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A globally applicable location-specific screening model for assessing the relative risk of pesticide leaching

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Abstract

A screening model of pesticide leaching loss is described which forms part of a multi-criteria risk-based indicator system called PRoMPT (Pesticide Risk Management and Profiling Tool). The leaching model evaluates pesticide fate in soil for any application rate and time of application (including multiple applications), for any land-based location in the world. It considers a generic evaluative environment with fixed dimensions and soil properties. The soil profile is conceptualised as a number of discrete layers. Equilibrium partitioning between adsorbed and dissolved chemical (based on the organic carbon–water partition coefficient [K_{OC}]) is assumed in each time step, in each layer. Non-leaching losses are described using first order kinetics. Drainage is assumed to be uniform throughout the soil profile but varies temporally. The drainage rate, which can be augmented by evapotranspiration-adjusted irrigation, is derived from long-term mean monthly water balance model calculations performed for 30 arc-minute grid cells across the entire ice-free land surface of the earth. Although, such predictions are approximate, they do capture the seasonality and relative magnitude of drainage and allow the model to be applied anywhere, without the need for extensive data compilation. PRoMPT predictions are shown to be consistent with those made by more sophisticated models (PRZM, PELMO and PEARL) for the FOCUS groundwater scenarios.

Keywords: Pesticide; Profiler; Leaching; Screening model; Groundwater; Risk

1. Introduction

Pesticides play an important role in ensuring good crop yields in conventional agriculture. However, inappropriate use can result in environmental problems and can present a risk to farm workers involved in pesticide application. In an effort to quantify the potentially detrimental impacts which pesticide use can have, a number of attempts have been made to develop indicator systems (*e.g.* Reus et al., 2002). There is an increasing consensus that such indicators should be based on risk (as opposed to hazard) and should be consistent with the methods employed in current regulatory assessment schemes (*e.g.* Brown et al., 2003; Hart et al., 2003; Lewis et al., 2003). Their aim is often to identify cases where pesticides are being used problematically (*e.g.* over use) and to help to target risk mitigation measures more effectively. They can also be used to monitor progress in pest management over time or to compare pesticide use among growers.

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As part of its Sustainable Agriculture Initiative, Unilever is developing a series of indicators which can be applied to agricultural operations in its supply chains in order to benchmark "sustainability" and track progress over time. There are eleven such indicators: (1) soil health; (2) nutrient management; (3) biodiversity; (4) water; (5) energy; (6) product value; (7) social and human capital; (8) local economy; (9) soil loss (10) animal welfare and (11) pest management (which includes control of fungal and bacterial disease and the use of plant growth regulators). A software tool (PRoMPT — Pesticide Risk Management and Profiling Tool) has been developed to support decision-making related to pesticide use. It is being applied, in proprietary plantations and with contract growers, to five key crops across the world for which Unilever is a major global buyer: black tea (Kenya, Tanzania and India), oil palms (Ghana and Malaysia), tomatoes (Australia, Brazil, California and Greece), peas (UK) and spinach (Germany and Italy). This direct and wide-ranging influence has important and immediate implications for the potential impact which the use of the tool can have.

PRoMPT makes screening-level assessments of crop-specific pesticide use in four domains: (1) risks to human health arising from groundwater contamination from leaching, (2) aquatic ecotoxicity; (3) terrestrial ecotoxicity and (4) risks resulting from operator exposure. Screening level assessments are generally simple and easy to apply and are intended to "screen" out those chemicals which are of little concern, allowing more detailed assessments to be made on a limited number of higher priority substances. A brief overview of the tool and some examples of how it is being applied are given by Whelan et al. (2005).

In this paper we describe the development of the groundwater risk component of PRoMPT, which is designed to estimate the relative risk arising from pesticide leaching loss. The methodology was specifically developed to use readily available data on chemical and environmental properties. It is intended for pesticides which are applied over a wide area (*e.g.* in sprays) and is not suitable for products, such as rodenticides, which are used in very small areas or formulated as baits. Although we recognise that some pesticides can be transferred to surface waters *via* leaching, the model described here is specifically orientated towards the potential contamination of groundwater and the risks posed to drinking water supplies.

In addition to the model description, PRoMPT predictions are benchmarked against output from more sophisticated one dimensional leaching models recommended for use in the FOCUS groundwater scenarios. These scenarios form part of the European regulatory approval process (FOCUS, 2000). We also analyse the sensitivity of the PRoMPT leaching model to key input parameters and explore the significance of uncertainties in principal input variables. Although benchmarking is not a substitute for model validation using field data, it does have the advantage of allowing comparisons to be made for a range of compounds and over a range of conditions for which consistent observations may not exist, or are not publically available. In the absence of suitable measured data, favourable model performance against well-established models can augment confidence in model output, particularly in the case of screening level models which are intended to make relative rather than absolute predictions.

2. Model description

2.1. Conceptual basis

The PRoMPT leaching model is based on a consideration of the mass balance and partitioning behaviour of a chemical in a generic soil profile with depth Z (assumed to be 1 m), receiving one or more discrete applications of active ingredient to the soil surface (E_0: g ha^{-1} day^{-1}) over the course of a year (Fig. 1). A depth of 1 m is consistent with the depth of the rooting zone for many crops. The soil unit is divided into a number of layers, n, each of equal depth $z=Z/n$ (m). The number of layers is set to 5 and z to 20 cm, which is representative of a plough layer depth as recommended for soil exposure to chemicals applied with sewage sludge in EU guidance on chemical risk assessment (EC, 2003). All layers are assumed to have the same hydraulic properties and bulk density but different organic matter contents can be assigned to different layers. All pesticides are assumed to achieve instantaneous and complete equilibrium with the soil organic matter in each layer (*i.e.* a linear sorption isotherm normalised to organic carbon). Assuming that degradation can take place in both the adsorbed and dissolved phases (at the same rate) and that non-leaching losses (biotic and abiotic degradation and volatilisation) can be described by a combined process which can be approximated using first order kinetics, then the mass balance equation for each layer (i), including leaching losses may be written:

$$\frac{dM(i)}{dt} = E(i-1) - k \cdot C_{OC}(i) \cdot M_{OC}(i) - k \cdot C_W(i) \cdot V_W(i) - q \cdot C_W(i) \cdot A$$

where, for each layer, M is the mass of substance in the soil of a given depth over an area of 1 ha (g ha^{-1}), M_{OC} is