IMPROVED PERFORMANCE OF ZERO-TENSION LYSIMETERS[1]

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Abstract

Published collection efficiencies (volume of water collected divided by percolating volume calculated from a water balance) of zero-tension lysimeters are <10%, suggesting that samples collected by such lysimeters may not be representative of the water percolating downward. By increasing catchment area to 2500 cm², and by pushing the lysimeter rim upward into the soil, collection efficiency was increased to 36% under grass and 17% under forest; failure rate (proportion of lysimeters yielding <50 mL) was decreased from 60 to 6% under grass and to 23% under forest.

Additional Index Words: **Humitropept, Costa Rica, water percolation.**

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Leaching can remove large quantities of nutrients from both managed and natural ecosystems. Zero-tension lysimeters are often used to collect such leachate for analysis (e.g., Jordan, 1968; Russell and Ewel, 1985), especially in forest soils where much water flows via preferred paths (Trudgill et al., 1983; Smettem and Trudgill, 1983). Questions arise, however, as to whether the samples collected are representative of the water percolating downward.

The likelihood that samples are representative increases as more of the percolating water is intercepted. However, *collection efficiency* of zero-tension lysimeters, which is defined here as volume of water collected divided by water flux as calculated from a water balance, appears to be very low. The only efficiency values we could locate were <10% (Russell and Ewel, 1985), although volumes reported by Haines et al. (1982) also suggest low efficiency. The low volumes create an additional problem in that 75 to 95% of the lysimeters installed in these studies did not yield sufficient water for chemical analysis.

In the present study, we measured performance of zero-tension lysimeters under field conditions and tested design features that might improve their performance. Our goal was to increase collection efficiency so that a larger proportion of the percolating water was intercepted.

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Materials and Methods

Study Site

Our study was conducted from February 1985 to January 1986 at La Selva Biological Station near Puerto Viejo, Costa Rica, on the uppermost of several terraces along the Rio Sarapiqui. Mean annual precipitation is 4015 mm, with a poorly defined dry season from December to April (La Selva Meteorological Station, 1957–1983).

The soil is a freely draining Oxic Humitropept developed in volcanic alluvium (P. Sollins, 1986, unpublished data). Bulk density averages <0.9 Mg/m³ to the 1.0-m depth, and initial infiltration rates are >1000 mm h⁻¹ (Radulovich and Sollins, 1985). After saturation, internal drainage rates approach zero in <1 h (Radulovich and Sollins, 1985, unpublished data). Surface runoff was never observed at the site even during intense rains (Radulovich and Sollins, 1985). Volumetric water contents, based on moisture release curves, were 49.2% at −33 kPa and 37.2% at −1500 kPa.

Two sites were selected for intensive study, both cleared of primary forest in the 1960s. One was dominated by a grass (*Olyra latifolia* L.) interspersed with ferns (*Pteridium* spp.). The other, 120-m distant, was in 15-yr-old, mixed secondary forest.

Evaluating Lysimeter Performance

A water balance was calculated in order to compute a water flux for comparison with lysimeter results. Two rain gauges were placed at the grass site, and five throughfall troughs were placed at the forested site. Volumes collected were measured after each rain event.

To calculate percolation at the 50-cm depth, we used mean monthly potential evapotranspiration (ET) rates calculated for the La Selva Station (Hargreaves, 1975). We multiplied these rates by 1.2 for the grass site and 1.6 for the forest site, coefficients typical for tropical forests (Ribeiro and Villa Nova, 1979). We assumed that 55% of the water stored between −33- and −1500-kPa matric potential in the upper 50 cm of soil (33 mm of water) was readily available to plants (Teare and Peet, 1983). We further assumed that; (i) the soil reservoir filled before water percolated, and (ii) surface runoff was nil.

Collection efficiency was defined as volume of water collected by lysimeters during rainfall events divided by volume of percolating water as calculated from the water balance for that same event. Dependability was defined by classifying volumes collected into four categories: 0, <50, 50 to 500, and >500 mL. Dependability for the "0" category was calculated only if the water balance predicted percolation.

Lysimeter Designs

The following lysimeter designs were compared:

1. Small, trough-like, stainless steel with a screen across the top; 5.4 cm wide, 30 cm long, and 4 cm deep, with a catchment area of 162 cm². These lysimeters were loaned to us by J. Ewel (c.f., Russell and Ewel, 1985).

Table 1. Performance of small, medium and large metal lysimeters installed under grass.†

Variable	Lysimeter design Small	Medium	Large
Catchment area, cm^2	162	500	2500
Mean depth of water collected, mm	2.9a**	6.6a	12.6b
Volume collected			
mean, mL	4.7a**	330a	3140b
mean coefficient of variation, %	111.1	83.3	44.0
Collection efficiency, %	(10.2)	(13.2)	(26.3)
Dependability, %			
total failure	38.3	20.0	3.3
<50 mL per collection interval	60.0	51.7	10.0
>500 mL per collection interval	1.7	18.3	78.3

** Means within a row followed by the same letter do not differ significantly (Duncan multiple range test, 99% confidence interval). Data for each lysimeter were treated as a subsample and dates of sampling as blocks, in a randomized complete block design.

† Values are based on 15 collection dates between June and September 1985. Standard deviation shown in parenthesis.

2. Medium, galvanized Fe; 20 cm wide, 25 cm long, and 10 cm deep, with a catchment area of 500 cm^2.
3. Large, galvanized Fe; 50 cm on each side and 10 cm deep, with a catchment area of 2500 cm^2.

All lysimeters were installed in tunnels from pit faces at the 0.5-m depth. The profile above the lysimeter, including surface litter and vegetation, was not disturbed. A metal screen was placed close to the bottom of the medium and large lysimeters to prevent any fallen soil from clogging the outflow tube. Once pits were completed, we were able to install about three lysimeters per day.

Jordan (1968) reported that water transfer from soil to lysimeter could be improved by placing a metal screen across the lysimeter and covering it with glass wool; filling lysimeters with sand has also been recommended. In initial trials, however, we found that these procedures did not significantly improve collection efficiency. In contrast, pressing the rim about 1 cm into the tunnel ceiling did give significant improvement, and we used this procedure throughout the remainder of the study.

Two sets of measurements were made. First, three metal lysimeters of each size (small, medium, and large) were installed at the grass site in June 1985 to test for effect of lysimeter size on performance. These lysimeters were monitored over 15 collection periods through September 1985. In August 1985, three additional large units were installed at the forest site to check performance of the large metal lysimeters under a second vegetation type. These large lysimeters, plus the large lysimeters under grass, were monitored through January 1986. In all, there were 31 collection dates for large lysimeters at the grass site and 18 at the forest site.

Results

The medium and small lysimeters performed poorly (Table 1). Increasing lysimeter size to 2500 cm^2 greatly improved performance; collection efficiency of the large units was 46.2% between June and September 1985, when lysimeters of all three sizes were monitored. When analyzed date by date, the large units collected significantly more water than did the others on 44% of the dates ($p < 0.05$).

For most of the study period, the vessels used with the large lysimeters overflowed during some of the heaviest rains; thus collection efficiency of the large lysimeters was underestimated. Variability in volume collected by lysimeters of each size, shown as mean coefficient of variation, decreased with increasing lysimeter size (Table 1). Dependability improved consistently with size. Incidence of total failure dropped to 3.3% for the large units; nearly 80% of the collections yielded >500 mL, sufficient for most analyses.

Table 2. Performance of large lysimeters under grass (31 collection dates between June 1985 and January 1986) under forest (18 collection dates between August 1985 and January 1986).†

Variable	Grass site‡	Forest site
Volume collected		
mean, mL	2900	1870
mean coefficient of variation, %	40.4	80.9
Depth collected, mm	1.16	0.75
Collection efficiency, %	36.2	17.3
	(24.5)	(19.6)
Incidence of total failure, %	6.4	23.4

† Standard deviation shown in parenthesis.

‡ Lysimeters under grass are the same units as in Table 1, but data span additional collection dates.

When the large lysimeters were evaluated over a longer period of time, collection efficiency averaged 36% under grass; the failure rate (<50 mL) under grass was only 6.4% (Table 2). The large lysimeters installed under forest did not perform as well as those under grass. Collection efficiency was lower (though still much improved over the smaller units under grass) and the incidence of total failure was 23.4%. Results were also more variable under forest than under grass (Table 2). Under both grass and forest, lysimeters yielded water during several periods when the water balance indicated that no water should have percolated. Explanations are that the water balance underestimated percolation or that water percolates along preferred paths before filling the soil-water reservoir.

Discussion

A collection efficiency of 36% under grass, along with a failure rate (<50 mL) of only 6.4%, represents substantial improvement over previously reported designs (Jordan, 1968; Russell and Ewel, 1985). (Percentages are based on Table 2, which includes the most data). Both the large size and the insertion of the rim into the soil appear to have contributed to the improvement.

The somewhat poorer performance of the large lysimeters under forest (17% efficiency) is hard to explain. Large roots and root channels were more abundant under forest than under grass, but cracks were more common under grass. Dye experiments (e.g., Smettem and Trudgill, 1983) might provide insight into effects of flow along preferred paths on performance of zero-tension lysimeters.

Despite inefficiency, zero-tension lysimeters offer advantages over other methods of collecting leachate. Tension lysimeters are more dependable, but their small size requires extensive replication, especially in forest soils where most water percolates along preferred paths rather than through the soil matrix (Trudgill et al., 1983; Smettem and Trudgill, 1983; Russell and Ewel, 1985). Maintaining vacuum at remote sites can also be difficult. Ceramic cups alter water chemistry (Silkworth and Grigal, 1981; Bottcher et al., 1984). Once installed, zero-tension lysimeters require little maintenance and can be built to sample a large area. They offer a practical technique for collecting leachate, especially if their collection efficiency can be further improved.

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