15. AN IMPROVED METHOD OF ESTIMATING THE CONTRIBUTION OF CROWN LEACHATES TO THE CHEMICAL COMPOSITION OF RAIN COLLECTED BENEATH TREES

K.H. LAKHANI

Amounts of solutes and suspended matter in rainwater collected as stemflow and throughfall beneath trees are generally greater than those in rainwater collected in the open. This enrichment, as rainwater passes over foliage and branches, is partly attributable to the removal of substances previously deposited on foliage and branches by impaction or adsorption, and partly to substances leached from within plants (ie crown leaching). The former provides a new input to the system, whereas crown leaching facilitates recycling. But how can the contributions made by these 2 processes be separately identified?

Atmospheric inputs can be estimated directly and indirectly. They can be estimated directly from (i) catches of airborne particles (White & Turner, 1970), but problems arise when ascribing amounts to unit areas of forest, and (ii) with methods based on nutrient budgets (Likens *et al.,* 1977) which tend to lack sensitivity because the fluxes of different substances are usually small relative to the sizes of the 'sinks', particularly soil. Indirect methods have relied on comparisons made of the chemical composition of stemflow and throughfall with those of rainfall collected in the open during the same period of time. However, the compositions of stemflow and throughfall reflect the extent of crown leaching in addition to dry deposition and wet deposition, whereas those of rainfall collected in gauges in the open reflect the latter, plus a small fraction of dry deposition (accumulated since the gauge was cleaned). Mayer and Ulrich (1974) argued that crown leaching of deciduous trees could be assumed to be negligible during leafless winter months, and then proceeded to obtain estimates of dry deposition during winter. Their method, however, assumes that significant leaching occurs only through leaves, and that rates of dry deposition to leafless trees in winter are similar to those to leafy trees during summer months. Miller *et al.* (1976), working with Corsican pine, *Pinus nigra var. maritima* (Ait.) Melv., observed that amounts of solutes and suspended matter in stemflow and throughfall (kg ha^{-1} wk^{-1}) were linearly and directly related to their amounts in rainfall collected in the open. They used the intercept of this regression as a measure of crown leaching, assuming that inputs in rain and from the removal of surface deposits could be combined as a single variable. However, the validity of this assumption has recently been questioned by Lakhani and Miller (1980) who were concerned with the partitioning of rain in a plantation of Corsican pine. Dr H.G. Miller of the Macaulay Institute analysed the chemical composition of:

(i) stemflow and throughfall

(ii) rain collected in the open in Nipher-shielded rain gauges (open gauges)

and (iii) rain collected in the open in funnels surmounted by an inert wind-filter of polyethylene coated wire mesh (filter gauges).

Samples of (i), (ii) and (iii) were taken simultaneously and at equally spaced intervals during the course of 2 years, the inclusion of filter gauges being essential if amounts of crown leaching were to be separately identified from those of wet and dry deposition.

1. Method

Suppose that rainwater is collected during 'n' equal time periods. Let the weight (kg ha^{-1}) of a given substance in stemflow and throughfall during the 'i'th time period be X_{1i}; and, let the corresponding weights of that substance in open and filter gauges be X_{2i} and X_{3i} respectively. Thus, the field data will consist of n triplets of observations X_{1i}, X_{2i}, X_{3i} ($i = 1, 2, \ldots\ldots, n$). If the wet deposition, dry deposition and leaching of different substances (kg ha^{-1}) during the 'i'th time period are denoted W_i, D_i and L_i, then the X_{ji} values ($j = 1, 2, 3$; $i = 1, 2, \ldots, n$) can be expressed in terms of these components and other effects. X_1, the concentration of different substances in combined stemflow and throughfall, is essentially the total of wet deposition, dry deposition and leaching during the 'i'th time period. But some part of some substances will be 'lost' through (i) foliar absorption, f_i, and (ii) the incomplete removal of surface deposits whatever their origin, l_i. On the other hand, there will be some gain, g_i, because rain of the 'i'th time interval will succeed in removing some of the surface deposits remaining from earlier periods. Additionally, X_1, the composition of stemflow and throughfall, will be subject to chance variations represented by the error term, e_i. Thus,

$$X_{1i} = W_i + D_i + L_i - f_i - l_i + g_i + e_i \qquad (1)$$

The loss and gain terms, l_i and g_i, are unknown functions of a range of variables which tend to cancel each other. By absorbing them and the unknown foliar absorption term, f_i, a new error term e'_{i} is evolved:

$e_{1i} = e_i - f_i - l_i + g_i$.

Thus $X_{1i} = W_i + D_i + L_i + e_{1i}$ (2)

Because the chemical composition of rain collected in the open gauge, X_{2i}, will be mainly attributed to wet deposition, with some contamination from dry deposition which is assumed to be proportional to dry deposition on forests,

$$X_{2i} = W i + aDi + e2i \quad (3)$$

where 'a' is a positive constant of proportionality and 'e_{2i}' is a random error term.

Finally, the chemical constituents in the filter gauge, X_{3i}, will also be attributable to wet deposition and dry deposition. Because their wind-filters will intercept some of the non-vertical rainfall which would otherwise not be captured, the filter gauges will tend to collect greater volumes of rain than open gauges. If the rain collection efficiency of filter gauges, relative to that of open gauges, is assumed to be constant, and if most wet deposition is attributable to rain in contrast to fog and mist, then amounts of wet deposition in X_{3i} can be equated to 'kW_i' where 'k' is an unknown positive constant. If it is assumed that filter gauges, as regards dry deposition, have a catching efficiency of 'b' relative to the catching efficiency of forests, then:

$$X_{3i} = kW_i + bD_i + e_{3i} \quad (4)$$

where e_{3i} is a random error term. As k is likely to be greater than 1, and b greater than a, X_{3i} will be expected to be greater than X_{2i}.

If V_i and U_i are the volumes of liquid collected in the open, and in filter gauges, during the 'i'th time period, then the estimate (k) of the constant k is given by:

$$k = \Sigma U_i / \Sigma V_i.$$

Dividing (4) by k gives the adjusted observation:

$$X'_{3i} = X_{3i}/k = \quad W_i + b'D_i + e'_{3i} \quad (5)$$

where $b' = b/k$, $e'_{3i} = e_{3i}/k$ and $k/k = 1$.

To eliminate the wet deposition term W_i from equations (2), (3) and (5), X_{2i} is subtracted from X_{1i} and X'_{3i} respectively to obtain the derived variables:

$$Y_i = X_{1i} - X_{2i} = (1 - a)D_i + L_i + e_{1i} - e_{2i} \quad (6)$$

and $$X_i = X'_{3i} - X_{2i} = (b' - a)D_i + e'_{3i} - e_{2i} \quad (7)$$

Thus, if L_i is independent of D_i, with the mean of L_i equal to M_L (this condition is less strict than the special case that L_i be constant), then Y_i is linearly related to X_i with the slope equal to $(1 - a)/(b' - a)$ and the intercept equal to M_L. Problems of estimating the parameters defining the structural relationship between 2 variables (in this instance X_i and Y_i), both of which are subject to random errors, are intrinsically difficult (Kendall & Stuart, 1961). In the present instance, the problems are exacerbated because the error term, e_{2i}, present in both equations, reduces the degree of independence. However, unlike the error terms e_{2i} and e_{3i}, the error term e_{1i} is a conglomeration in which, because of the large spatial variation beneath a forest canopy, even the single term e_i is likely to be large relative to e_{2i} or e_{3i}. On the other hand, because k is likely to be greater than 1, e'_{3i} will tend to be less than e_{3i}. Thus, if it is assumed that e_{1i} is likely to be relatively large compared with e_{2i} or e'_{3i}, then the parameters defining the relationship between Y_i and X_i can be readily estimated using standard regression techniques. Theoretically, the magnitude of the different errors can be controlled by varying the intensity of sampling.

2. Discussion

Previously, Miller *et al.* (1976) used the intercept of the regression of X_{1i} on X_{2i} as an estimate of crown leaching. But, because $X_{1i} \sim Wi + Di + Li$ and $X_{2i} \sim Wi + aDi$, it was necessary to assume that Di was proportional to Wi, so that they could be treated as a single variable; and also that L_i was independent of W_i. In practice, D_i and W_i are likely to be correlated, but not proportionately. In contrast, L_i and W_i are unlikely to be independent (Abrahamsen *et al.,* 1976).

By including the additional variable, X_{3i}, it has been possible to eliminate W_i from equations (2), (3) and (5) so enabling the estimation of leaching (L_i) on the assumption that they are independent of dry deposition (D_i). In the event, the filter gauge is likely to oversample rainfall, so requiring the adjustment of the X_{3i} values via the estimate of k (see equations (4) and (5)). Alternatively, the gauge may be modified to have a large funnel with inset filter.

In addition to facilitating estimates of crown leaching, the method described in this chapter can be used to estimate dry deposition (D). From equation (7), $X \sim (b' - a)\ D$ and hence $D \sim X/(b' - a)$ which may be written as:

$$(1 - a)D \sim X.\ (1 - a)/(b' - a)$$

with $(1 - a)/(b' - a)$ being estimated from the slope of the regression of Y_i on X_i. The term (X. slope) underestimates mean dry deposition, the extent of the underestimation being equal to a.D, which tends to zero as 'a' tends to 0, as happens when the open gauge is designed to collect negligible dry deposition.

References

Abrahamsen, G., Bjor, K., Horntvedt, R. & Tveite, B. 1976. Effects of acid precipitation on coniferous forest. In: *Impact of acid precipitation on forest and freshwater systems in Norway,* edited by F.H. Braekke, 37-64. Oslo-As: SNSF. (Research report SNSF project no. 6).

Kendall, M.G. & Stuart, A. 1961. *The advanced theory of statistics, Vol. 2,* London: Griffin.

Lakhani, K.H. & Miller, H.G. 1980. Assessing the contribution of crown leaching to the element content of rainwater beneath trees. In: *Effects of acid precipitation on terrestrial ecosystems,* edited by T.C. Hutchinson and M. Havas, 161-172. New York: Plenum.

Likens, G.E., Bormann, F.H., Pierce, R.S., Eaton, J.S. & Johnson, N.M. 1977. *Biogeochemistry of a forested ecosystem.* New York: Springer.

Mayer, R. & Ulrich, B. 1974. Conclusions on the filtering action of forests from ecosystems analysis. *Oecol. Plant.,* **9**, 157-168.

Miller, H.G., Cooper, J.M. & Miller, J.D., 1976. Effect of nitrogen supply on nutrients in litter fall and crown leaching in a stand of Corsican pine. *J. appl. Ecol.,* **13**, 233-248.

White, E.J. & Turner, F. 1970. A method of estimating income of nutrients in a catch of airborne particles by a woodland canopy. *J. appl. Ecol.,* **7**, 441-461.