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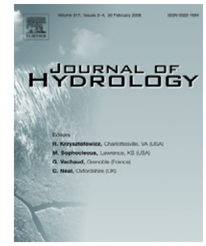

Variations in the depth distribution of phosphorus in soil profiles and implications for model-based catchment-scale predictions of phosphorus delivery to surface waters

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Summary The PSYCHIC process-based model for predicting sediment and phosphorus (P) transfer within catchments uses spatial data on soil-P derived from the National Soil Inventory (NSI) data set. These soil-P values are based on bulked 0–15 cm depth and do not account for variations in soil-P with depth. We describe the depth distribution of soil-P (total and Olsen) in grassland and arable soils for the dominant soil types in the two PSYCHIC study catchments: the Avon and the Wye, UK. There were clear variations in soil-P (particularly Olsen-P) concentrations with depth in untilled grassland soils while concentrations of total-P were broadly constant within the plough layer of arable soils. Concentrations of Olsen-P in arable soils, however, exhibited maximum values near the soil surface reflecting surface applications of fertilisers and manures between consecutive ploughing events. When the soil-P concentrations for the surface soil (0–5 cm average) were compared to both the profile-averaged (0–15 cm) and the NSI (0–15 cm) values, those for the surface soil were considerably greater than those for the average 0–15 cm depth. Modelled estimates of P loss using the depth-weighted average soil-P concentrations for the 0–5 cm depth layer were up to 14% greater than those based on the NSI data set due to the preferential accumulation of P at the soil surface. These findings have important implications for the use of soil-P data (and other data) in models to predict P losses from land to water and the interpretation of these predictions for river basin management.

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Introduction

Understanding the causes of, and being able to control, phosphorus (P) concentrations in soil and water supplies is important because of its impact on water quality and associated effects on public health (Bell and Codd, 1996; Correll, 1998). Increasing soil-P concentrations resulting from P surpluses in intensive farming systems have been associated with higher P concentrations in surface and sub-surface runoff from both grassland and arable field sites (Sharpley et al., 2000). Surpluses in soil-P are spatially variable and this leads to variable distribution of soil-P both horizontally (e.g. Page et al., 2005) and vertically within the soil profile (Eckert and Johnson, 1985) depending on land management practices. In non-tilled and grassland soils, P accumulates near the soil surface, while in conventionally tilled soils mechanical mixing of the soil results in lower P concentrations at the soil surface and a more even P distribution with depth (Weil et al., 1988; Simard et al., 2000).

Phosphorus is mobilised due to rainfall-generated soil erosion (Kronvang et al., 1997; Quinton et al., 2001), or leaching processes (Maguire et al., 1998). Soil in the top 0 to 2 cm of the soil profile is most at risk from erosion by rill and inter-rill processes (Morgan, 2005), and in particular the smaller size fractions are preferentially eroded and transported (Walling, 1990). Mobilisation of the finer soil fraction has significance because P is preferentially bound to the finer fractions, and in particular clay- and silt-sized material (Sharpley and Rekolainen, 1997; Quinton et al., 2001; Owens and Walling, 2002), and this material will stay in suspension longer compared to coarser material (which will also have a lower P content). Leaching of dissolved P occurs either from recently applied manure or fertiliser, or by desorption, dissolution and extraction of P from soil and plant material. Leaching is often associated with rainfall interaction with the surface 0–5 cm of soil (Sharpley, 1985).

Export of P from catchments is highly spatially and temporally variable because of differences in landform, continuously changing hydrological conditions and farming practices (Lennox et al., 1997; Withers et al., 2000; Page et al., 2005). In an attempt to understand and control, at the catchment-scale, the delivery of P to surface waters from diffuse sources a variety of models have been developed and applied, such as PolFlow (De Wit, 2001), CREAMS (Cooper et al., 1992), MONERIS (Kronvang et al., 2005) and SWAT2000 (Arnold and Fohrer, 2005). In the UK, recently developed models include the Export Coefficient Model (Johnes, 1996), the P-Expert System Model (Harrod and Fraser, 1999), the Phosphorus Indicators Tool (PIT, Heathwaite et al., 2003), PSYCHIC (Davison et al., this volume) and more bespoke models (e.g. Van der Perk et al., 2006, 2007). Many of these models, including PSYCHIC, depend on available data sets, such as the National Soil Inventory (NSI) for England and Wales (McGrath and Loveland, 1992) and the Representative Soil Sampling Scheme (RSSS, Baxter et al., 2006), to provide information relating to the spatial distribution of soil-P concentrations, in addition to other parameters such as soil texture and soil series. Such data sets are used because of the cost and time implications of having to conduct a specific and detailed survey of soil-P over large areas. The successful outcome of models such as PSYCHIC as a tool for management and decision-making is, therefore, dependent on how accurate the model estimates P fluxes from land to surface waters, which in turn depends on how representative the values given in these data sets are to the actual concentrations of soil-P in the field.

In the case of the NSI data set, values of total-P and Olsen-P are given for bulked 0 to 15 cm soil samples collected on a 5 km grid throughout England and Wales between 1978 and 1983 (McGrath and Loveland, 1992). Similarly, the RSSS data set is also based on bulked 0–15 cm soil samples. Models such as PSYCHIC tend to use the value for the lumped 0–15 cm soil to represent the P concentration of topsoil and, therefore, eroded soil. However, it is uncertain as to how representative a bulked value for 0–15 cm depth is of P concentrations in the upper few centimetres of soil. Information on the depth distribution of P in soil profiles is surprisingly limited in the literature, although studies (e.g. Weil et al., 1988; Haygarth et al., 1998; Simard et al., 2000; Page et al., 2005) have demonstrated that there are variations in soil-P with depth, especially in non-tilled soils, as described earlier.

We determined the depth distribution of soil-P (total and Olsen) in grassland and arable soils for the dominant soil types in the two PSYCHIC study catchments, namely, the Hampshire Avon and the Herefordshire Wye, UK. This was done to evaluate the importance of soil-P input data on PSYCHIC model predictions of P delivery to watercourses. In particular, the research aims were:

(1) To determine the depth distribution of soil-P in dominant soils in the two study catchments;
(2) To compare values of soil-P (0–5 and 0–15 cm depth-averaged) for the collected samples with values from the NSI data set; and
(3) To evaluate the implications of (1) and (2) on the values of P loss from fields to surface waters calculated by the PSYCHIC model.

Study area and methods

Catchments

The Avon catchment (~1700 km^2) is located in the counties of Wiltshire, Dorset and Hampshire in southern England. The upper catchment is characterised by rolling chalk lands and sheltered river valleys and includes the arable landscape of Salisbury Plain. Land use within the catchment is dominated by arable cropping (33%) and permanent grassland (26%), with temporary grassland, woodland and lowland heath occupying 19%, 9% and 3%, respectively. The Wye catchment (~ 4000 km^2) is located in the Welsh borders and has a varied landscape. The upper catchment in the Plynlimon Hills is dominated by upland and moorland landscape, while the midsection, in the Hereford Plain, is a more gentle agricultural landscape with intensively managed farmland to the east, and the lower sections above Chepstow are characterized by steep-sided limestone gorges. Land use within the Wye catchment is dominated by permanent grassland (29%), arable cropping (20%) and ley grassland (15%), with smaller areas of the catchment being occupied by upland grazing (12%) and woodland areas (10%). The long-term (1961–1990) annual average rainfalls range from