Monitoring and Modeling Pesticide Residue Movement in Field-Based, Zero-Tension Lysimeters for Ground Water Risk Assessment – Pilot Study

California Department of Pesticide Regulation, Environmental Monitoring Branch

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I. Abstract

The California Department of Pesticide Regulation (DPR) conducts risk assessments for the potential of pesticides to impact ground water using data typically from terrestrial field dissipation studies, laboratory studies characterizing physical/chemical properties and computer simulation models. Registration submission data have included field studies utilizing zero-tension column lysimeters. While not explicitly required by DPR or US EPA, such data are routinely evaluated by regulators in Europe for higher tier assessments of pesticide leaching potential (Focus, 2009). Advantages for using zero-tension lysimeters in field studies to characterize the fate of pesticides are:

1. all leachate is captured,
2. detection limits for analytical methods are more sensitive to residues in solution compared to soil, and
3. when lysimeter collection reservoirs are located below the soil evaporative depth extracted solutes reflect a direct measurement of drainage water and leaching residues.

In a pilot study, pesticide residue movement within and outside the confines of zero-tension, column lysimeters were compared for consistency under California irrigated agricultural conditions. Patterns of soil residue movement were found to differ between the two sites. Model simulations of water and residue movement provided a basis for explaining differences noted in soil residue movement.

II. Methods & Materials

1. Study Design. The study was conducted on a bare, sandy loam soil in Fresno County, California, considered by DPR as vulnerable to pesticide leaching. Two adjacent sites each received water applications at either 110% or 160% of evaporative demand for approximately 140 days. Treatments at each site consisted of four equispaced lysimeter and control plots configured in a single line as a completely randomized design.
2. Lysimeter Design. Each unit was constructed of PVC tube with a diameter and length of 30 cm and 120 cm, respectively. The base consisted of a sealed PVC dome-cap modified to accept a solute extraction tube and an air vent. The soil, consisting of a 90 cm core was encapsulated in an undisturbed state above a 2 cm deep sand layer and stainless steel screen filter.
3. Chemical and Water Applications. Irrigation was provided weekly by micro-sprinklers oriented in a single line with the treatment plots. Bromacil, diuron, hexazinone and norflurazon were initially applied by chemigation. Potassium bromide was applied with the pesticides as a tracer for water movement.
4. Chemical Sampling. Solute collection from lysimeter reservoirs occurred weekly. Soil coring of control and lysimeter plots occurred at conclusion of the field study.
5. Analysis.
   a. Contrast and compare measured chemical residue movement in control and lysimeter plots.
   b. Calibrate HYDRUS 1D (Šimůnek et.al., 2008) vadose zone model to study site using soil analyses and computer optimization processes.
   c. Compare simulated and measured bromide movement to explain any potential differences in pesticide residue movement between unconfined and lysimeter-confined soil.

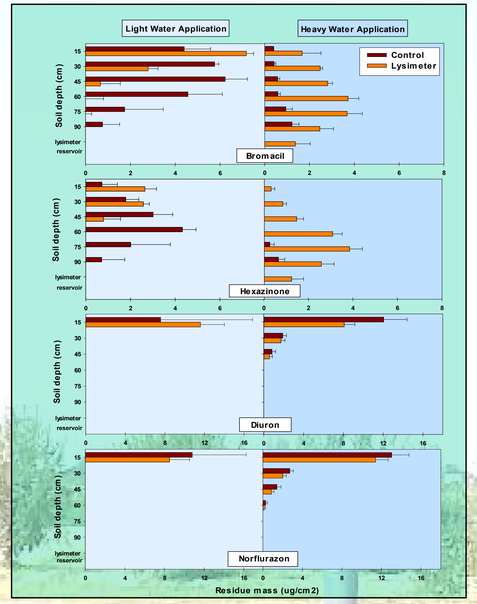

Fig. 1. Pesticide residues sampled from light- and heavy-irrigated plots of unconfined (control) and lysimeter-confined (lysimeter) soil, and from lysimeter reservoir solute approximately 140 days after pesticide application.

III. Results & Discussion

1. Field-Measured Pesticide Movement in Soil. Differences in soil residue movement between control and lysimeter plots occurred for some pesticides and not others and were related to the overall extent of their movement in the soil. Bromacil and hexazinone experienced large differences where residues in the control plots moved to greater depths compared to lysimeter plots (Fig. 1). Their high mobility was reflective of low Koc and high solubility values (Table 1). Minor or negligible differences occurred for diuron and norflurazon (Fig 1), relating to their more moderate movement potential in the soil (Table 1). In contrast to this study, Kasteel et.al. (2010) found no differences in movement between mobile and less mobile residues in lysimeters and has advocated the possibility of preferential flow within lysimeters
2. Model Calibration. Several soil physical and hydraulic properties were measured including soil-water matric potential and retention. Hydraulic conductivity and longitudinal dispersivity were optimized by the HYDRUS model using field-measured bromide mass in soil and lysimeter reservoirs, and cumulative depth of water drainage. HYDRUS obtained an acceptable fit under both irrigation regimes for both treatments (Fig 2).
3. Simulating Water / Residue Movement in Lysimeters. Consistent with the highly mobile residues of bromacil and hexazinone, bromide movement in control plots occurred to greater depths than in lysimeter plots (Fig 2). Preferential flow was not indicated in this study as lower water-flow boundary condition of the transport domain was the sole variable accounting for simulated differences between control and lysimeter treatments. This boundary condition for control and lysimeter treatments were set as 'free drainage' and 'seepage face', respectively. Drainage in the latter occurred only by gravity when the pressure head at the boundary was non-negative. Consequently, and in contrast to the control treatment, the lysimeters maintained saturated or near saturated conditions at their base (Fig 3).

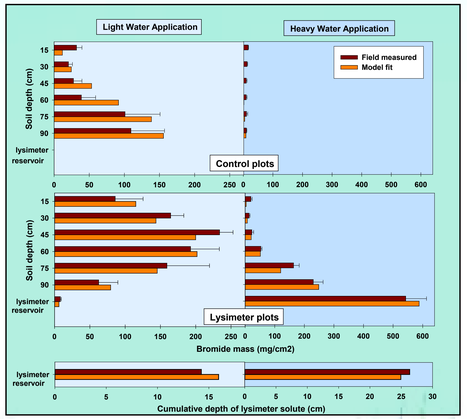

Fig. 2. Fit of HYDRUS-simulated data in light- and heavy-irrigated plots to bromide residues measured in unconfined (control) and lysimeter-confined (lysimeter) soil, and in lysimeter reservoir solute. The fit also was simultaneously made to measured cumulative depth of lysimeter solute.

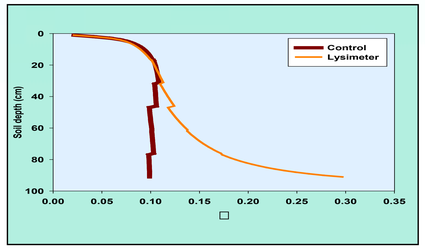

Fig. 3. HYDRUS-simulated volumetric water content (θ) in unconfined (control) and lysimeter-confined (lysimeter) soil at conclusion of the field study.

Table 1. Soil mobility-related parameter values of soil adsorption coefficient (Koc) and solubility.

Pesticide	Koc (ml/g)[x]	Solubility (mg/L)[x]
Bromacil	20	929
Hexazinone	41	29800
Diuron	386	36
Norflurazon	441	34

[x]Median values from California Department of Pesticide Regulation Pesticide Chemistry Database.

IV. Conclusions

1. European regulators accept lysimeter studies for higher tier assessments of pesticide leaching potential to ground water, however, there is little consensus as to how representative lysimeters are to field conditions and to modeling results (Hardy et al., 2008; FOCUS, 2009; Kasteel et al., 2010).
2. This pilot study showed:
   a. lysimeters are representative of field conditions for relatively low soil-mobility chemicals but not for those with high soil mobility,
   b. HYDRUS model satisfactorily simulated movement of high mobility residues in both unconfined and lysimeter-confined soil, and
   c. saturated soil conditions at the base of lysimeters explained differences in residue movement between unconfined and lysimeter-confined soils.

V. Future Research

1. Calibrate HYDRUS model to simulate pesticide movement and persistence in field-based, zero-tension, column lysimeters using data collected from current study.
2. Generate an independent field-data-set to validate HYDRUS predictions of bromide and pesticide residue movement and persistence in field-based, zero-tension, column lysimeters and relate such predictions to pesticide movement in unconfined soil.
3. For pesticides of concern, couple leaching residues measured in lysimeter reservoirs to DPR's deep vadose zone empirical model for predicting residue concentrations in ground water.

VI. References

FOCUS 2009. Assessing potential for movement of active substances and their metabolites to ground water in the EU. Report of the FOCUS Ground Water Work Group, EC Document Reference Sanco/13144/2010, version #1.

Hardy, I., B. Gottensburen, A. Huber, B. Jene G. Reinken and H. Resseler. 2008. Comparison of lysimeter results and leaching model calculation for regulatory risk assessment. Journal fur Verbraucherschutz und Lebensmittelsicherbeit, Vol. 3, No. 4, 364:375.

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