Management practices to minimize atrazine loss in surface water runoff

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ABSTRACT

Atrazine herbicide remains widely used for weed management in corn (*Zea mays*) and grain sorghum (*Sorghum bicolor*). Its predominant use in the US Great Plains is soil surface application at seeding time, coinciding with the period of highest annual precipitation. On the predominately fine-textured soils of the region, this use may result in excessive atrazine loss in surface water runoff. Management options are available which reduce atrazine loss in runoff by 70 percent or more, without jeopardizing the weed control benefits. These include: 1) pre-plant soil incorporation in tilled fields; 2) fall application in no-till fields; and 3) post-emergence applications at reduced rates.

INTRODUCTION

Atrazine leads all herbicides in usage in the United States (Gianessi and Marcelli, 2000). About 80 percent of all field corn and grain sorghum acreage receives annual applications of atrazine at rates averaging about 1.3 kg/ha. After over forty years of use, it remains a key component of economical and effective broadleaf weed control, and grass suppression, in these crops.

Atrazine performs well over a broad range of application timings and rates. It has excellent residual activity in many soils at rates above about 1.5 kg/ha. Most commonly it is soil surface applied immediately after seeding corn or sorghum. However, it may also be pre-plant soil incorporated in tilled fields, or soil surface applied several weeks prior to planting, to eliminate weed establishment in no-till fields. For such soil applied situations, it is often applied with acid amide herbicides (e.g. metolachlor, acetochlor, etc.) to broaden the spectrum of weed species controlled.

In addition to its residual activity, atrazine has excellent foliar activity when applied with appropriate adjuvants. Most post-emergence herbicides for corn and sorghum benefit greatly from being applied with 0.6 to 0.8 kg/ha atrazine.

Both residual and foliar atrazine activity has been exploited in the High Plains region of the USA to help manage weeds and volunteer wheat in wheat stubble fallow, a practice called "eco-fallow." This chemical-fallow system is playing a major role in reducing soil erosion by wind and water, enhancing soil water storage, and increasing dryland corn and sorghum acreage and yields in a semi-arid region where previously the main crop was winter wheat only, alternating with 15-month long fallow periods (Dhuyvetter *et al.*, 1996).

Despite its continuing popularity with corn and sorghum producers, atrazine brings water quality concerns. It is commonly detected in streams and rivers. In 1994, the US Environmental Protection Agency announced that a maximum contaminant level for atrazine of 3 µg/Litre would be set for finished drinking water. This is an enforceable level for public drinking water systems and, according to the EPA, is a concentration that is safe to drink over a 70-year lifetime.

FACTORS INFLUENCING ATRAZINE MOVEMENT IN SURFACE WATER

Chemical properties

The chemical properties of individual pesticides influence their potential for becoming water quality problems. Atrazine is poorly adsorbed to clay and organic matter, and is relatively persistent in the environment, with a half-life of about 60 days (Ahrens, 1994). Furthermore, it is highly soluble in water. Therefore, atrazine and other weakly soil-adsorbed herbicides leave the field primarily in runoff water and not with eroding soil particles.

Soil type and site characteristics

Soil type and site characteristics are major factors influencing atrazine runoff. Soils are categorized into four hydrologic groups (A, B, C and D), based on water infiltration rates under field conditions. Many of the soils of the Great Plains are group D soils with high clay content, very slow infiltration and rapid runoff potential. Most farm fields have gradient terraces to reduce soil erosion by reducing slope length and surface drainage velocity.

Tillage practices

For many soils, no-till systems that maintain moderate to high levels of plant residue on the field surface will reduce water runoff, compared to tilled systems. Long-term no-tillage improves soil aggregate formation and plant residues hold rainwater in place longer, encouraging greater infiltration. Some soils, however, have low to very low permeability due to restrictive clay layers. Even after long-term no-till management, surfaces of such soils are often wet during spring planting when atrazine is typically applied.

Rainfall timing, intensity and duration

The surface soil moisture at time of herbicide application, the interval from application until first rainfall, and the intensity and duration of the first rainfall, greatly influence the amount of atrazine lost in surface runoff. The wetter the soil surface at the time atrazine is applied, the sooner runoff begins during a rain storm and the greater the potential for atrazine runoff. If the soil is dry at the start of a rainfall event, more water infiltration will occur, moving some atrazine below the soil surface before runoff begins.

It is well documented that atrazine is most susceptible to loss during the first runoff event following application (Hall, 1974). Figure 1 shows water runoff volume and atrazine loss from a grain sorghum field with chisel-disk (CD) and no-till (NT) management (Olson *et al.*, 1998). Note that early in the growing season, greater water runoff occurred in NT treatments, and that the pattern shifted as the crop developed. Atrazine loss from the pre-plant NT application (on

20 May) decreased with each successive event, and very little atrazine runoff loss occurred in the chisel-disk treatment where atrazine was soil incorporated.

Long-term precipitation and storm intensity records for Manhattan, KS, indicate that the highest amount and intensity of rainfall, and the period of highest potential for runoff, occur during the peak atrazine application window of May, June and July.

In summary, atrazine runoff is less when: 1) it is applied to dry soil surfaces; 2) at least 7 days time elapses between application and the first rain storm causing runoff; and 3) the first rain event after application is of low intensity.

BEST MANAGEMENT PRACTICES TO MINIMIZE RUNOFF LOSS

Atrazine is extremely versatile, with regard to application timings, both residual and foliar activity, and rates. This versatility helps account for the high volume of total use, and suggests that there should be management options that minimize off-site loss while maintaining weed control benefits (Regehr *et al.*, 1996). These best management practices should reflect regional climatic conditions, soil types, and production patterns. Three core management alternatives are presented.

Soil incorporate atrazine

This is a option for soils with moderate to poor permeability where tillage is planned. Atrazine, or an atrazine-containing product, is applied from 0 to 14 days before planting and incorporated into the top 5 cm of soil with a field cultivator.

Mechanical incorporation reduces the amount of atrazine on the soil surface where it is most vulnerable to runoff. On a poorly permeable silt loam soil with a restrictive claypan in eastern KS, pre-plant incorporation of atrazine in a chisel-disk system reduced atrazine loss in surface runoff by about 75 % over a 4-yr period, compared to soil surface applications in a no-till system (Olson *et al.*, 1998; Hoobler, 1999). On such soils, pre-plant tillage helps the soil surface to dry, and sets the stage for greater water infiltration during the first rains following herbicide application. The longer the delay of the onset of runoff in the initial precipitation event, the lower the amount of atrazine loss.

In another recent KS study (unpublished), atrazine herbicide was subjected to natural rainfall, and to natural rainfall supplemented by 6.4 cm/hr additional precipitation applied with a rainfall simulator (Swanson, 1965) at 2 and at 9 days after planting. This rate represents a one-hour storm with the frequency of occurring once every ten years (Hershfield, 1961). Averaged over the 1999 and 2000 growing seasons, soil incorporated atrazine loss was 48 % less than atrazine surface applied to tilled soils, and 61 % less than atrazine surface applied to no-till soils. Percent reductions in runoff loss were similar under both precipitation regimes. These findings show that soil incorporation can reduce atrazine runoff losses under a wide range of precipitation amounts and intensities.

The weed control efficacy of atrazine can be affected by soil incorporation. When application is followed by very limited precipitation, then efficacy is often enhanced by mechanical incorporation because less rainfall is required to activate the herbicide. On the other hand, when precipitation is high, then surface applications may give better weed control because the concentration of herbicide near the soil surface is higher. For good weed control efficacy, it is desirable that mechanical soil incorporation not exceed a depth of about 5 cm.

Use fall or early spring applications

In the western Great Plains, precipitation amounts and intensity are generally much lower during fall, winter, and early spring, than from late April through July. Atrazine has sufficient longevity that it can be applied during periods of low precipitation amounts and intensity. Fall or early spring applications are a management option for no-till fields where pre-plant incorporation is not possible. Once the atrazine has been subjected to several small precipitation events, enough product is adsorbed in the surface soil so that subsequent more intense rains cause little herbicide loss. On an eroded silty clay loam soil near Manhattan, KS, fall-applied atrazine from 1996 through 1999 averaged 1.4 % of applied, lost in runoff despite several unusual winter storm events (unpublished). These field runoff data are being used to test runoff from fall or early spring applications as predicted by the GLEAMS (Groundwater Loading Effect of Agricultural Management Systems) model.

In KS, atrazine may be applied to row-crop stubble following fall harvest, a practice analogous to the eco-fallow management of wheat stubble in the High Plains. This option is best suited to fields where soybeans have just been harvested, that will be no-till planted to corn or sorghum the following spring. Atrazine applied in fall, with crop oil concentrate and 2,4-D ester, controls a wide range of winter annual weeds including the mustards (*Cruciferae*), *Lamium amplexicaule*, *Conysa canadensis*, annual brome (*Bromus* spp.), *Taraxacum officinale*, etc. It reduces or eliminates the need for pre-plant burndown applications in spring. No-till farmers find that soils warm up earlier in spring when it is weed-free, and seasonal time management is improved if the number of spring field operations can be reduced.

Atrazine is not an appropriate herbicide for fall application to highly permeable soils, or in regions where winter precipitation is high. For example, in the central and eastern Corn Belt, and in the southeastern US, simazine may be a better fit for fall application. It has greater adsorptivity to clay and organic matter, is more persistent, and less soluble in water (Ahrens, 1994).

Use post-emergence atrazine applications at reduced rates

Using soil-applied acid amide herbicides for grass control, followed by post-emergence herbicides containing from 0.56 to 0.84 kg/ha atrazine, is a highly effective weed management strategy for corn and sorghum that is widely used in the US Great Plains and Corn Belt. Season-long control of broadleaf weeds such as *Amaranthus* spp., *Abutilon theophrasti, Xanthium strumarium, Ipomoea* spp, and *Helianthus annuus* is routinely achieved. The effectiveness of herbicides such as bromoxynil, bentazone, carfentrazone-ethyl, dicamba, 2,4-D, and prosulfuron is greatly enhanced by application with atrazine.

Post-emergence atrazine offers several advantages for reducing atrazine loss in runoff. Foremost is the reduction in application rates, since post-emerge tank mixtures often contain only about one-third the atrazine rate of typical planting-time tank mixtures. Hoobler (1999) showed that atrazine loss in surface runoff is proportional to the application rate (Figure 2). Low rates used in tank mixtures result in low runoff concentrations. Also, applications made to

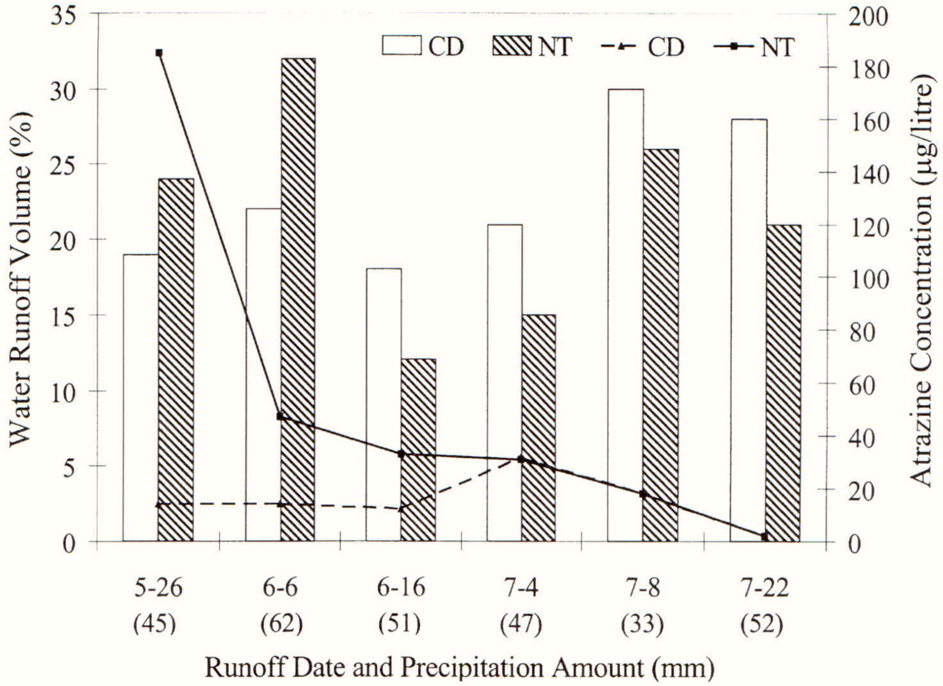

Figure 1. Percent water runoff from the six storm events that resulted in runoff during the 1996 sorghum growing season, for chisel/disk (CD) and no-till (NT) treatments, and mean atrazine concentration in runoff water (adapted from Olson *et al.*, 1998).

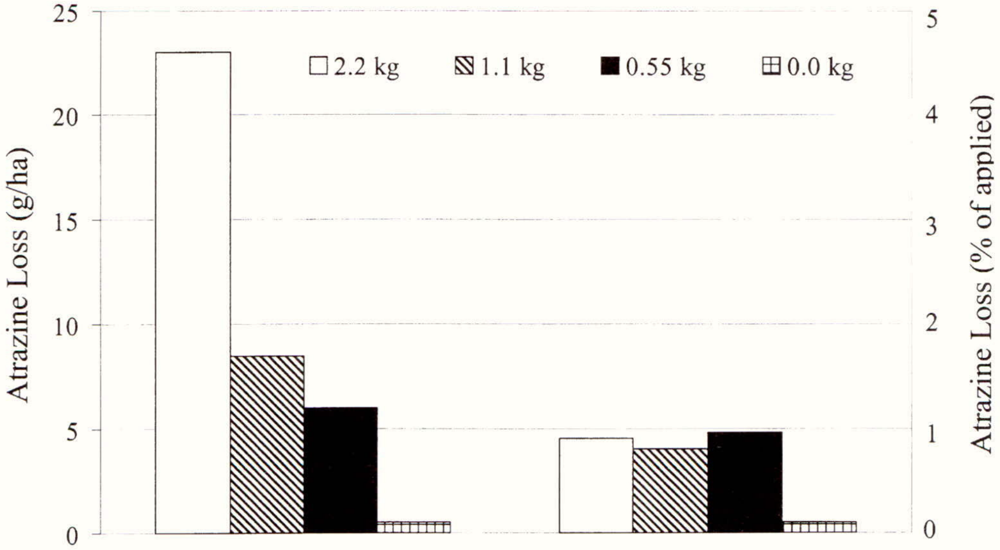

Figure 2. Effects of post-emergence atrazine rate on loss (g/ha), and percent of applied, in surface water runoff (adapted from Hoobler, 1999).

fields with growing crops and weeds would tend to have less runoff than applications to bare fields. Furthermore, soil temperatures and evaporative demand are higher during the post-emerge application time. Atrazine losses from precipitation events in a Kansas grain sorghum field in 1997 and 1998 were less than one percent of applied, whereas runoff losses from planting time applications typically run 5 to 10 % of applied, and have been documented to reach 20 % percent of applied under the most adverse conditions (Smith *et al.*, 1999).

The use of low-rate post-emerge atrazine mixed with other herbicides is effective for all tillage systems and nearly all soil types where corn and sorghum are grown. Tank-mix partners are selected to help with control of specific weed species. Even fields with coarse-textured soils can be treated because atrazine rates are low, and both corn and sorghum show excellent ability to metabolize the applied atrazine under good growing conditions.

Other best management practices to minimize atrazine loss

The core practices discussed above may be modified and/or combined in ways that further reduce atrazine loss in surface runoff. All herbicides should be used in the context of integrated weed management and crop production systems, and on fields with appropriate soil and water conservation structures. Substantial reductions in atrazine runoff loss can be achieved without sacrificing the benefits of atrazine herbicide for weed management.

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The design of a pesticide handling and washdown facility

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ABSTRACT

Point source contamination of surface water by pesticides within agricultural catchments can be significant. One major source of potential contamination is the farmyard where activities involved in handling pesticides, filling sprayer equipment and washing down the sprayer after applications take place. The characteristics of the farmyard surface determine how quickly any spilt pesticide or sprayer washings reach surface waters. Impermeable surfaces which generate rapid runoff do not permit any *in situ* retention and hence degradation of pesticides to take place. Permeable surfaces and underlying material allow the pesticide residues to infiltrate into the substrate where opportunities for physical, chemical and biological degradation do exist. ADAS, Coventry University and HRI Wellesbourne are currently undertaking a collaborative research project investigating the performance of different surfaces for pesticide handling and washdown areas with a view to developing a design manual that specifies how these areas should be constructed to minimise the risk of surface water contamination by pesticides. This paper focuses on the experimental work to date.

INTRODUCTION

The pollution of water resources by pesticides can arise from a number of sources and produce a number of detrimental impacts, both environmentally and economically. Pollution of surface water can lead to a detrimental impact on water quality and aquatic ecosystems. The pollution of water resources, both groundwater and surface water, has an additional effect in terms of the quality of potential drinking water supplies at the points of abstraction. Pesticide pollution can either cause the abstraction water to be rejected as being too polluted or can require that expensive water treatment is required prior to discharge into the potable water system. This water treatment cost is passed on to the consumers of water, i.e. the whole population. There are many stakeholders involved in the use of pesticides for plant protection and the quality of water resources in the UK (e.g. agrochemical companies, Environment Agencies, water supply companies, conservation bodies, Government). Groundwater and surface water is at risk of contamination from agricultural pesticides. In some cases this contamination is more likely to result from point sources than as diffuse sources a result of pesticide application to crops in the field. Such point sources could include areas on farms where pesticides are handled, filled into sprayers or where sprayers are washed down.

There is a range of relevant EU and national legislation, codes of practice and advisory information currently available to farm managers and pesticide users concerning the pesticide handling, and disposal of associated washings and other materials. There is also impending future legislation which will impact on 'on-farm' activities such as the Waste Framework and the Incineration Directive.

A number of monitoring projects in the UK and other countries (Carter, 2000; Mason *et al.*, 1999; Kreuger, 1998) have identified that point sources of pesticides can be responsible for a significant portion of the total amount of pesticide loading in water and can account for the peak concentrations detected. The ranges reported vary from at least 20% of the total load in a catchment but could be as high as 70% depending on catchment characteristics. The farmyard characteristics, operating practices and local conditions vary but all researchers report similar reasons for the origin of the point source contamination.

Point source contamination can range in concentration from that found in dilute washings to the concentrated, formulated active substance depending on the nature of loss. Given that point sources are largely attributable to operator error or bad practice, equipment faults and the physical characteristics of the handling/mixing area it is considered that point sources can conceivably be controlled more easily than diffuse pollution. Better training of operators and good machinery maintenance, with storage undercover, are considered to be fundamental to minimising the risk of pollution from many point sources. Another important consideration is the design and operation of pesticide handling and washdown areas on farmsteads. Traditionally these areas have been mainly on concrete pads, close to farm buildings where there is access to a mains water supply. Often these concrete pads drain to sumps which connect then direct to the nearest watercourse or soakaway. As a results direct and rapid contamination of water resources can arise from these pesticide handling and washdown operations. In 2000 a research study commenced with the objective of producing a new cost-effective design manual for pesticide handling and washdown areas which significantly reduces the risk of contamination of water resources. One aspect of this work was to test the effectiveness of various test surfaces (with underlying substrates) for retaining and degrading a range of pesticides *in situ*.

MATERIALS AND METHODS

During summer 2000 six fibreglass tanks, 1.92m long by 0.91m wide by 0.61m deep were installed at HRI Wellesbourne in holes dug into the local soil. The tanks were installed such that they protruded approximately 0.05m above the surrounding soil. The tanks were laid onto a bed of sand and tilted to give a slope of 1.5% towards the front end. Along the front edge of the tanks a 10m long by 1.5m wide x 1.5m deep instrument pit was dug and lined with wood. The floor of the instrument pit was covered with gravel. Once all the tanks and the wooden liner for the pit were in place soil was backfilled in around the tanks to ensure that a good contact was made between the tanks and surrounding soil. Each tank had a 0.06m diameter perforated drainage pipe installed running diagonally across its bottom. A hole was cut at the bottom front end of the tank to allow the pipe to carry water from the bottom of the tanks into a 27 litre removable glass leachate collector. This container was housed in a 68 litre plastic tank to enable the collection of any overflow. For each tank a 0.06m layer of pea shingle was laid in the bottom of the tank to cover the drainage pipe. This would permit all the water that infiltrated through the overlying layers to drain out of the tanks and become available for sampling. A layer of geotextile covered the pea shingle to prevent the in-wash of fine particles.

The six test surfaces investigated were:
i) Concrete
ii) Porous asphalt
iii) Hardcore
iv) Porous paving
v) Soil with a grass turf surface
vi) Biobed (a mixture of topsoil, straw and peat substitute) with a grass turf surface

The two surfaces likely to produce surface runoff (i.e. concrete and asphalt) also had the facility to monitor the rate of runoff and sample the runoff water.

In order to eliminate the variability of contamination arising from spray operator activities each area was 'artificially' contaminated by simulating pesticide losses based on the data for isoproturon obtained from the Cherwell project (Mason *et al.*, 1999). A grid was imposed on each surface and representative surface spots, spills, leaks and vehicle washing waste were applied in a standard manner to specific grid squares. Rainfall was simulated (when necessary) to achieve a worst case event (e.g. 25mm in 24 hours) within 48 hours of an application by adding irrigation water. Subsequent natural rainfall was allowed to fall on the test areas.

Six pesticides were chosen to be applied to the test surfaces. They represented a range of physico-chemicals properties, with three that would normally be applied in the spring period (chlorothalonil, dimethoate, epoxiconazole) and three that would normally be applied in the autumn period (isoproturon, chlorpyrifos, pendimethalin).

The first application of pesticides took place to the test surfaces in June 2000. Only the three normally spring applied chemicals were used. The application rates represented the scaled-down Cherwell project findings on spills, drips, dilute sump liquid and sprayer washings when applied to the much smaller test surfaces. For the second application (in October 2000) all six pesticides were applied at the same scaled down applications rates. The third application (in December 2000), of all six pesticides, represented the worst case scenario. All the Cherwell pesticide losses onto the full-scale farmyard were applied but they were not scaled down to the size of the test surface. One litre samples were collected from the drainage water (surface runoff and/or throughflow) discharging from the test surface tanks immediately following the artificial application of the pesticides and then subsequently after rainfall/drainage events. All the samples were kept in a cold store (2-6^{o}C) prior to laboratory analysis.

Subsamples of the drainage water (500ml) were passed through a solid phase extraction cartridge (Envirogard C18; 1g; Merck) and adsorbed residues were eluted with 2ml acetone:hexane (50:50 v/v). The elutes were then analysed by gas-liquid chromatography with a nitrogen/phosphorus detector. The limit of detection of the method was between 0.1-0.3μg/litre for the six pesticides.

RESULTS

In order to rank the performance of the test surfaces in a way that eliminated the complications of the different amounts of drainage water (i.e. throughflow and surface runoff, where collected) it was decided to calculate the total amount of all pesticides measured as a proportion of that applied to the surface per mm of rainfall (natural or artificial) falling on the surfaces. The results are given in tables 1, 2 and 3 for each of the applications.

Table 1. Test surface performance - First application (3 spring pesticides only)

Surface	Total loss of pesticide (% applied per mm of rainfall)
Biobed	<0.001
Soil/grass	<0.001
Hardcore	0.002
Asphalt	0.130
Porous paving	0.162
Concrete	0.355

Table 2. Test surface performance - Second application (all 6 pesticides)

Surface	Total loss of pesticide (% applied per mm of rainfall)
Soil/grass	0.001
Biobed	0.001
Hardcore	0.011
Asphalt	0.013
Porous paving	0.158
Concrete	0.725

Table 3. Test surface performance - Third application (all 6 pesticides)

Surface	Total pesticide loss (% applied per mm of rainfall)
Biobed	<0.001
Soil/grass	0.024
Hardcore	0.058
Asphalt	0.097
Porous paving	0.498
Concrete	0.938

The results indicate that all the surfaces provided a significant improvement in the retention and degradation of the test pesticides when compared to the performance of the traditional concrete surface. Both the biobed and the soil/grass surfaces reduced the total pesticide loss generally by a factor of over 100 when compared to the concrete surface. Pesticide losses from these two surfaces were very low even with the worst case scenario of very high pesticide contamination during the third application. Porous paving, designed to eliminate surface runoff and provide the capacity for immediate infiltration into the substrate, allowed the rapid transport of pesticides through the test tank and into the drainage water.

Table 4. Maximum pesticide concentrations (μg/litre) in drainage water – Third application.

Pesticide	Concrete	Asphalt	Porous Paving	Hardcore	Soil/grass	Biobed
Dimethoate	46000	730	980	210	70	<0.1
Chlorothalonil	200600	2500	1970	180	50	<0.1
Isoproturon	421300	1810	9570	2170	230	<0.1
Chlorpyrifos	157600	1800	4980	160	70	<0.1
Epoxiconazole	18100	500	530	30	<0.1	<0.1
Pendimethalin	371900	6180	14140	250	290	0.2

The maximum concentration of any pesticide lost from the biobed in any single sample collected during all three application periods was 0.2μg/litre; for soil/grass it was 290μg/litre. Taking isoproturon as a typical soluble and hence very mobile herbicide as an example, all samples of drainage water from the biobed failed to have a single determination for isoproturon of above 0.1μg/litre. In comparison, the maximum concentration of isoproturon in the drainage water from the concrete surface was in excess of 420,000μg/litre during the worst case scenario third application (Table 4). For porous paving and soil/grass it was 9570μg/litre and 230μg/litre respectively.

DISCUSSION

The performance of the biobed in retaining and degrading pesticides agrees well with the results from other studies in the UK and Europe. Fogg and Boxall (1998) in the UK, Torstensson (2000) in Sweden and Henriksen *et al.* (1999) in Denmark, all found that the biobed matrix provided numerous opportunities for the pesticides to the adsorbed onto organic matter where thriving microbial populations (bacteria and fungi) could then degrade the pesticides *in situ.* Other physical and chemical degradation processes could also take place within the biobed matrix that contained areas of both aerobic and anaerobic conditions. In a similar way the microbial population resident in the soil system, together with organic matter and clay adsorption sites, produced good opportunities for pesticide retention and degradation. Careful management of the water entering these systems was seen as critical to their longer term effectiveness in treating these pesticides, as sustained periods of water saturation and anaerobic conditions would be detrimental to the well-being of the microbial populations. The results also showed that a period of 3-6 months maturing of the biobed matrix, in terms of its microbial composition and activity, contributed to its improved performance even with greatly increased pesticide contamination episodes.

Even though the other three surfaces provided a significant improvement in the retention and degradation of the test pesticides over that of the traditional concrete surface they did permit concentrations of pesticides in the drainage water to frequently exceed the 0.1µg/litre Drinking Water Standard. However, the results did reiterate the current advice on good agricultural practice to spray operators to, wherever possible, move all the pesticide handling and washdown operations away from concrete surfaces or other areas where there is a direct connection for the drainage water to rapidly reach nearby watercourses and potentially produce deleterious a environmental impact on aquatic ecosystems and downstream water users.

The next phase of this project will involve the construction and monitoring of full farm-scale pesticide handling and washdown areas that are connected to biobed and soil/grass treatment systems. The findings of this work will assist in the development of a design manual for these areas that provide farmers and spray operators with a cost-effective way of reducing the risk of polluting water resources from farmyard operations.

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