ELSEVIER Agricultural Water Management 44 (2000) 75–83

Agricultural water management

www.elsevier.com/locate/agwat

Evaluating pesticide leaching models: the Brimstone Farm dataset

G.L. Harris[a], J.A. Catt[b], R.H. Bromilow[b], A.C. Armstrong[a,*]

[a]ADAS Gleadthorpe, Meden Vale, Mansfield, Notts NG20 9PF, UK
[b]IACR-Rothamsted, Harpenden, Herts, AL5 2JQ, UK

Abstract

This paper describes the Brimstone Farm dataset used for the comparison of pesticide leaching model performance. The tasks set to the modellers are then described. The soil of the site is heavy clay, in which cracks have a major effect on the hydrology. Data are presented for the leaching of isoproturon and mecoprop from two contrasting plots. Contrasting soil moisture states, resulting from different cropping, result in higher drainage rates from the wetter plot, which were associated with higher and earlier losses of isoproturon to the drains. No mecoprop was detected in the drainflows from this site. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Cracked clay soils; Macropores; Drainflow; Pesticide leaching

---

1. Introduction

Clay soils present a major challenge for pesticide leaching models. The presence of pathways for the preferential transmission to the drainage system of water, and, with it, pesticide, can lead to the rapid transmission of contaminants to surface water courses. This paper presents a set of data collected on one such soil, which was used for the basis of a comparison between models. Only those data relevant to the COST-66 exercise on the 'Evaluation of Pesticide Leaching Models' are presented here.

2. The experiment facility at Brimstone Farm

This facility was established in 1978 near Faringdon, Oxfordshire, UK, on a clay soil of the Denchworth series, a pelo-stagnogley (Clayden and Hollis, 1984) also classified as

---

[*] Corresponding author. Tel.: +44-1623-844-331; fax: +44-1623-844-472.
E-mail address: adrian_armstrong@adas.co.uk (A.C. Armstrong).

PII: S0378-3774(99)00085-2

verti-eutric gleysol (FAO, 1989). The site is considered to be typical of much of the lowland clay in arable use in England (Goss et al., 1988). As the soil of the site dries out in summer, large vertical cracks occur which can provide rapid pathways for the transport of water and solutes to the mole drains (Goss et al., 1983, 1993). In winter when the soil wets up, the cracks close, and a larger proportion of the incoming water is lost as surface runoff. Where the soil is ploughed, the connectivity of the macropores is interrupted at the base of the plough layer. In the first phase of the experiment (1978–88), this resulted in lower flow rates and a less peaky hydrograph than for direct-drilled plots (Harris et al., 1993).

The facility consists of 20 hydrologically isolated lysimeters, each 0.2 ha in size, which is sufficiently large to contain a complete drainage system, and to permit normal agricultural operations. In the initial phase, which was concerned primarily with the movement of nitrate, half the plots were drained, and the plots were also split between conventional and direct-drilling treatments, giving a five-fold replication of a simple factorial design. In the second (1988–93) and third (1993–present) phases of the experiment, the fate of pesticides was also examined. In addition variable drainage treatments were imposed on some plots. The data presented in this paper come from this second phase of the experiment. The procedures for the collection of the data and a discussion of their significance are presented by Harris et al. (1994).

This site has been intensively monitored for agronomy and hydrology, and so provides an ideal source of data and parameters for the validation of leaching models. Details of the initial installation are given by Cannell et al. (1984) and Harris et al. (1984). A summary of much of the data and results from the first phase of the experiment are contained in Catt (1991) and the references cited therein.

3. Modelling data

For the modelling exercise, data were selected which presented both a typical set of results and yet were also sufficiently complete to allow good comparisons of the models. These data were gathered from the archives for the site, and distributed as a package to the various modellers. A list of the data distributed is given in Table 1.

The data chosen were for the winter period of 1990/91, and for Plots 6 and 9. Plot 6 grew winter oats in 1988/89, and was in winter wheat in 1989/90. Plot 9 had white mustard (a winter cover crop) and spring wheat in 1988/89, and winter barley in 1989/90. Isoproturon and mecoprop were applied to both plots on 11 March 1990, as part of the control programme for the crop. After harvest in 1990, the two plots grew different crops and so required different agricultural operations. Plot 6 was cultivated and the crop residues incorporated by conventional ploughing techniques. The plot was sown with winter wheat, and the same two pesticides (isoproturon and mecoprop) were applied to the soil surface on 8 October 1990 for autumn weed control. Plot 9, however, was to be sown with field beans in the following spring, so autumn cultivations were restricted to a single pass with a power harrow. No pesticide was applied and the plot was in bare fallow over winter. Pesticide leaching data from this plot thus relate to the residual pesticide from the previous (1990) spring. Hydrological data for 1990/91 from this undisturbed plot thus contrast with the recently ploughed Plot 6.

Table 1
Data distributed for comparative modelling exercise

Contents	Comments
Soil parameters	Table 3
Pesticide parameters	Table 4
Met. data, 21/12/90–13/1/91	Hourly
Met. data, 8/10/90–31/3/91	Daily
Water table depth and drain flows, Plot 9, 1/10/90–31/3/91	Hourly
Water table depth and drain flows, Plot 6, 1/10/90–31/3/91	Hourly
Pesticide (isoproturon) concentrations in drainage water, Plot 6, 6/1/91–12/1/91	As sampled
Pesticide (isoproturon) concentrations in drainage water, Plot 6, 6/1/91–12/1/91	As sampled
Isoproturon concentrations in soil, Plot 6, 4/10/90–15/1/91	Table 6

The two plots also differed slightly in their drainage systems. Plot 6 had been mole drained in 1988 with a large expander. Plot 9 had been drained by small-bore plastic pipes installed at a spacing of 3 m and a depth of 0.5 m to replace previous mole drains. Both of these systems (which were intended to be broadly comparable in their water table control) were connected to the permanent drainage system installed in the plots (Table 2). However, Harris et al. (1993) identified differential tillage as having a major impact on the hydrology of this site, and it was thought that the differences between the plots would be due to the effects of soil disturbance in the autumn of 1990.

Within this dataset, two major test periods were identified for the modelling exercise:

- A period of intensive monitoring, from late December 1990 to mid January 1991, which covered the first drain flow events after the autumn application. As this period was monitored intensively, data with a temporal resolution of 1 h or less were available for testing short term model performance.
- The whole of winter, from the time of application to the end of drain flow in the following March (1991).

Modellers were asked to provide hourly simulations of the intensively monitored period and daily simulations for the whole winter period.

Table 2
Characteristics of the two experimental plots

	Plot 6	Plot 9
Drainage system	Moled 1988, with large expander	Close spaced pipes installed 1988 (depth 0.5 m, spacing 3.0 m)
Crop 1989/90	Winter wheat	Winter barley
Crop 1990/91	Winter wheat	Bare fallow/spring beans
Agronomy	Crop residues incorporated by ploughing	Crop residues burnt. Over winter fallow
Pesticide application, 11/3/90	Isoproturon 1625 g ha^{-1}; mecoprop 1179 g ha^{-1}	Isoproturon 1625 g ha^{-1}; mecoprop 1179 g ha^{-1}
Pesticide application, autumn 1990	Isoproturon 2248 g ha^{-1}; mecoprop 2395 g ha^{-1}	
Pre-1988 treatment	Direct drilled	Direct drilled

Table 3
Typical soil properties for each horizon (% for soil components) (information from Cannell et al., 1984)

	Name of horizon (with depth in cm)				
	Ap (0–20)	Bg1 (20–35)	Bg2 (35–62)	Bgk (62–89)	BCgk (89–112)
Sand (60 μm to 2 mm)	7	6	3	2	1
Silt (2–60 μm)	39	39	37	36	37
Clay (<2 μm)	54	56	60	62	62
Organic carbon	3.3	0.8	0.7	0.6	0.6
$CaCO_3$ equivalent	<0.1	<0.1	0.2	12.3	21.6
Field capacity (%)	48	52	50	46	46

3.1. *Soil physical information*

Basic physical information on the soil was gathered from the site. Wherever possible, it was obtained from the plots in question (Plots 6 and 9). However, to protect the integrity of the plots for long term experimentation, excavation within the plots was kept to a minimum, so many of the parameters were derived from investigations in the discard areas around the plots. Detailed soil survey and examination of soil profiles exposed during the installation of the drainage systems at the start of the experiment had indicated that the soil was generally very uniform (Cannell et al., 1984), so no major inaccuracies should be introduced by taking site rather than plot specific parameters. A summary of the major parameters is given in Table 3.

3.2. *Hydrology*

Detailed hydrological measurements are a feature of the dataset. Water moving through the drainage systems, and that moving across the surface plus that in the surface soil to 25 cm depth was collected and sampled separately, and flow rates recorded at half hour intervals using the weir and head device described by Talman (1983) with electronic interrogation. The position of the water table in open auger holes was recorded onto analogue charts using the mechanical device described by Talman (1980) and then digitised every hour. Care needs to be taken in interpreting the water table data, as the water table effectively disappears in summer, and reappears in autumn. It is probable that a zone of unsaturated soil below the apparent water table remains until late into winter, and consequently that the water table recorded is in fact ‘perched’. However, because the transmission through the base of the profile is very slow (Youngs and Goss, 1988), interaction with deeper water can safely be ignored. Although these water table readings were complemented in summer by neutron probe measurements of the soil moisture content, these were not taken during the experimental period.

3.3. *Meteorology*

Meteorological data were made available from the nearby synoptic weather station at Brize Norton. Potential evapotranspiration was calculated using the MORECS prediction

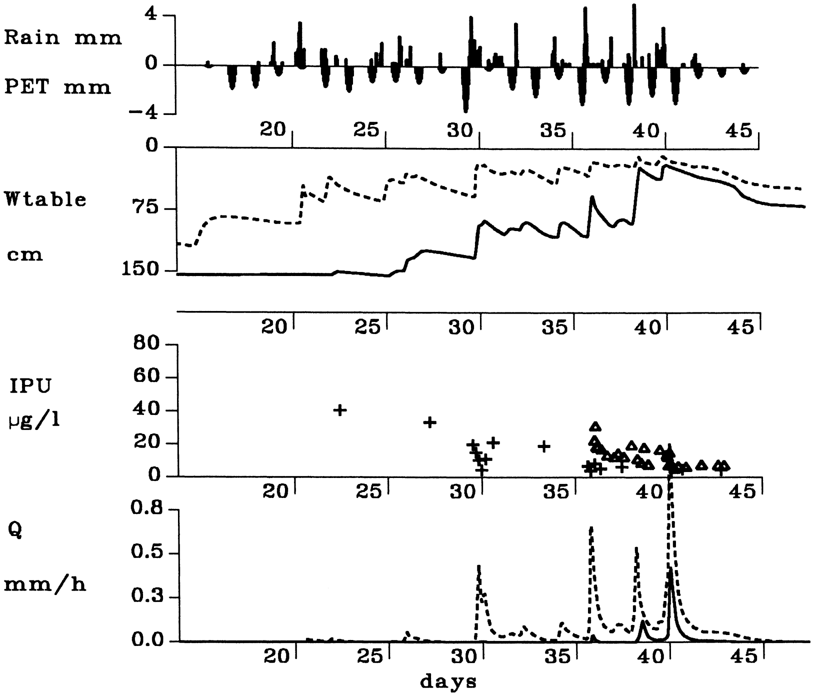

Fig. 1. Detailed (hourly) data for the Brimstone Farm site Plots 6 and 9 for the period 20 December 1990 to 15 January 1991. Day 1 is 1 December. The graph shows in succession from top to bottom: hourly rainfall (mm/h); hourly evapotranspiration estimated from daily values (mm/h); observed water tables (cm below ground level): Plot 6 (solid line), Plot 9 (dashed line). Concentrations of isoproturon in the drainage (µg/l): Plot 6 (Δ), Plot 9 (+). Hourly drainflow rates (mm/h): Plot 6 (solid line), Plot 9 (dashed line).

system (Thompson et al., 1981) using the data from Brize Norton. Rainfall data were collected on the Brimstone Farm site, and this was used wherever possible. For the detailed modelling dataset (December 1990 to January 1991) hourly rainfall data were available for the site. However, due to instrumentation problems, these on-site data were not available for all the longer modelling period, and values from Brize Norton were inserted in the gaps.

3.4. Pesticides

For winter 1990/91, water samples were taken from the drains using a flow-proportional sampling scheme. This involved linking the electronic flow recorders to programmable water samplers (Harris et al., 1991, 1994). Concentrations of isoproturon measured in the drain flow are shown in Figs. 1 and 2. At no time was any mecoprop detected in the drainage waters.

The soils were sampled on a number of occasions during winter on Plot 6 only, and the pesticide concentrations in the soil were determined as a function of depth in the soil

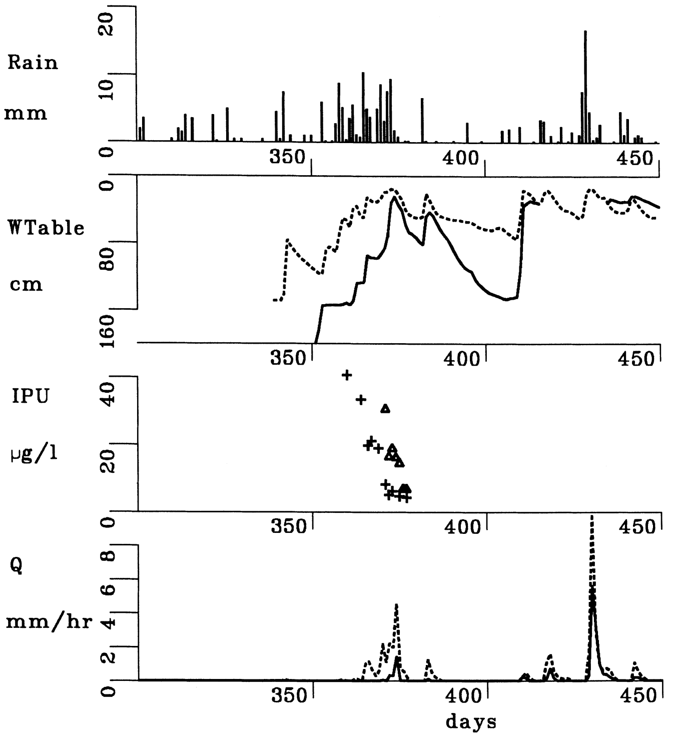

Fig. 2. Daily data for the Brimstone Farm site for the period October 1990 to March 1991. (Note Day 1 is 1 January 1990 (1/1/90)). (Horizontal axis is days after 1/1/90. Note Day 300 = 27/10/90, Day 350 = 16/12/90, Day 400 = 4/2/91, and Day 450 = 26/3/91). The graph show in succession from top to bottom: daily rainfall (mm); observed water tables (cm below ground level). Plot 6 (solid line), Plot 9 (dashed line).

(Tables 4 and 5). The details of the procedures used, as well as estimates of the pesticide behaviour parameters (half-life and sorption, Table 6) were reported by Harris et al. (1991, 1994).

Table 4
Plot 6, isoproturon residues in the soil (µg g^{-1} dry soil)

	Depth (cm)							
	0–2.5	2.5–5	5–10	10–20	20–30	30–45	45–60	60–90
4/10/90	0.0	0.0	0.8	0.35	0.0	0.0	0.0	0.0
9/10/90	5.83	2.88	0.57	0.48	0.06	0.04	0.0	0.0
15/10/90	6.14	2.94	0.99	0.36	0.04	0.0	0.0	0.0
22/10/90	4.20	1.00	0.55	0.55	0.05	0.008	0.009	0.0
5/11/90	5.9	1.8	0.38	0.11	0.02	0.01	0.0	0.0
3/12/90	5.0	1.8	0.22	0.08	0.008	0.0	0.0	0.0
15/1/91	1.49	1.28	0.73	0.0	0.0	0.0	0.0	0.0

Table 5
Plot 6 mecoprop residues in the soil (μg g^{-1} dry soil)

	Depth (cm)							
	0–2.5	2.5–5	5–10	10–20	20–30	30–45	45–60	60–90
4/10/90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9/10/90	4.5	2.4	0.34	0.0	0.0	0.0	0.0	0.0
15/10/90	4.41	1.73	0.32	0.6	0.01	0.0	0.0	0.0
22/10/90	3.7	0.6	0.25	0.09	0.0	0.0	0.009	0.0
5/11/90	0.85	0.5	0.1	0.0	0.0	0.0	0.0	0.0
3/12/90	0.21	0.09	0.0	0.0	0.0	0.0	0.0	0.0
15/1/91	0.06	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 6
Pesticide properties at Brimstone Farm

	Isoproturon topsoil (0–0.3 m)	Isoproturon subsoil (0.3–1.0 m)	Mecoprop topsoil (0–0.3 m)
Adsorption K_d (l kg^{-1})	2.9	2.9	0.61
Half-life (days)	55	200	4.5
Measured at moisture content (%)	40	45	40
Measured at temperature (°C)	10	10	10

4. Discussion and conclusion

The data made available to the modellers are shown graphically for the short test period in Fig. 1, and for the longer period in Fig. 2. They demonstrate the contrast between the two plots. As Plot 9 had no crop in autumn it transpired less water, and so was wetter than Plot 6 which had a growing crop of winter wheat. Plot 9 therefore returned to field capacity earlier, and had a higher water table than Plot 6 during the first drain flow period in late December. The higher water tables in Plot 9 generated greater drain flows during this period. However, by the end of winter, the water table levels in the two plots came together (noting the gap in the data for Plot 6 in Fig. 2), and when this happened the drain flow rates became similar.

The amounts of pesticide leached from the two plots were broadly similar. As Plot 9 started to flow earlier, the pesticides in the drain flows are recorded earlier. It is observed that there are only small differences in the concentrations in the two plots, despite there being no autumn application on Plot 9. The concentrations in Plot 9 must have come from residual pesticide that had not yet been completely degraded.

The data provided the test set for the modelling comparisons reported elsewhere in this volume. In practice, the simulations concentrated on Plot 6 to the exclusion of Plot 9, as it was felt by most modellers that it was easier to predict the leaching of the autumn application, and there was no information on the location or concentration of isoproturon in the soil of Plot 9.

The dataset also provided a contrast between a short period of intensive observation and a longer period of less detailed data. It was anticipated that the contrast between the two would indicate the value (or otherwise) of detailed mechanistic models which can reproduce the short term behaviour to also make reasonably accurate predictions for the whole winter period.

Acknowledgements

The financial support of the UK Ministry of Agriculture Fisheries and Food is gratefully acknowledged. We also thank our colleagues, too numerous to mention individually, for their work in gathering, processing and analysing these data. The financial support for performing the comparison exercise was given by the COST 66 Action 'Pesticides in the soil environment' of DGXII-EU. The dataset described in this paper is available to other modellers, on request to the corresponding author.

References

Cannell, R.Q., Goss, M.J., Harris, G.L., Jarvis, M.J., Douglas, J.T., Howse, K.R., Le Grice, S., 1984. A study of mole drainage with simplified cultivations for autumn sown crops on a clay soil. 1. Background, experiment and site details, drainage systems, measurement of drainflow and summary of results 1978–80. Journal of Agricultural Science 102, 539–559.

Catt, J.A. (Ed.), 1991. The Brimstone experiment. In: Proceedings of a conference on collaborative work by ADAS Field Drainage Experimental Unit and Rothamsted Experimental Station. Lawes Agricultural Trust. Harpenden, Herts, p. 85.

Clayden, B., Hollis, J.M., 1984. Criteria for differentiating soil series. In: Soil Survey Technical Monograph, Vol. 17. Harpenden, Herts.

FAO, 1989. Soil map of the world: revised legend. International Soil Reference and Information Centre, Wageningen.

Goss, M.J., Colbourn, P., Harris, G.L., Howse, K.R., 1988. Leaching of nitrogen under autumn-sown crops and the effects of tillage. In: Jenkinson, D.S., Smith, K.A. (Eds.), Nitrogen Efficiency in Agricultural Soils. Elsevier, London, pp. 269–282.

Goss, M.J., Harris, G.L., Howse, K.R., 1983. Functioning of mole channels in a clay soil. Agricultural Water Management 6, 27–30.

Goss, M.J., Howse, K.R., Lane, P.W., Christian, D.G., Harris, G.L., 1993. Losses of nitrate-nitrogen in water draining from under autumn-sown crops established by direct drilling or mouldboard ploughing. Journal of Soil Science 44, 35–48.

Harris, G.L., Bailey, S.W., Mason, D.J., 1991. The determination of pesticide losses to water courses in an agricultural clay catchment with variable drainage and land management. Brighton Crop Protection Conference, Weeds 3, 1271–1277.

Harris, G.L., Goss, M.J., Dowdell, R.J., Howse, K.R., Morgan, P., 1984. A study of mole drainage with simplified cultivation for autumn sown crops on a clay soil. 2. Soil water regimes water balances and nutrient loss in drain water. Journal of Agricultural Science 102, 561–581.

Harris, G.L., Howse, K.R., Pepper, T.J., 1993. Effects of moling and cultivation on soil-water and runoff from a drained clay soil. Agricultural Water Management 23, 161–180.

Harris, G.L., Nicholls, P.H., Bailey, S.W., Howse, K.R., Mason, D.J., 1994. Factors influencing the loss of pesticides in drainage from a cracking clay soil. Journal of Hydrology 159, 235–253.

Talman, A.J., 1980. Simple flow meters and water table meters for field experiments. MAFF Land Drainage Service Technical Report 79/1, MAFF Publication, Pinner, 18pp.

Talman, A.J., 1983. A device for recording fluctuating water levels. Journal of Agricultural Engineering Research 28, 273–277.

Thompson, N., Barrie, I.A., Ayles, M., 1981. The Meteorological Office Rainfall and Evaporation Calculation System: MORECS, July 1981. Meteorological Office Hydrological Memorandum No. 45. 72pp.

Youngs, E.G., Goss, M.J., 1988. Hydraulic conductivity profiles of two clay soils. Journal of Soil Science 39, 341–345.