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Phytoremediation: Physiological procedures for scaling from laboratory to field

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Abstract

Plants can increase the removal of organic compounds from soil by three basic mechanisms: rhizosphere degradation; uptake, translocation, and volatilization of unmetabolized compounds; and uptake, metabolism or storage. The importance of each of these mechanisms is typically estimated from measurements made on plants in containers in controlled environments or from field studies of single plants and it is necessary to scale this data to the community level. Over the past century physiologists have developed and refined procedures for scaling from measurements made in small chambers to determine mass transport in ecosystems. Here we review procedures and apply the principles to scaling from measurements of volatile and non-volatile contaminants in small chambers to plant communities. Numerical examples from measured literature values are given.

Two types of extrapolation are necessary:

1) estimating plant communities from a few sampled leaves (extrapolation in space); and
2) estimating annual effects from short sampling intervals (extrapolation in time).

Scaling of the efflux of volatile compounds from leaves is best done on the basis of water transpired per unit time. Scaling of nonvolatile contaminants in plant tissue is best done on the basis of tissue concentration.

Scaling of volatile compounds via transpiration rate requires:

1) measurement of the ratio of contaminant efflux to water efflux in the sample chamber,
2) an estimate of the transpiration rate of the plant community per unit ground area, and
3) the assumption that the concentration of contaminant in the transpiration stream from the sample chamber is the same as from the plant community.

Transpiration rates of plant communities are well studied and seasonal average values are quite constant, so the total transpiration of a plant community that is not water stressed can be estimated with about " 15% accuracy over a growing season. As a rule of a thumb, the annual transpiration rate with complete cover of the ground by vegetation is similar to the annual rainfall total. If the transpiration rate exceeds rainfall, the plant community must eventually draw water from the groundwater; when rainfall exceeds transpiration, leaching of rainfall into the groundwater occurs.

*Factors affecting uniformity of volatile efflux from leaves***.** Solutes can move laterally in the xylem so differences in the contaminant concentration in the transpiration stream on different sides of a tree would typically occur only if the concentration of organics in the root-zone was very different on one side of the tree. The leaves on the top of a tree are in direct sun all day and thus transpire much more water than lower leaves, but the concentration of organics in the transpired water should be very similar at the top and the bottom of the tree. The high transpiration rate at the top of the tree affects the transpiration multiplier but not the uniformity assumption.

Scaling on the basis of leaf mass requires:

1) a measurement of the concentration of contaminant per unit leaf mass,
2) an estimate of the mass of leaves per unit ground area, and
3) the assumption that the contaminant concentration is uniform among all the leaves on the tree.

The mass of leaves per unit ground area is best done by estimating values for two factors: 1) the leaf area index (number of layers of leaves per unit ground area), LAI; and 2) the specific leaf area (leaf area per unit leaf weight), SLA. A typical leaf area index for vegetation is about six leaf layers per unit ground area. A typical specific leaf area is 30 m^2 per kg. Dividing LAI by SLA indicates a leaf density of 0.2 kg of leaves per m^2 of ground area. When the leaves are thicker there are fewer leaf layers so the components tend to offset each

other. Assuming that the leaves turn over once per year means that there is 0.2 kg of new leaves per m^2 ground per year.

Factors affecting uniformity of contaminant concentration among leaves. Contaminants are typically drawn into leaves with the transpiration stream, so it is important to sample a portion of the tree that has a transpiration rate that is typical of the average for all the leaves on the tree. Transpiration rate is primarily determined by the amount of radiation that is intercepted by the leaves. Leaves on the outside edges of a tree have higher transpiration rates than leaves on the interior of the tree, and leaves at the top of the tree have higher transpiration rates than leaves at the bottom of the tree.

Assessing the Environmental Importance of stored and transpired contaminants.

These procedures provide estimates of the quantity of stored or transpired contaminant per unit ground area per year. The environmental importance of these quantities depends on the quantity of contaminant in the ground water. This is often poorly characterized, but we start by assuming that there is a cubic meter of ground water per m^2 of ground surface area (30% solids and groundwater 1.3 meters deep). If this ground water is uniformly contaminated at 1 ppm there would be 1 gram of contaminant per m^2 of ground area (1 mg per L times 1000 L per m^3). Clean-up of the ground water over a 10 year period would thus require a total of 0.1 g removal per m^2 per year. Assuming 0.2 kg of leaves per m^2 , this would require a leaf concentration of 500 mg kg^{-1} along with associated leaf collection and removal from the site. Alternatively, the volatile efflux with the transpiration stream would need to be about 10% of the ground water concentration to achieve clean-up over a 10 year period (a continuous transpiration concentration of 0.1 mg per L of water transpired to clean-up 1 mg per L of contaminated ground water).

Reported concentrations of contaminants in leaves are typically several orders of magnitude less than the concentrations required to accomplish significant removal. Contaminant concentrations in the transpiration stream are not well characterized, with reported values ranging from very high to nondetectable, even with the same compound and the same plant species. For more information see poster No. 40 by Hayhurst et al.; No. 41 by Orchard et al.; No. 42 by Chard et al.; and oral talks by Pajak (1:30 Weds) and Orchard (2:00 Weds).