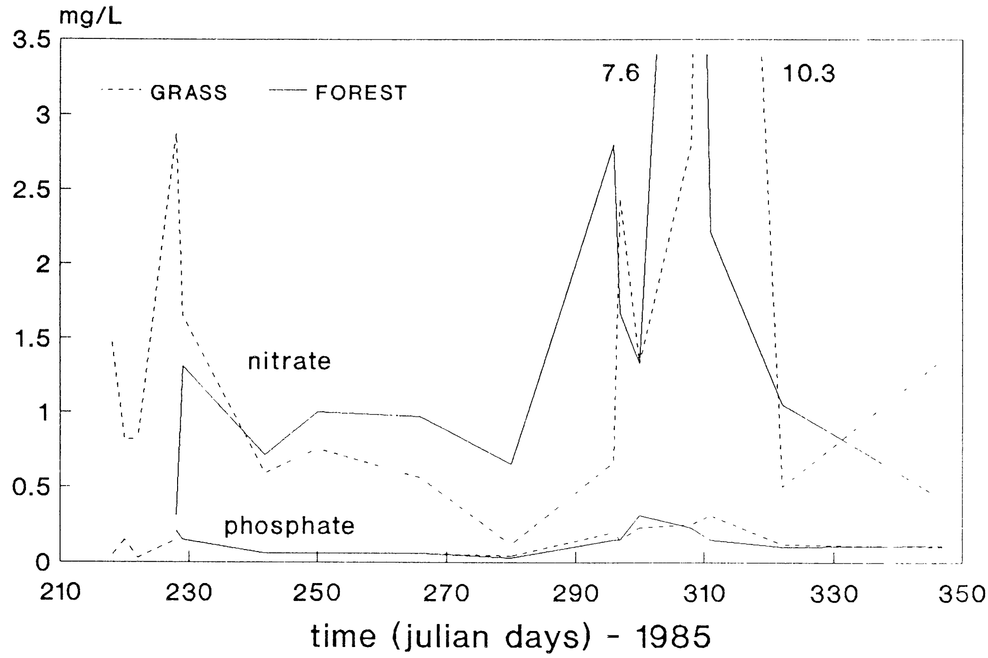

FIGURE 1. Concentration of nitrate and phosphate in soil leachate through time at grass and forest sites, La Selva, Costa Rica.

after addition of H_2SO_4 (E.P.A. 1983). All samples were analyzed within 15 d of collection. Samples from a total of 16 sampling dates from the grass site, and 13 from the forest site, were analyzed chemically.

Only inorganic forms of N and P were measured: NO_3^- by the cadmium reduction method, NH_4^+ by the phenate method, and PO_4^{3-} by the stannous chloride method (APHA-AWWA-WPC 1981). No difference was found between PO_4^{3-} concentration in solutions entering and exiting the lysimeters in the laboratory, indicating that the galvanized iron did not affect PO_4^{3-} concentrations.

Figure 1 shows the mean concentrations of NO_3^- and PO_4^{3-} in the collected solutions for all sampled events. NH_4^+ was undetectable in all samples (detection limit 0.01 mg liter^{-1}). There were two distinct peaks in NO_3^- and PO_4^{3-} concentrations, the first around julian day 230 (approx. 20 August) and the second and largest peak between days 300 and 320 (approx. end of October–first two weeks of November), during which NO_3^- concentrations rose to 10.3 (SE = 4.1) mg liter^{-1} under grass and to 7.6 (4.6) mg liter^{-1} under forest (Fig. 1). Interestingly, concentrations of both nutrient species peaked under both vegetation types at about the same time. In fact, a linear regression analysis between NO_3^- and PO_4^{3-} concentrations produced a highly significant correlation ($P < 0.01$), with $r = 0.58$.

The concentration of NO_3^- averaged 1.82 (0.61) mg liter^{-1} for the grass site and 1.70 (0.53) mg liter^{-1} for the forest site. Individual values ranged from 0.09 to 15.50 mg liter^{-1} under grass and from 0.22 to 13.28 mg liter^{-1} under forest. This variability is similar in magnitude to that found by Russell and Ewel (1985). The concentration of PO_4^{3-} averaged 0.13 (0.02) mg liter^{-1} for the grass site and 0.14 (0.02) mg liter^{-1} for the forest site; individual values ranged from <0.01 (detection limit) to 0.46 mg liter^{-1} in grass and from <0.01 to 0.31 mg liter^{-1} in forest.

Table 1 shows that NO_3^- and PO_4^{3-} concentrations varied substantially among lysimeters under grass, with means ranging from 0.96 to 2.42 mg NO_3^- liter^{-1} and from 0.09 to 0.16 mg PO_4^{3-} liter^{-1}. High levels of NO_3^- were accompanied by high levels of PO_4^{3-}, and vice versa. Variability was less at the forest site (Table 1).

Overall, mean concentration of NO_3^- and PO_4^{3-} differed little between grass and forest sites, despite substantial variation through time (Fig. 1) and among lysimeters within each sampling site (Table 1).

TABLE 1. *Mean nutrient concentrations in leachate by lysimeter.*

Lysimeter	NO_3^- (mg liter^{-1})	PO_4^{3-} (mg liter^{-1})	Lysimeter	NO_3^- (mg liter^{-1})	PO_4^{3-} (mg liter^{-1})
	Grass			Forest	
1	0.96 (0.19)[a]	0.09 (0.02)	1	1.45 (0.32)	0.12 (0.03)
2	2.42 (0.92)	0.16 (0.04)	2	1.95 (0.87)	0.13 (0.02)
3	1.76 (0.84)	0.13 (0.04)	3	1.70 (0.32)	0.10 (0.01)
	1.71 (0.42)	0.13 (0.02)		1.70 (0.14)	0.12 (0.01)

[a] Mean (SE).

The data showed no apparent correlation between amount of precipitation and NO_3^- and PO_4^{3-} concentrations or between such concentrations and percolation as calculated from a daily water balance (Radulovich & Sollins 1987). From the mean concentrations, each mm of percolating waters represents a loss of 4.10 and 3.85 g NO_3^--N ha^{-1}, and of 0.43 and 0.45 g PO_4^{3-}-P ha^{-1}, for grass and forest, respectively.

Based on the fact that these soils reach field capacity in a short time after saturation (Sanchez 1976), even in <1 hr (Sollins & Radulovich 1988), and on other evidence pointing to bypass flow (McVoy 1985, Russell & Ewel 1985, Radulovich & Sollins 1987), it can be assumed that much if not most water percolates rapidly at or close to zero-tension. In this case, zero-tension leachate may best represent leaching losses.

From an annual water budget calculation, with 4015 mm precipitation and 1425 mm evapotranspiration per year, approximately 2600 mm percolate each year (surface runoff is nil). With this percolation rate, annual losses would be 10.7 and 10.0 kg ha^{-1} for inorganic N and of 1.1 and 1.2 kg ha^{-1} for inorganic P under grass and forest, respectively. Losses from under forest may be overestimated, however, since the evapotranspiration rate may be substantially higher than from grass. Given the high contents of N, and the intermediate values of available P in these soils, losses of 10 kg N ha^{-1} and of 1 kg P ha^{-1} would not represent significant proportions of total available amounts of these nutrients. This type of leaching loss would then represent a minor nutrient output from these little-disturbed systems and highly aggregated soils.

Our previous work at this site (Sollins & Radulovich 1988) indicates that water flows at zero-tension through the macropores, and is thus collectible in zero-tension lysimeters, even if the soil is not saturated. That zero-tension percolation occurs when no percolation is predicted by a water balance (Radulovich & Sollins 1987) suggests that zero-tension flow may occur even when the soil water content is below field capacity.

Given that zero-tension water flow appears to be an important process at this site, several assumptions regarding water and solute fluxes through these well aggregated soils may need to be reexamined. In particular, the assumption that the application rate of water on the soil must exceed the infiltration rate in order for zero-tension flow to occur (*e.g.*, Seyfried & Rao 1987) appears untenable for these soils. Also, solutions collected by tension lysimeters over periods of one or more days may be unrelated to leaching losses, since most water (and nutrients) percolate in much shorter times. Thus, at least in these little-disturbed, well aggregated soils, solutions from zero-tension lysimeters probably give good estimates of total leaching losses.

Research funded by the University of Costa Rica and by NSF Grants BSR-8317198 and 8605047 to the Organization for Tropical Studies, Duke University.

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Ricardo Radulovich[1]

Department of Agricultural Engineering
University of Costa Rica
San Jose, Costa Rica

and

Phillip Sollins

Department of Forest Science
Oregon State University
Corvallis, Oregon 97221, U.S.A.

[1] Present address: Department of Soil, Crop and Atmospheric Sciences, Cornell University, Ithaca, New York 14853 U.S.A.

BIOTROPICA 23(1): 87–90 1991

Flooding Affects Survival of Lecythidaceae in *Terra Firme* Forest near Manaus, Brazil

The importance of different sized gaps in determining the structure and diversity of tropical forests has been well documented (see reviews in Denslow 1987, Ewel 1980, Platt & Strong 1989). The many ways in which gaps are formed influence their size, structure, and substrate properties and thereby affect what species colonize them. In this note, we report on the formation of gaps caused by unusual flooding of scattered areas of *terra firme* forest in central Amazonia.

The rainy season from January through May 1989 at Manaus, Brazil, was unusually heavy and prolonged. The total of 1886 mm of rainfall was the greatest for these five months since 1910 and exceeded the mean for this period by 41 percent (Instituto Nacional de Meteorologia do Brasil, unpublished data for the station at Igreja de São José, 03°08′S, 60°01′W). In *terra firme* forest, the soil became saturated and water collected in shallow depressions to depths as great as 1.5 m in places which normally do not flood (Fig. 1).

In August 1989, we quantified the effects of flooding on Lecythidaceae (Brazil nut family) in a 100 ha plot of *terra firme* forest on yellow, clayey latosols. The plot is 90 km north of Manaus in Reserve 1501 of the Biological Dynamics of Forest Fragments Project managed by the Smithsonian Institution and Instituto Nacional de Pesquisas da Amazônia (INPA). Eighty-six flooded quadrats (20 × 20 m)