Pesticide leaching potential in the Trasimeno Lake area. Assessment of uncertainty associated with the simulation process

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ABSTRACT

The potential leaching of atrazine in the area around Trasimeno Lake is evaluated using the PELMO model and the uncertainty associated with the simulation process is assessed. Simulation has been performed for all combinations obtained from weather (15 years), soil profile (115 different soil profiles), and pesticide properties. The amount of atrazine leached below 1 m depth is used as an indicator of the potential leaching. Two approaches are compared: stochastic and "megaplot". The stochastic approach is based on 400 simulations performed through a Monte Carlo generator simultaneously modifying key input data such as soil texture, organic carbon and pesticide properties. Megaplot is based on simulation of the 44 unique combinations of weather, soil and crop characteristics identified in the area. The uncertainty of the stochastic approach is about 62% but it is difficult to upscale to a large scale. The uncertainty of the megaplot approach ranges between 55 and 88% and upscaling to a large scale is easier.

INTRODUCTION

Potential groundwater contamination may be defined as the possibility that a given fraction of applied pesticide reaches the water table and the actual contamination depends on the meteorological conditions following application. As the measurement of pesticide concentrations in groundwater is laborious and costly, in recent years a number of pesticide leaching models, at the field scale, have been developed to predict the fate of pesticides in soil and water (FOCUS, 2000). Groundwater vulnerability to contamination depends on the various physical, chemical, and biological processes that determine the environmental fate of pesticides. The rate and importance of each process is strongly affected by various space and time dependent environmental factors (soil, weather and crop) and the properties of the pesticide itself. Then, upscaling procedures to transfer data from edge-of-field to larger scales are affected by uncertainties. Accounting for uncertainties is therefore the only way to get some insight regarding the overall reliability of a regional assessment (Soutter & Pannatier, 1996). Several procedures are proposed (Bouma et al., 1998) such as metamodels, megaplots, stochastic and analytical model methods. In this paper, the potential leaching of atrazine in the area around Trasimeno Lake is evaluated using the PELMO model, a FOCUS groundwater model (FOCUS, 2000). The uncertainty of the simulation process is evaluated for stochastic and megaplot approaches.

MATERIALS AND METHODS

Field study

The study area is located around Lake Trasimeno near Perugia (Italy). The area is of about 280 km^2. 115 soil profiles were taken across the whole area as representative of the landscape. Texture, hydrologic properties, organic carbon content (OC) and pH have been determined for each soil horizon (Giovagnotti et al., 1999). An analysis of correlation of soil properties has been carried out as shown in Table 1. In Table 2 are reported the descriptive statistics of those parameter values not correlated with each other and obtained by dividing the soil profiles into three depths (0-35, 35-70, 70-100 cm). The distribution of texture, OC, pH, and depth have been characterised for each depth interval.

Table 1. Correlation matrix of soil properties

	sand	silt	clay	bulk density	field capacity	wilting point	pH	organic carbon
sand	1.000							
silt	-0.858	1.000						
clay	-0.893	0.537	1.000					
bulk density	0.348	-0.322	-0.291	1.000				
field capacity	-0.936	0.717	0.912	-0.327	1.000			
wilting point	-0.888	0.678	0.870	-0.321	0.941	1.000		
pH	-0.422	0.250	0.481	-0.231	0.496	0.474	1.000	
organic carbon	-0.184	0.256	0.080	0.314	0.154	0.126	-0.113	1.000

Table 2. Distribution of soil profile characteristics

Profile (cm)	Properties	n	mean	max	min	Std. dev.
0-35	Sand	115	51.6	95.2	6.1	19.0
	Clay	115	19.2	51.2	2.3	11.1
	pH	92	6.7	8.2	5.3	1.1
	OC	92	2.4	19.5	0.5	2.8
	Depth	115	23.6	40.0	3.0	13.4
35-70	Sand	115	53.2	91.3	3.7	22.2
	Clay	115	20.1	63.8	1.0	13.4
	pH	92	7.1	8.3	5.3	1.0
	OC	92	1.2	6.9	0.1	1.1
	Depth	115	55.9	75.0	45	8.4
70-100	Sand	115	46.8	91.6	0.8	26.0
	Clay	115	25.8	75.6	0.7	17.1
	pH	92	7.3	8.8	4.7	1.1
	OC	92	0.8	4.2	0.1	0.7
	Depth	115	106.8	140	75	17.4

Meteorological data, collected at four weather stations situated around the lake, are available from 1980 to 1995. They include daily rainfall, minimum and maximum temperature and pan evaporation. The area is characterised by a typical Mediterranean climate with winterdominant rainfall ranging from 700 to 900 mm/year. Potential evaporation exceeds precipitation from May to August so that irrigation is required for maize, which is the crop mainly grown in the area. For this exercise it is supposed that the whole area was cropped by maize and treated the same day with atrazine at a rate of 2 kg a.s./ha. Crop information is reported in Table 3. Koc and half-life values of atrazine were determined for nine soil profiles (Vischetti & Businelli, 1992; Table 3). Other pesticide properties are from Tomlin (1994).

Table 3. Agronomic and pesticide information

max interception water (%)	30	date of emergence	5/05
max active root depth (cm)	80	date of treatment	1/05
max soil cover (%)	100	date of maturation	28/9
soil condition after harvest	residue	date of harvest	15/10
irrigation (mm)	300		
atrazine Koc (ml/g)	108 ± 40	atrazine half-life in soil (days)	80 ± 15

Model

PELMO is a one dimensional model simulating the vertical movement of chemicals in soil by chromatographic leaching. PELMO version 3.2 was used (FOCUS, 2000). Two strategies of simulation are compared: stochastic and megaplot. The stochastic approach is based on many simulations performed through a Monte Carlo modification of key input data such as soil texture, organic carbon and pesticide properties. Upscaling is performed by assigning the mean of the results (i.e. cumulative fluxes of pesticide below 1 m depth) over the whole area. The megaplot approach is used to simulate the potential for pesticide leaching at a large scale and to reduce the number of simulations. Megaplot is based on identification of unique combinations of weather, soil and crop characteristics. Upscaling is performed assigning the same parameter value to all profiles within the same unique combination.

Stochastic approach

Simulations were carried out for a soil profile divided into three horizons. All parameters are defined according to the FOCUS parameterisation procedure (FOCUS, 2000). Spatially distributed input data for PELMO (soil clay and sand content, soil organic carbon content, pH, horizon depth, and atrazine Koc) were statistically analysed in order to assign the type of distribution. A total of 400 values have been randomly created using a Monte Carlo generator (Poptool). The number of Monte Carlo random values could be calculated from the event probability and the confidence interval of the error. In case of a confidence interval of 95% and event probability of 50, the number of Monte Carlo random values is 400 (Snedecor & Cochran, 1989). The 400 simulations were performed for a period of 15 years randomly varying the meteorological data and considering for the analysis only the results of the last 10 years of simulation. Cumulative fluxes of water and pesticide below 1 m depth were recorded for each year of simulation.

Megaplot approach

Weather conditions are quite similar for the whole area and maize is assumed to be the only crop. Therefore unique combinations were determined using only soil profile characteristics. The actual sand, clay and organic content parameters of the first horizon were divided into five classes, as shown in Table 4. Considering all the class combinations, 44 unique combinations were found: 29 combinations included more than one profile, and the first 9 represent 45% of the profiles. Simulations for all the unique combinations were performed for a period of 15 years using fixed pesticide data (Koc = 108 ml/g, and $t_{1/2}$ = 80 days) and considering for the analysis results from only the last 10 years of simulation. Annual average concentrations of pesticide below 1 m depth were recorded for each year of simulation and the 90[th] percentile calculated.

Table 4. Class distribution of spatially distributed variables of the upper soil horizon

Class	Range	n° profiles	mean	Std. deviation	Coefficient of variation
Sand					
1	0 - 24	15	15.71	7.01	44.6
2	24 - 42	22	34.04	4.66	13.7
3	42 - 60	27	51.36	5.41	10.5
4	60 - 70	20	64.21	2.81	4.4
5	70 - 100	27	78.75	6.20	7.9
Clay					
1	0 - 10	29	7.01	2.51	35.8
2	10 - 20	37	13.91	2.64	19.0
3	20 -30	17	24.94	3.02	12.1
4	30 - 40	19	34.57	2.84	8.2
5	40 - 100	9	48.79	8.81	18.0
OC content					
1	0 - 0.45	10	0.36	0.10	28.2
2	0.45 - 0.75	17	0.66	0.06	9.3
3	0.75 - 1.5	46	1.13	0.20	17.3
4	1.5 - 2.0	14	1.72	0.13	7.3
5	2.0 - 9.0	24	2.94	1.19	40.5

RESULTS AND DISCUSSION

Stochastic approach

3910 simulations were performed and the annual average concentrations of pesticide leached below 1 m depth were recorded. Descriptive analysis is reported in Table 5.

Table 5. Descriptive statistics for the stochastic and the megaplot approaches.

	AAC (μg/l) stochastic	DAC (μg/l) megaplot	AAC (μg/l) megaplot	90AAC (μg/l) megaplot
Mean	0.12	0.61	0.61	1.56
Std. Error of Mean	0.01	0.32	0.15	0.80
Median	0.00	0.09	0.002	0.25
Std. Deviation	0.61	2.13	3.10	5.30
Minimum	0.00	0.00	0.00	0.00
Maximum	13.08	14.06	43.18	34.93
90[th] Percentiles	0.16	1.17	1.16	2.23

AAC = annual average concentration below 1 m; DAC = 10-year average concentration below 1 m; 90AAC = 90[th] percentile of annual average concentration

The mean ranges between 0.10 and 0.14 µg/l (at 95% of probability). Stepwise regression indicates that spatially distributed input data and outputs from the model are not well correlated. The best model explains only 11% of variability (Table 6). Analysis of variance shows that weather conditions significantly (p=0.0026) affect the results.

Megaplot approach

440 simulations were performed (44 unique combinations for 10 years) and the annual and 10-year average concentrations of pesticide below 1 m depth were recorded. The 90th percentiles of these data were also computed to take into account the influence of weather conditions. Descriptive analysis is reported in Table 5. The mean at 95% probability of the annual average concentration of pesticide leached below 1 m ranges between 0.32 and 0.90 µg/l. The same mean of 10-year average concentration ranges between 0.00 and 1.24 µg/l.The 90th percentile of the annual average concentration of pesticide leached below 1 m weighted to take into account the unique combination frequencies is 1.28 µg/l. This value is higher than the 90th percentile from the stochastic approach (0.16 µg/l) which is a comparable result.

Table 6 summarises the results of a stepwise regression carried out to evaluate the relationship between outputs and either spatially distributed variables or the classifying variables of unique combinations. A stepwise regression builds a regression model by repeating a process that adds (probability F=0.05) and deletes (probability F=0.05) variables from a list of candidates. The stepwise process stops when no variables not already in the model meet the selection criterion and no variables in the model meet the elimination criterion. For spatially distributed variables, the model obtained explains 25% of variability and this indicates that this approach has a high level of uncertainty. For classifying variables of unique combinations, the model obtained explains 3% of the variability.

Table 6. Summary of stepwise regression of annual average concentration of pesticide leached below 1 m against all input data of the stochastic approach (A), all input data of unique combinations (B) and classifying variables of unique combinations (C).

	Predictors	R^2	SE of the Estimate
A	CL2, CL3, DAY80, KOC, OC1, OC2, OC3, PH2, PROF3	0.111	0.574
B	CL2, CL3, DAY80, OC3, PROF1, SA2, SA3	0.243	2.712
C	OC1	0.026	9.342

CL2=clay content 2nd horizon; CL3=clay content 3th horizon; DAY80=total rainfall in the first 80 days; OC1=Organic carbon content 1st horizon; OC2=Organic carbon content 2sd horizon; OC3=Organic carbon content 3th horizon; PH2= pH 2sd horizon; PROF1=depth of 1st horizon; PROF3=depth of 3th horizon; SA2=sand content 2nd horizon; SA3=sand content 3th horizon.

Uncertainty evaluation

Due to the lack of correlation with spatially distributed data, upscaling of results from the stochastic approach to a large scale is possible only by assigning the same value to the whole area. The uncertainty related to this procedure could be assumed to be the standard error of the mean (0.12 ± 1.96*0.01, where 1.96 is the value of *t* for probability=0.05 and degrees of freedom = ∞). In this case the uncertainty (at 95% of probability) is approximately 14%. The uncertainty is also affected by weather conditions: this effect could be assumed to be the standard error of the annual mean grouped by weather condition and the uncertainty related is approximately 25%. Then the total uncertainty becomes approximately 40%.

The megaplot approach allows upscaling by assigning the same value to profiles belonging to the same unique combination. The uncertainty related to this procedure could be assumed to be the error encountered during the process of selection of unique combinations. As indicated in Table 7, only organic carbon content describes the variability of the results. It is possible to calculate the uncertainty deriving from the definition of unique combinations definition from the coefficient of variation of organic carbon content (Table 4): it ranges from 7 to 40% depending on the class. The uncertainty related to the weather conditions could be the same as the previous approach and the total uncertainty of the megaplot approach ranges between 32 and 65%.

The combination of the two approaches seems to be very interesting. Then the stochastic variation of input data for each unique combination increases the knowledge of uncertainties linked with the process of classification and simultaneously the megaplot approach allows to upscale to a large scale. The time of simulation could be reduced, for example, by decreasing the number of Monte Carlo runs (Snedecor & Cochran, 1989) or by using a latin hypercube generator (Soutter & Pannatier, 1996).

ACKNOWLEDGEMENTS

Work funded by EU–FP5 contract n° EVK1-CT-1999-00028 project PEGASE

REFERENCES

Bouma J; Finke P A; Hoosbeek M R; Breeuwsma A (1998). Soil and water quality at different scales: concepts, challenges, conclusions and recommendations. *Nutrient Cycling in Agroecosystems* **50**, 5-11.

Giovagnotti C; Calandra R; Giovagnotti E (1999). Risorse naturali ed attività dell'uomo. Suolo. In: *Sviluppo agricolo sostenibile del bacino del Lago Trasimeno*, eds. A Boggia & F Pennacchi, pp. 124-162. Regione Umbria, Università Perugia: Città di Castello, Italy

FOCUS (2000). FOCUS groundwater scenarios in the EU plant protection product review process. *Report of the FOCUS Groundwater Scenarios Workgroup*, pp. 197, EC Document Reference Sanco/321/2000.

Snedecor G W, Cochran W G (1989). Statistical methods. Eighth edition, pp. 503, Iowa State University Press, Ames, Iowa, USA.

Soutter M; Pannatier Y (1996). Groundwater vulnerability to pesticide contamination on a regional scale. *Journal of Environmental Quality* **25,** 439-444.

Tomlin C (1994). The Pesticide Manual. Tenth Edition, pp. 1341, BCPC: Farnham, UK.

Vischetti C; Businelli M (1992). Simulazione del movimento e della persistenza di alcuni erbicidi s-triazinici nei suoli umbri. *Annali della Facoltà di Agraria dell'Università di Perugia* **54,** 547-562.

FOCUS surface water scenarios: influence of soil degradation and sorption parameters on simulated losses of pesticides via drainflow and runoff in step 1, 2 and 3 scenarios

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ABSTRACT

The influence of soil degradation and sorption parameters on simulated losses of pesticides via drainflow and runoff in FOCUS surface water Step 3 scenarios were investigated in a collaborative project. Losses via drainflow in six standard scenarios were simulated using MACRO, whilst losses via runoff in a further four scenarios were simulated with PRZM. Further evaluation of these results will be used to develop appropriate losses via drainflow or runoff at earlier steps (1 and 2) of the proposed procedure and will be compared with measurements from field studies and monitoring data.

INTRODUCTION

The FOCUS Surface Water Scenarios Working Group proposes a stepwise procedure for the determination of exposure of pesticides in surface water. Exposure scenarios will be used to determine PEC_{sw} and PEC_{sed} as part of the aquatic risk assessments conducted by the EU rapporteur member states for consideration of the inclusion of plant protection products on Annex 1.

Entry routes from drift, runoff and drainage are considered. At Step 1, loadings from drift and runoff or drainage occur simultaneously. At Step 2, runoff or drainage occurs four days after the last application. At Step 3 deterministic models (MACRO and PRZM) are used to derive runoff and drainflow concentrations from predefined scenarios of soil, crop and weather. These are inputs (together with drift events) into TOXSWA, which simulates the fate of agrochemical products in standardized water bodies (ditches, streams and ponds). Descriptions of this process and the scenarios have been previously reported (Linders, 2001)

The proposed introduction of ten "Step 3" scenarios, representative of vulnerable agro-climatic areas of Europe is a new development within the EU exposure assessment process. This paper summarises a collaborative effort to evaluate the influence of pesticide soil degradation and sorption parameters on the flux and concentrations in surface runoff and drain flow. The results of these Step 3 tests will be used to derive generic losses from runoff or drainage for the Step 2 scenarios. This feedback mechanism ensures that the PEC_{sw} and PEC_{sed} values calculated at Step 2 are in the range of the highest values calculated at Step 3. A comparison of the runoff and drainage losses at Step 3 and Step 2 is presented.

MODEL SIMULATIONS

Test compounds

Model simulations were conducted with a series of eight test compounds. These are not real compounds but cover the typical range of half-life and adsorption values influencing losses of pesticides to surface water via runoff and drainage. Koc values ranged from 10 to 1000 L/kg; soil degradation half-lives (at 20°C and –10kPa soil moisture content) ranged from 3 d to 300 d (Table 3). A ninth possible combination of Koc (10) and half-life (300 d) was not evaluated as this was considered an unrealistic combination of parmaters. Other environmental fate parameters were kept constant. The Freundlich exponent (1/n) was assumed to be 1, water solubility was set as 1 mg/litre and all compounds were assumed to be non-volatile (vapour pressure = 1×10^{-7} Pa).

MACRO Simulations with Step 3 Scenarios

Losses of the test compounds to surface water via drainflow were simulated with a β-test version of the shell program "MACRO in FOCUS" which utilises MACRO v4.2. This shell program includes the Step 3 drainage scenarios (each a function of soil, crop and weather) defined by the FOCUS working group. The Step 3 evaluation consists of a sixteen-month assessment period. Pesticide applications (100g a.i./ha) were made for seven consecutive years (six-year warm-up period followed by 16-month assessment). The pesticides were assumed to be applied to a winter wheat crop as this was a crop common to all six drainage scenarios. The impact of application timing on losses was evaluated for each test substance. Simulations were performed following application pre-emergence (September to November, depending upon Scenario), early post-emergence (February to May) and late post-emergence (March to July).

PRZM Simulations with Step 3 Scenarios

Losses of the test compounds to surface water via runoff were simulated with a β-test version of the shell program "PRZM in FOCUS" which utilises PRZM v3.12. The procedures were similar to those described for the drainage scenarios above. A total of 96 simulations were performed (8 test substances x 4 scenarios x 3 application dates). However, only results for the water balance are presented here.

Runoff/Drainage Losses using "Steps1-2 in FOCUS"

At Step 2, runoff/drainage inputs to surface water represent the 'worst-case' loss from a rainfall event occurring 4 days after the final application of pesticide. The amount of pesticide entering surface water is a function of the season of application (autumn, spring or summer), region (Northern or Southern Europe), crop interception factors and pesticide fate properties. Currently losses via runoff or drainage can range from 1% to 4% of the pesticide residue remaining in soil at the time of the discharge to surface water, although the amount entering in the dissolved phase is a function of soil adsorption. In the current version of the steps1-2 in FOCUS calculator, the maximum losses are:
4% - Autumn, N Europe
2% - Spring, S Europe
1% - Spring, N Europe; Summer, N and S Europe

RESULTS AND DISCUSSION

Water balance

Tables 1 and 2 show the water balances predicted by MACRO for the six drainage scenarios and by PRZM for the four runoff scenarios respectively. Drainage predicted by MACRO varies between 115 mm/year at Scenario D4 (Skousbo) weather to 264 mm/year at Scenario D3 (Vredepeel weather). As an example the drainflow at scenario D5 (La Jalliere weather for 1978) is shown in Figure 1. At all locations the pattern of drain flow for the selected assessment years is similar, with little or no drainflow through the summer months.

However, selection of appropriate assessment years for runoff is more complex as runoff events are generally a response to periods of intense rainfall, sometimes only one day (or less) in duration. Therefore a different calendar year was selected for each scenario depending upon the timing of the first application of the pesticide (Table 2). For example, a pesticide applied in March for scenario R1 was assessed using the weather data for 1984 from Weiherbach (the 50th percentile year for runoff during the period March to May) whereas for a pesticide applied in June, weather data for 1987 is used. The 50th percentile runoff for the scenarios range between 11-110 mm during the selected season and between 32-184 mm per year. These represent between 4-24% of all precipitation received during the year. In general the order of runoff risk was: summer = spring < autumn.

Pesticide Balance and Drainflow/Runoff Concentrations

Figure 2 presents the simulated average daily drainflow concentrations for Pesticide D (Koc = 10, half-life = 30 d) for scenario D5 following application to a winter wheat crop in Autumn (19 October), Spring (14 March) and Summer (31 May). The product of these concentrations and the drainflow allow the daily flux to receiving water bodies to be calculated. The peak concentration for test compound D following application in the autumn in Scenario D5 was 6.83 ppb and occurred on 24 January near the start of the evaluation period. This occurred on a day with the equivalent of 10.9 mm of drainflow and corresponded to a peak daily flux of 0.74% of each annual application. This value together with maximum daily fluxes for the eight test compounds for all six drainage and four runoff scenarios are presented in Table 3. This table also includes the % of applied pesticide calculated to be lost at Step 2 in runoff or drainage and entering the water phase of a receiving water body.

The maximum daily fluxes from the drainage scenarios varied from < 0.01% to 7.63% of applied pesticide depending upon pesticide fate properties, scenario and timing of application. In general simulated losses for any one compound were greater from scenarios D1, D2 and D6 than D3, D4 and D5. Losses were greater following autumn and spring applications than summer. For compounds with a Koc value of 1000, maximum daily fluxes of greater than 1% of applied pesticide were only predicted for compound I (half-life of 300 days) in 1 scenario (D6, autumn application). Maximum daily fluxes of greater than 1% were predicted for compounds with a Koc of greater than 10 following autumn and spring applications in scenarios D2 and D6.

In most cases the maximum fluxes of pesticides were less than corresponding losses calculated at Step 2. Of the 144 drainage simulations only 20 values at Step 3 exceeded the calculated losses at step 2 and most were associated with compounds with a long degradation half-life (300 d).

CONCLUSIONS

Results from these tests have helped in an understanding of the relative vulnerability of the ten Step 3 scenarios. Further evaluation of these simulations is needed. The model outputs will be used as loading inputs into the TOXSWA model. This will allow comparisons of predicted environmental concentrations in surface water at each of the steps and the scenarios to be made in order to assess relative vulnerability and define appropriate inputs for runoff or drainage losses in the earlier Steps 1 and 2.

REFERENCES

Linders (2001). The Development and Status of the FOCUS Surface Water Scenarios within Directive 91/414/EEC. *proceedings of the SETAC Conference, Madrid, Spain*

Table 1. Water balances predicted by MACRO for the drainage scenarios for winter wheat. All figures are in mm, for the last 12 months of the 16-month simulation (1/5 to 30/4).

Scenario	Weather Station	Precipitation	Drainage	Percolation	Evapo-transpiration	Runoff
D1	Lanna	534	159	20	344	0
D2	Brimstone	623	260	15	354	0
D3	Vredepeel	818	319	0	523	0
D4	Skousbo	706	145	39	521	12
D5	La Jailliere	626	199	0	429	3
D6	Thebes	733	300	22	433	0

Table 2 Water balances predicted by PRZM for the runoff scenarios for winter wheat (except for R2, maize). All figures are in mm, for each four-month period.

Scenario	Weather Station	Season for First Application	Selected Year (50^{th} %ile for runoff)	Precipitation	Runoff
		Mar to May	1984	817	40
R1	Weiherbach	Jun to Sep	1987	778	32
		Oct to Feb	1975	807	39
		Mar to May	1977	1906	184
R2	Porto	Jun to Sep	1989	1370	178
		Oct to Feb	1977	1906	168
		Mar to May	1977	688	85
R3	Bologna	Jun to Sep	1977	688	95
		Oct to Feb	1986	969	64
		Mar to May	1992	1000	164
R4	Roujan	Jun to Sep	1985	573	122
		Oct to Feb	1985	573	136

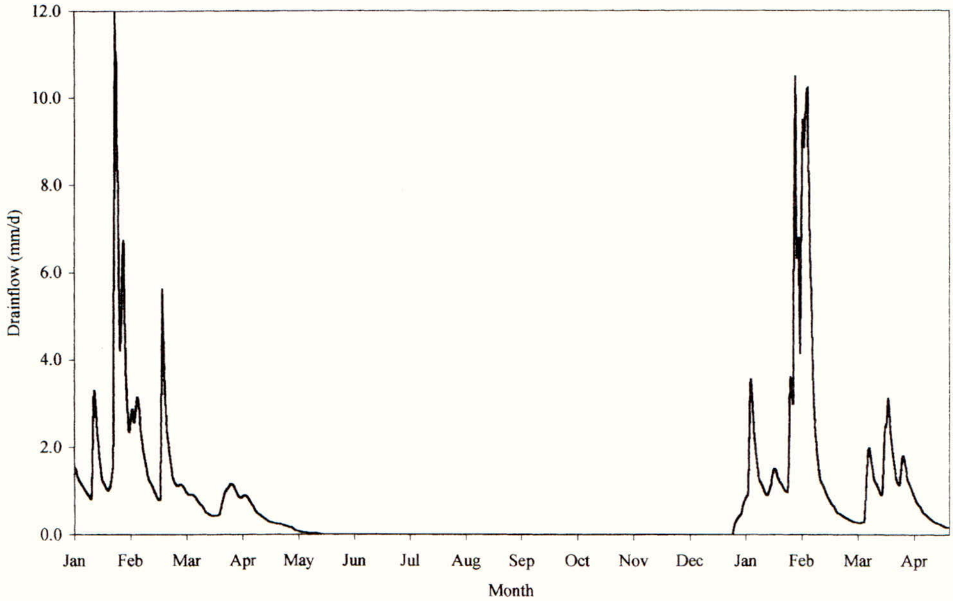

Figure 1. Simulated drainflow for scenario D5 (La Jalliere weather January 1978 to April 1979) under a winter wheat crop.

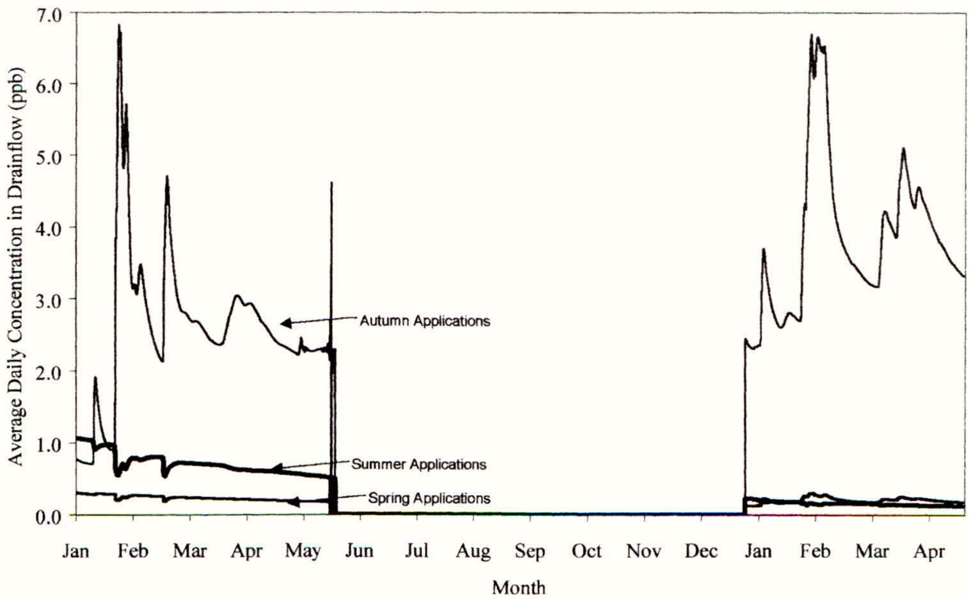

Figure 2. Simulated daily concentrations in drainflow for scenario D5 (La Jalliere weather January 1978 to April 1979) under a winter wheat crop following application of test compound D

Table 3. Simulated maximum daily fluxes (% of applied) via drainage for the six Step 3 drainage scenarios and two Step 2 scenarios following applications of test compounds in Autumn, Spring and Summer.

Scenario	Application time	Test compound							
		A	B	C	D	E	F	H	I
	Koc (L/kg)	10	100	1000	10	100	1000	100	1000
	DT50 (d)	3	3	3	30	30	30	300	300
D1	Autumn	0.10	0.04	0.01	0.67	1.1	0.10	2.05	**0.85**
	Spring	<0.01	<0.01	<0.01	0.05	0.37	0.02	0.73	**0.46**
	Summer	0.01	<0.01	<0.01	0.07	0.26	0.03	0.23	**0.21**
D2	Autumn	1.39	0.58	0.01	**3.84**	1.53	0.15	**2.79**	**0.92**
	Spring	**1.51**	**0.38**	0.01	**2.17**	**1.66**	0.02	**2.3**	**0.6**
	Summer	<0.01	<0.01	<0.01	0.11	0.32	0.01	0.3	**0.15**
D3	Autumn	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	0.11	<0.01
	Spring	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.09	<0.01
	Summer	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.02	<0.01
D4	Autumn	<0.01	<0.01	<0.01	0.53	0.21	0.02	0.87	0.17
	Spring	<0.01	<0.01	<0.01	0.05	0.02	<0.01	0.50	0.12
	Summer	<0.01	<0.01	<0.01	0.03	0.05	0.01	0.14	0.04
D5	Autumn	<0.01	<0.01	<0.01	0.74	0.29	0.02	1.26	0.17
	Spring	<0.01	<0.01	<0.01	0.03	0.01	<0.01	**0.60**	0.12
	Summer	<0.01	<0.01	<0.01	0.07	0.04	<0.01	0.24	0.06
D6	Autumn	0.09	0.22	0.01	1	0.82	0.43	2.19	**1.67**
	Spring	**2.00**	**4.43**	0.05	**7.63**	0.53	<0.01	**6.14**	**0.87**
	Summer	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.44	**0.38**
Step 2, N.Europe	Autumn	1.48	0.96	0.20	3.42	2.19	0.48	2.38	0.52
	Spring	0.37	0.24	0.05	0.85	0.55	0.12	0.59	0.13
	Summer	0.37	0.24	0.05	0.85	0.55	0.12	0.59	0.13
Step 2, S.Europe	Autumn	1.48	0.96	0.20	3.42	2.19	0.48	2.38	0.52
	Spring	0.74	0.48	0.10	1.71	1.09	0.24	1.19	0.26
	Summer	0.37	0.24	0.05	0.85	0.55	0.12	0.59	0.13

Values in bold indicate maximum daily flux at Step 3 is greater than loss in corresponding scenario at Step 2