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Processes influencing pesticide transport in a drained clay catchment

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Abstract A study of processes that influence pesticide transport is being conducted in a drained-clay catchment in southern England. Initial results showed that high concentrations of the pesticide isoproturon, applied to a winter cereal crop, were translocated into runoff. The isoproturon detected during two rainfall events following pesticide application was 2.7% of that available at the surface. The peak isoproturon concentration in the first significant drain flow event exceeded of 500 ppb. For these first two rainfall events, 1% of the compound applied was lost. Comparison of isoproturon with chloride and sulphate concentrations suggested different origins for the drain water, reflecting new rainwater with a high pesticide and low salt concentration, in contrast with soil water from deeper within the soil. Wide differences occurred in pesticide concentrations within the plot, from runoff traps and within mole drains, and between field drains. Variations in pesticide concentration are discussed relative to surface topography and temporal changes.

INTRODUCTION

Concern about water quality in Europe has risen from the detection of pesticides in pumped groundwater (Leistra & Boetsen, 1989) and river water (Lees & Mcveigh, 1988) that are used as drinking water. Although spectacular contamination episodes can be linked to point sources, the study of headwater catchments has illustrated the loss of pesticides from normal agropractice to water courses. An example of this type of work at Rosemaund, UK (Williams *et al.*, 1991), on a predominantly artificially drained clay soil revealed the episodic arrival of pesticides in ditches and streams (up to 1% of applied pesticide lost in this manner). This work raised further questions, such as whether pesticide was lost equally from all parts of the field, and which antecedent conditions and soil processes led to pesticide being lost from the topsoil. It was clear that the stream sampling system gave information that was too coarse to answer these questions. To provide a closer focus on the in-field processes that led to pesticide transport and to look at spatial variation in pesticide loss within a field, at a number of different scales, a field site was established at Wytham, UK. The experiment was designed to provide information on processes at scales ranging from a soil column to a field unit. Measurements were made over two winter seasons at the field site, and complementary experiments were carried out in the laboratory.

MATERIALS AND METHODS

The pesticide and field site

The compound studied was isoproturon (3-(4-isopropylphenyl)-1,1-dimethylurea), which is a residual soil-applied herbicide commonly used for pre- or early post-emergence weed control in winter cereals in Western Europe. The compound is considered to be moderately persistent (DT_{50} of 30 days), fairly mobile, with a solubility of 50 mg l^{-1}, and weakly sorptive.

The clay catchment chosen for this study was at Oxford University Farm, Wytham in Oxfordshire. The experimental area was on a structured clay soil, under arable cultivation of winter wheat, that had been moled and ploughed in September, 1992. These soils are particularly important as they exhibit a propensity for water to move rapidly through the soils via macropores during preferential flow events. The soil within the plot was classified as a heavy clay belonging to the Denchworth series (Jarvis & Hazelden, 1982).

Ploughing had incorporated the straw and stubble forming a "buried straw horizon" at a depth ranging from about 0.15 to 0.2 m. The plot, approximately 25 m by 50 m in size, covers the area between two field drains and is intersected by a series of mole drains at 3-m spacings. The moles are at a depth of 0.5 m and drain into the gravel back-fill above the field drains, which are 0.75 m below the soil surface. Mole drains are channels, approximately 5 cm in diameter, which are created in the sub-soil by the farmer using a special beam plough. The site slopes towards the drainage ditch at a gradient of approximately 1:20.

Field instrumentation

Rainfall was monitored using a tipping bucket rain gauge connected to a logger (Campbell Scientific, USA) and soil-water potential was assessed by logging pressure transducer tensiometers (PTT), installed at 10, 30, and 100 cm depths. To monitor (and sample) field drain water emanating from the plot area, a pit was dug to intercept the drain at the end of the plot. The "catchment" of this field drain prior to its interception was estimated to be 1800 m^2. This estimation was carried out by measuring the distance to the expected catchment divide both up slope and to the side of the field drain. The drain was cut, and the end placed into 82-mm plastic pipe. The pipe led 15 m down the slope to a flow gauge, consisting of a v-notch weir box that contained a pump-operated sampling tube activated by a float switch. The autosampler (Dalog Sampling Equipment, Alton, UK) is designed to collect 24 $\times$ 1-litre samples when triggered. A pressure transducer determined the height of water in the weir box, from which the flow rate was deduced.

Access tubes (110 mm) were installed directly over three mole drains and glass beakers (100 ml) were installed in the bottom of the moles to act as sumps to collect drain water for manual sampling. Care was taken to ensure that the soil immediately beside the access tubes (and suction samplers) was compressed around the tubes, to minimize water ingress down the walls from the soil surface. In the following season (1993-1994) access tubes and sumps were placed in other mole drains, so that six mole drains were connected to an automatic sampling system, triggered by LED level switches.

Two 2-m surface-runoff traps were installed and connected to 5-l plastic sampling vessels. The traps represented a steel gutter with a leading edge lip (which was pushed in just below the soil surface) and a lid to keep out the rain. The traps were installed so that they collected water running along the soil surface. Water samples were taken manually from two field-drain outflow pipes, where they emptied into the ditch and from the ditch at the bottom of the field. Isoproturon was applied to the field site on 10 February 1993, at a rate of 2.5 kg ha^{-1}, and on 12 March 1994, at a rate of 0.9 kg ha^{-1}.

RESULTS AND DISCUSSION

From analysis of pesticide residues on filter-paper discs placed on the field on application day, there was found to be minimal spatial variation, with a mean of 2.45 kg ha^{-1} and a standard deviation of 0.33. After pesticide application in both years only a few rainfall events were of a duration and intensity to generate preferential flow and measurable drain flow. The changes in soil-water potential associated with these rain events are illustrated by the pressure-transducer tensiometer (PTT) data shown in Fig. 1. In response to sufficient rainfall during this period, saturation and then a head of water built up in the soil A horizon as shown by the 10-cm PTT. Once a head of water had been induced in the top soil, drain flow commenced. In contrast, soil in the B horizon at 100 cm remained unsaturated. Thus, it seems that water arrived at the drains from above as preferential flow through the top soil rather than from saturated conditions reaching the level of the drain from below. A schematic diagram which illustrates the water pathways associated with vertical by-pass flow is shown in Fig. 2.

Marked spatial variability is often associated with pesticide concentrations associated with surface runoff (Smith *et al.*, 1978). The isoproturon concentration found in trap 1 on day 50 was 1100 ppb and in the trap a few metres away was 535 ppb, a 50% difference; 40 days later the concentration in trap 2 was only 30% (20 to 61 ppb) of that in trap 1. The influence of surface topography, particularly tramlines (Baker & Laflen, 1979) left by agricultural machinery, appears to have a major influence on which parts of a field will yield the most surface runoff. When calculating the loss of pesticide from a field the wide variations in runoff concentrations over a field are probably not so important in the UK, as surface runoff is not usually a large part of the water balance. Additional data from the Wytham site (Johnson *et al.*, 1994) suggested that surface runoff accounted for no more than 3% of the rainfall.

Isoproturon found in the mole drain water in 1993 and 1994 is shown in Fig. 3. The variations in mole-drain isoproturon concentrations may be attributable to variations in surface topography over the mole drains enhancing or reducing the mixing of rainwater with pesticide-rich soil water at the soil surface, and different dilution effects of new rainwater by old soil water in the soil profile before it reaches the mole drain. The variation in the hydrological pathways to the mole drains and the differing efficiencies of the drains can be seen when studying the amount of water pumped by the mole samplers during a storm event (Fig. 4); this figure describes the amount of water removed over a 3-day period (days 73-75).

The drain flow and concentration of indigenous solutes found in the field drain for

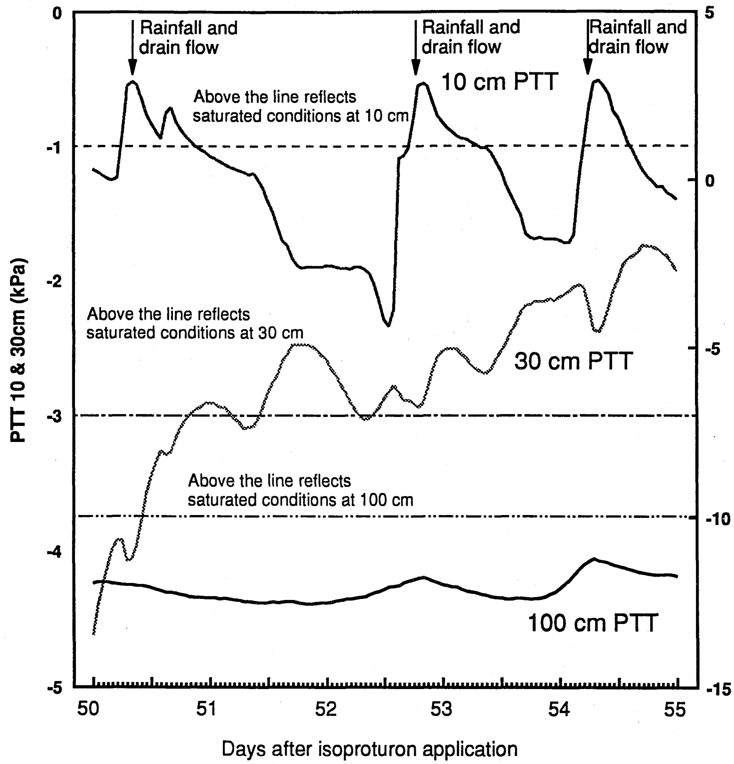

Fig. 1 Total potentials in the soil at Wytham measured by pressure-transducer tensiometers (PTT) buried at 10, 30, and 100 cm depths. This 5-day period coincided with three major rainfall events that led to drain flow.

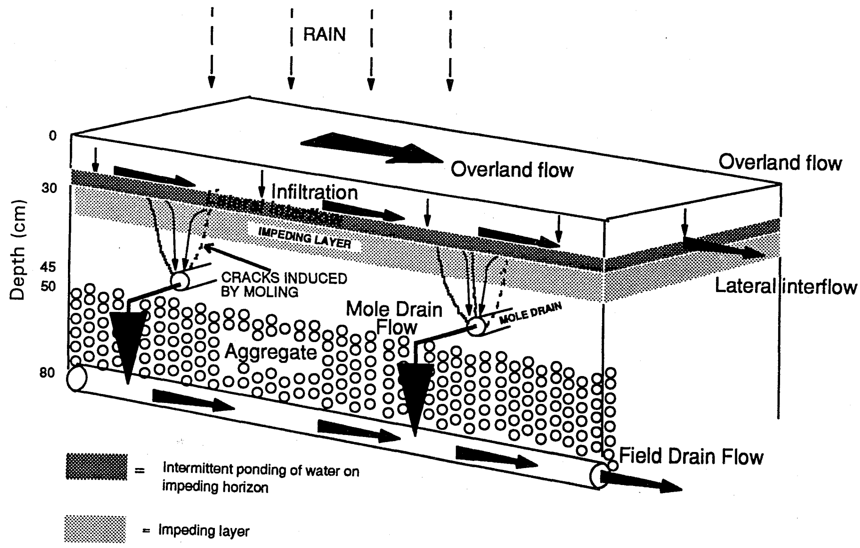

Fig. 2 Schematic diagram of preferential water flow pathways through and over the soil at Wytham.

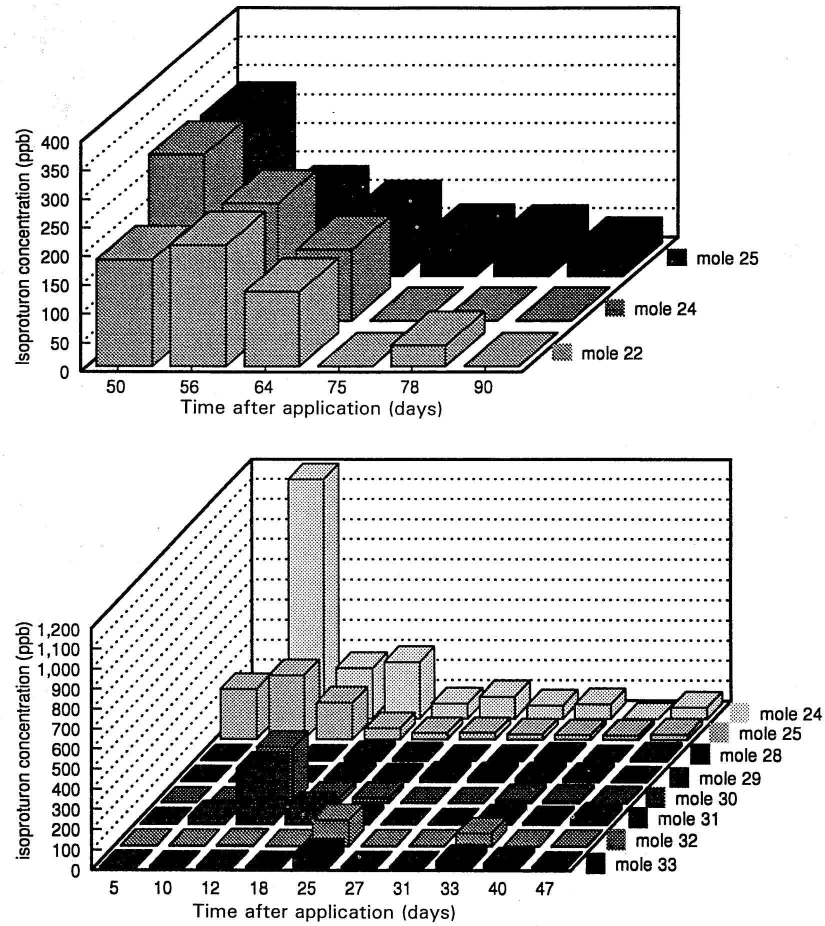

Fig. 3 Comparison of isoproturon concentrations measured in mole drain water found in three instrumented mole drains in 1993, and eight in 1994.

a storm event are shown in Fig. 5. Isoproturon concentration and drain flow velocity appeared to be closely related, with pesticide concentrations declining more slowly with time. Chloride and sulphate concentrations showed an inverse relation to both drain flow and isoproturon concentration; as isoproturon concentration and drain flow velocity increased, chloride and sulphate concentrations decreased, and vice versa.

The pesticide losses were calculated using the area of the field drain catchment for the plot, together with the amount of pesticide known to be available in the soil surface at the time from the soil residue analysis, and the amount of drainage water to emanate from the plot. From the first major rainfall event on 1 April 1993 (Fig. 5), 1.5% of the available pesticide was lost to the drainage system. In the combined events of 1-3 April 2.7% of the pesticide was lost to the drainage system in 3 days. Therefore, 1% of the original isoproturon applied on 10 February was lost in these events.

Water samples were taken on a routine basis (once a week on average) both from two field drain outfalls and from the ditch 15 m downstream from the field drain outfall.

Unfortunately, the field and the adjacent ditch at Wytham did not comprise a hydrologically defined catchment. A component of the water in the ditch would have come from Wytham wood nearby, and would have therefore diluted the water and pesticide from the field. However, Fig. 6 reveals pesticide concentrations in a ditch which ultimately enters the River Thames. Pesticide concentrations found in the field drain outflows, where they enter the ditch, correlate poorly although it is difficult to make assessments as the actual volumes of water emanating from the outflows was not measured. Studying the field topography revealed a much smaller "catchment" for FD 3 than for FD 2, and soil analysis indicated that the soil was of a slightly different composition (lower clay content) over FD 3. Pesticide concentrations in the ditch from spraying day (10 February 1993) until 100 days after spraying were routinely above 0.1 ppb (Fig. 6). The highest concentrations of 16.8 and 23 ppb corresponded to the rainfall events on, or prior to, days 42 and 50.

CONCLUSIONS

The field experiment helped to indicate the processes involved in rapid pesticide transport in a heavy clay soil. Also, the work confirmed the high pesticide concentrations

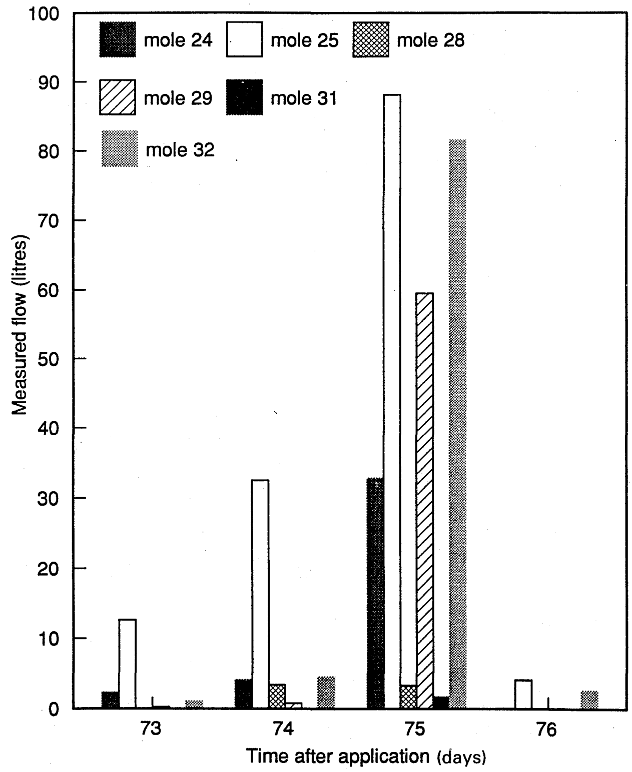

Fig. 4 Comparison of volumes of water carried through six mole drains over a 4-day period in 1994.

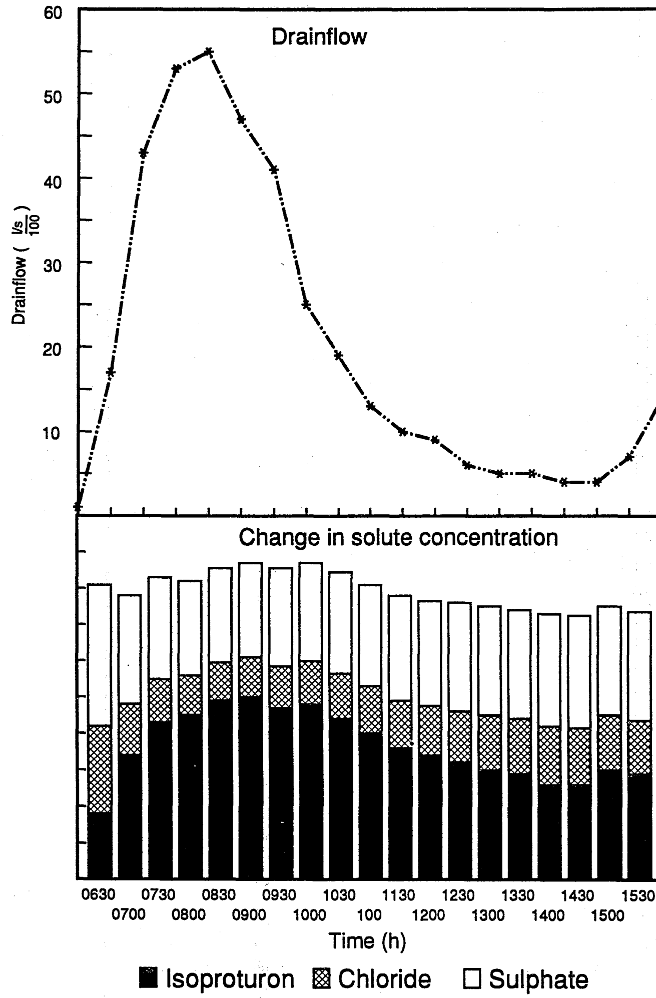

Fig. 5 Comparison of drain flow with solute concentration for a storm event in 1993.

found in drain and stream water in response to winter or early spring storm events from structured soils with a high clay content and extensive drainage system. Spatial differences, however, even on a small scale, show variations in pesticide concentration of up to 2 orders of magnitude in drain water, such as between mole drains, a few metres apart. The variation in pesticide concentrations found in mole drain water illustrates the heterogeneity of soil. Volumes of water carried by the drainage system and variations in pesticide concentrations may be ascribed to differences in micro-topography over the field and in macropore distribution. These spatial differences in drain performance and amounts of pesticide carried will increase over time as the drainage system decays. Whilst it is difficult to scale up from a detailed field study in an area with a very complex hydrology, this type of work should improve process-based models, and also should lead to the identification of areas of agropractice which could be altered to minimize pesticide losses to water.

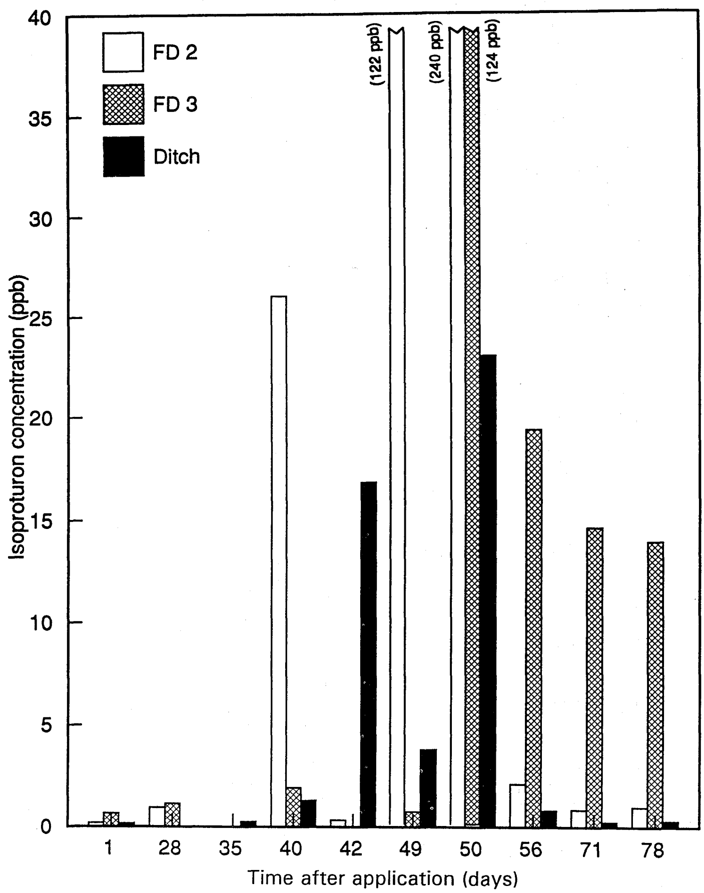

Fig. 6 Variations in isoproturon concentration in drain water from two field drains, and in the ditch that received drain water during the 1993 season.

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