Session 6
Management Practices

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PESTICIDE LOSS TO WATER - A REVIEW OF POSSIBLE AGRICULTURAL MANAGEMENT OPPORTUNITIES TO MINIMISE PESTICIDE MOVEMENT

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ABSTRACT

The movement of pesticides to surface and groundwater has been an area of increasing concern as EC Directives on water quality have been introduced. Losses of pesticides to groundwater form part of a long-term cycle as the water can take decades to reach depths where water abstraction takes place. As a result, concentrations tend to be lower for most chemicals than those found in water leaving the top metre of the soil, and measures adopted now to reduce pesticide levels in groundwater will take many years to show effect. In contrast, pesticide losses to surface waters are more immediate and concentrations can be transient at the small catchment scale. Various agricultural measures are being evaluated in the U.K., and elsewhere, to minimise loss of pesticides to surface waters. These measures, if effective, will have a counterpart role in the effort to reduce pesticide losses to depth. This paper reviews the mechanisms of pesticide transport and some of the opportunities being assessed in the U.K. to reduce the movement of pesticides.

INTRODUCTION

It is generally recognised that the movement of pesticides through soils will depend on many factors, including the physico-chemical characteristics, degradation of the chemical, the soil properties and the method of application. As a consequence the behaviour of each individual pesticide can be different, and factors that might influence one pesticide may have little or no effect on a different chemical.

However, it is possible that a number of relatively simple agricultural measures could be introduced which together would reduce the risk of pesticide loss. This paper reports on the possible benefits to be obtained through several agricultural measures that could be introduced by the farming community. These include reduced pesticide inputs, manipulation of the soil profile and the use of field buffers. A new collaborative U.K. research programme investigating the potential benefits of these measures is outlined.

MECHANISMS FOR PESTICIDE TRANSPORT

Once a pesticide has been applied to either the crop or soil surface, subsequent movement can occur either over the soil surface as surface runoff, through the soil profile to a water course or groundwater or by sub-surface drainage systems to surface waters. Some pesticides, particularly those that are mobile, are likely to be readily transported in this water movement, others are more likely to be adsorbed to particulate matter and then moved in the sediment phase. The mechanisms behind such transport are considered briefly below.

Surface runoff

Surface runoff can occur when the soil surface becomes saturated or when rainfall exceeds the infiltration capacity. Surface runoff usually originates from areas of compaction such as tramlines, water eventually spilling over into less compacted agricultural land adjacent and potentially creating small erosion rills. Whenever surface runoff occurs there is a risk that soil will also be transported. This might be little more than shallow erosion rills in cultivated fields, although in coarse textured soils more serious erosion can occur (Spiers & Frost, 1985). The generation of surface flow and sediment transport however, is not uniform, with flow often concentrated in concavities in the field slope or associated with the wheelings (tramlines) caused during agrochemical applications (Boardman, 1990). On moderately sloping clay-based soils, especially where compaction is evident, sediment may be transported downslope and be deposited at field margins or in adjacent watercourses. In the U.K., the risk of sediment transport is greatest in the autumn following seedbed preparation before the establishment of the crop, i.e. when the soil is bare. (Chambers *et al.*, 1992). This period often coincides with the application of autumn pesticides.

Soil erosion has generally increased in the U.K. since the 1970's as more land is sown to autumn cereals, seedbeds have increasingly been rolled, fields have become larger and permanent tramlines have become common. As a result, sediment transport in surface waters has increased, with many headland streams showing sediment discoloration during peak flow conditions.

Drainage

In many catchments, sub-surface flow is the major transport route for the removal of excess water. However, in clay-based soils, intensive agriculture is often accompanied by sub-surface drainage. The underdrainage controls the water table in the soil and enables rapid water movement from the near-surface horizons to the sub-soil to occur. In the heavier clay soils, as are typical of large areas of the U.K., underdrainage is often combined with a secondary drainage treatment such as mole-drainage channels. These consist of open channels, drawn in the soil at about 600 mm depth and 2 m spacings. The close-spaced drainage and cracking associated with creation of the mole drainage channels (Trafford & Oliphant, 1977), together with the natural macropores that develop in clay soils, influence the route by which water leaves the soil profile (Harris *et al.*, 1993a; Beven & Germann, 1982). In addition, the presence of considerable bypass flow through this crack structure can lead to the onset of winter drainage well before the soil is fully saturated and reaches field capacity (Harris *et al.*, 1993a).

There is little published evidence on the quantities of sediment that pass through sub-surface drainage systems. Values quoted in the scientific literature vary enormously; for example, a range from 5 to 75 kg/ha/yr was given by Logran & Schwab (1976) for a silt loam and silty clay soils in Ohio compared to 407 to 1044 kg/ha/yr in silty clay loams in Iowa suggested by Hanway & Laflen (1974) where crackflow was considered an important part of the process. Generally however, the highest sediment loading was observed at the start of drainflow and could lead to significant losses by this route.

PESTICIDE USAGE

Trends in cropping pattern will affect pesticide usage. Recent data for the U.K., which is likely to broadly reflect the wider picture in the northern European Countries where the Common Agricultural Policy is adopted, showed that the total area of arable farm crops fell by 1% from 1990 to 1992 and was just 0.5% lower than ten years previously (Davis *et al.*, 1993). Comparison of total arable land in England and Wales showed that the area fell from 6,982,000 ha in the 1982-1984 period to 6,657,000 ha in 1990 and 6,127,000 in 1993 (Anon, 1994).

Davis *et al.*, (1993) reported that 36% of the total pesticides applied by area were fungicides, with herbicides and desiccants accounting for 30%, seed treatments 15%, insecticides 11%, growth regulators 8% and others less than 1%. The most extensively used fungicides were fenpropimorph (applied to cereals and beans), chlorothalonil and carbendazim (applied to all crops except sugar beet) and phenylmercury acetate, propiconazole and flutriafol (to cereals). Isoproturon was the most extensively used herbicide (applied to mostly cereals in England and Wales) whereas other widely used herbicides were metsulfuron-methyl (to cereals and linseed) and fluroxypyr, diflufenican and mecoprop-P (all to cereals). Cypermethrin was the most extensively used insecticide; usage declined by 5% from 1990 to 1992. Other extensively used insecticides were lindane (gamma-HCH), dimethoate, deltamethrin and pirimicarb. Although Davis *et al.* (1993) reported a 5% reduction in the area of cereals grown, there was only a 1% reduction in the total area treated. Of much greater importance however, was that a reduction of 22% occurred in the quantity of pesticides (as A.I.s) in the period. This was seen to be mostly a result of reduced rates per hectare for fungicides and a reduction in the usage of herbicides.

Comparative data, as tonnes applied as either a single A.I. and/or in tank-mixes, are given in Table 1 for the six most widely used herbicides, together with three key fungicides and three insecticides for the cereal crops of winter wheat, winter barley, spring barley, oats and a total for crops. Several of the pesticides listed are likely to be highly adsorbed to particulate matter, and hence prone to movement in surface waters.

PESTICIDE LOSSES TO WATER

The main classes of pesticides found in surface waters are herbicides. This is probably because of the widespread application of this group of pesticides to heavy clay land to control grass and broad-leaved weeds in autumn cereals immediately prior to the onset of winter drainflows. Some of the compounds detected are persistent, e.g. isoproturon, and hence are available for a considerable period of time in the soil after application, with a consequent propensity to be lost to surface waters.

Harris *et al.*, (1993b) reported fairly frequent detections of several pesticides in small, predominantly agricultural catchments in the U.K., ranging from a few hectares in size to 1500 hectares. Although most of these losses resulted from diffuse movement, following recent applications, point source inputs were also important. These occurred both in wholly agricultural catchment as a result of farmyard spillages and from urban usage, such as alongside roads. The urea herbicides, isoproturon and chlorotoluron were found frequently, along with the triazine simazine.

TABLE 1. Usage (tonnes) on cereal crops - wheat, winter barley and spring barley - as active ingredient. Source: Davis *et al.* (1993)

Active ingredient		K_{OC}	Wheat	W Barley	S Barley	Oats	All crops
Herbicide	isoproturon	106	2205	812	4	2	3028
	chlorotoluron	110	347	107	-	-	470
	mecoprop-P	9	359	68	85	25	539
	pendimethalin	5000	408	208	-	-	623
	mecoprop	9	230	69	93	12	404
	trifluralin	8000	302	125	-	-	455
Fungicide	mancozeb	1000	253	12	1	1	1281
	chlorothalonil	1380	777	8	2	-	948
	fenpropimorph	4300	463	143	102	9	720
Insecticide	dimethoate	20	83	1	2	-	113
	gamma-HCH	683	13	6	2	-	65
	aldicarb	17	-	-	-	-	57

In the Rosemaund catchment study in Herefordshire (Williams *et al.*, 1991) studies were undertaken into the fate and behaviour of a range of pesticides including isoproturon, mecoprop and lindane applied to a small silty clay loam catchment. A number of detections were made for these chemicals in winter runoff in the catchment. Typical concentrations were around 3, 0.5 and 0.85 μg/L respectively. However, observations in the U.K. of the actual transport processes at the catchment scale occurring are relatively rare and usually rely on detailed plot studies where measures are made of pesticide movement in a combination of surface and sub-surface flows.

Wauchope & Decoursey (1986) and Leonard (1990) have both recently cited the importance of pesticide transport in runoff over the ground surface. However, although Jones (1993) found no surface runoff from a cracking clay soil of the Hanslope series (45% clay) he cited cultivated layer flow and macropore flow as the most likely source of pesticide contamination in an adjacent ditch. At Cockle Park (Brown *et al.*, 1995) found losses of isoproturon in surface runoff from undrained clayland plot studies were at least equal to or higher than losses from adjacent underdrained land. Short-term peak concentrations of isoproturon of 4-6 μg/L were found in winters 1990 and 1991 respectively in drainflow, compared to 32-35 μg/L in limited surface runoff from the same land. In contrast, losses in surface runoff from undrained land were 50-39 μg/L in the same two years respectively. Brown *et al.* (1995) found that losses of isoproturon in surface runoff were particularly important in the first flushes after application of herbicides. In contrast, losses of the less soluble and less mobile herbicide trifluralin were lower and were related to the sediment load in the water. They found that losses of sediment at Cockle Park were greatest in late winter, suggesting that this could have been due to the breakdown of soil aggregates associated with the freeze/thaw cycle. Thus although significant erosional events, and possible transport of particulate bound pesticides are more likely early in the winter (Chambers *et al.*, 1992), transport of particulate matter may also be of importance later in the winter.

In plot studies in the cracking clay soils at Brimstone Farm losses of isoproturon in 1990 and 1991 were generally higher than seen at Cockle Park, typically around 30-50 µg/L in autumn drainflows, compared to transient peak concentrations in surface runoff from undrained land well in excess of 100 µg/L in the same period (Harris *et al.*, 1994). Examination of the data showed that concentrations in drainflow resulted from rapid movement of water through the macropores, falling rapidly to 2-4 µg/L for the rest of the winter (Harris *et al.*, 1994). In further studies in autumn 1993 concentrations of up to 465 µg/L were observed for isoproturon, with total losses representing around 1.7-3.3 % of the applied compound (Harris *et al.*, 1995). Losses for pendimethalin in the same period were appreciably lower representing up to 0.04 % of applied (Harris *et al.*, 1995). However, of equal importance was that losses of the mobile herbicide isoproturon were detected in two consecutive autumns in drainage water, whereas the interval between application and drainage was sufficient for herbicide mecoprop to be degraded leading to no observed loss to water (Harris *et al.*, 1994).

In a review of the potential of buffers to control pesticide movement to surface waters, Muscutt *et al.* (1993) concluded that there was evidence of considerable pesticide loss in surface runoff in the United States where cropped land was subject to runoff adjacent to watercourses. However, from the limited U.K. work they concluded that losses could also be considerable by this route but that sub-surface drainflow would dominate in many areas leading to substantial pesticide loss by this route. Data on the potential for pesticide transport bonded to particulate matter is somewhat variable. For example, Wauchope (1978) concluded that pesticide concentrations were often two or three orders of magnitude higher in sediment than in water but that most pesticides were still lost in the water phase, simply because sediment was usually such a small fraction of the total runoff process. Although Wauchope (1978) suggested that only pesticides with solubility in excess of 10 ppm were lost primarily in the water phase, and hence erosion control practices would only be effective for strongly adsorbed pesticides, Buttle (1990) found between 20 and 46 % of the pesticide metachlor, (a moderately soluble herbicide) was carried on sediments over the monitoring period.

In the U.K. House *et al.* (1992) and Worrall *et al.* (1993) have started to address the importance of particulate adsorption of pesticides. House *et al.* (1992) reported that simazine and atrazine were found in water in three study sites in Oxfordshire with lindane, DDT and other strongly adsorbed pesticides also detected in bed and suspended sediments. Of importance, they found concentrations in the suspended solids were higher than in the deposited bed sediments.

POTENTIAL FOR REDUCING PESTICIDE LOSSES

Lower usage

Lower usage of pesticides offers a potential to reduce the total loss of pesticides to surface waters. Lower usage (tonnage) can be effected by altering the area treated (changed cropping), lower application rates and improved targeting (e.g. integrated crop management).

The data reported by Davis *et al.* (1993) showed that the total area of arable land in England and Wales fell by nearly 5% between 1982 and 1984 with a further fall of 8% by 1993. However, although the area of arable land is reducing, the pattern of pesticide usage has also changed. Several pesticides, in particular fungicides, had been applied at lower rates, which together with the reduced usage of herbicides could reduce the risk of leaching. Any future reductions should however, target those mobile or highly adsorbed pesticides which might be rapidly transported in autumn drainage or autumn/winter surface runoff. Table 1 shows that a number of the widely used pesticides fit this range.

Integrated crop management

There have been in the past and continue to be various initiatives to utilise crop management activities to reduce usage either to established thresholds or to lower input levels. Integrated U.K. programmes such as LEAF (Linking Environment and Farming) can provide the farming community with the opportunity to establish a regime where chemicals are applied only when necessary (Drummond & Lawton, 1995). Undertaking a rotation (e.g. winter barley, oilseed rape, winter wheat, potatoes/peas and winter wheat) that helps prevent weeds, pests and diseases from building up, combined with the selection of varieties of crops resistant to the most likely problems, can reduce the need for agrochemicals. A LEAF approach could be further enhanced by computerising on-farm records through the creation of a crop/agrochemical database, thus for example, indicating an area where persistent problems occur or where low fertility is a regular problem.

Tillage/soil structure

The development of soil structural cracks which encourage rapid movement of pesticides (Harris *et al.*, 1994; Brown *et al.*, 1995) has demonstrated that manipulation of the soil profile could help reduce pesticide movement. In particular, Harris *et al.* (1993a) showed that reduced tillage compared to mouldboard ploughing enhanced the opportunity for rapid water movement, and the potential for pesticide loss, to the sub-surface drainage system in a clay soil. By contrast, deep cultivations, combined with drainage systems that limit early autumn flow of water before field capacity should reduce the opportunity for rapid loss of pesticides. Once water flow is reduced, pesticides should be held longer in the soil profile, increasing opportunities for soil adsorption and degradation.

The timing of pesticides applications is governed by the need to treat the growing crop and opportunity to access the land. However, Harris *et al.* (1994) showed that losses of pesticides could be considerable for persistent compounds if the first drainflow occurred shortly after application. Applications close to rainfall and drainflow should be avoided whenever possible, as considerable pesticide loss is likely.

Buffers

Another potential measure for reducing the problem of contamination of water course from diffuse sources is the establishment of buffers. These can vary from a narrow field margin to prevent direct over-spray of an adjacent watercourse to a carefully managed vegetative strip aimed at influencing direct runoff of water and pesticides to surface waters.

The creation of overspray buffers is now recommended in the U.K. where field boundaries run alongside open watercourses. By limiting the area where pesticides can be applied, transient high concentrations from direct overspray or by spray-drift can be avoided (Marrs *et al.*, 1991), especially as such contamination is most likely to occur early in the autumn and spring when opportunities for dilution in rivers are limited due to low base-flows.

In contrast, vegetative buffers represent a permanently vegetated area of land, which is separately managed from the rest of the field. However, as diffuse pollution from agriculture reaches water bodies through a range of transport mechanisms, the effectiveness of buffers will vary considerably, depending especially on whether sub-surface drainage is installed in the vicinity of the buffer. A buffer will only be effective in this context if it can act in a retentive manner, and reduce pesticide movement. Buffer areas may reduce pollutant transport through infiltration within the buffer zone itself, which reduces surface runoff, and through the reduction in surface flow velocities due to the increased roughness of the vegetation. Together with the opportunity for improved soil structure under the permanent vegetation, and hence better infiltration, buffers should be seen as a potential tool to reduce pesticide movement.

Plot studies in the United States have suggested that grass buffers are effective sediment filters with retention of over 80 % reported (Dillaha *et al.*, 1987; Parsons *et al.*, 1990). However, Neibling & Alberts (1979) found that buffers were less effective in the clay particle size range, especially for narrow buffers. Although many workers have recommended the use of buffers there is no clear design available to maximise their effect. Muscutt *et al.* (1993) who reviewed the range of data available, mainly from U.S. plot studies, reported that pollutants transported in surface runoff may be retained in relatively narrow buffers, with 8 m being sufficient to remove most of the coarser particles and as little as 5 m being considered effective in some work. Jones (1993) also reported studies in Germany using 5 m buffers on a 13 % slope. He found that although runoff was little effected by a bare soil buffer, herbicide losses were reduced by 40 %. In contrast a grass buffer virtually eliminated soil erosion, reduced water movement and substantially cut pesticide movement to surface waters. He concluded that although more research was needed to optimise the size and performance of buffers, they could be effective in reducing pesticide losses to surface waters.

U.K. COLLABORATIVE RESEARCH

Two collaborative research programmes were initiated in the U.K. in 1993 to establish agricultural measures that would reduce pesticide movement to surface waters. These are based on replicated core and experimental pilot plot facility at Brimstone Farm (Harris *et al.*, 1994) and a range of small catchment sites (ADAS Rosemaund, ADAS Boxworth and Trent) which are representative of key soil types (Harris *et al.*, 1993b).

Brimstone Farm

The Brimstone Farm site, near Faringdon, Oxfordshire, is a long-standing facility established between ADAS and IACR. As reported previously, Harris *et al.* (1993a) showed that soil structure was important to the movement of water in the heavy clay site. Also, Harris *et al.* (1994) demonstrated that rapid movement of autumn applied pesticides occurred through this structure to the sub-surface drains, on occasions before field capacity was reached. This information enabled a programme of research funded by MAFF and BAA to be designed with the specific objective to reduce losses of pesticides following autumn applications to the cracking clay soil. The studies and results from the first year are described by Harris *et al.* (1995). A range of treatments was established in autumn 1993 to seek to influence both the quantity of applied pesticides and the subsequent transport of a range of pesticides with different physico-chemical properties. The work assessed the impact on pesticide loss following the restriction of sub-surface drainage to periods when a watertable was present in the soil profile. In addition the work examined the influence of a fine seedbed, the method of straw incorporation and the use of a soil sealant (designed to reduce wind-erosion) added to the soil surface after drilling. A further treatment assesses whether reduced application rates would result in decreases in pesticide losses which were at least proportional to the reduced application rate.

Although the data are preliminary, and limited to the herbicides isoproturon and pendimethalin only, reduced pesticide losses were evident with the restricted drainage treatment. With a half-rate application, pesticide loss was reduced to at least half of the full-rate, confirming that for these chemicals direct benefits could be obtained by relatively simple measures. Manipulation of the soil conditions, tested for the same two herbicides, plus triasulfuron and prochloraz indicated that soil tillage and the use of the soil sealant warranted further investigation. Further trials, initiated in autumn 1994, are also investigating the impact of deep tillage.

Small catchment studies

New U.K. MAFF funded research has started in three key catchments, representative of a silty clay, a clay loam and a chalky boulder clay within a collaborative programme between ADAS, Soil Survey and Land Research Centre, Central Science Laboratory MAFF and the Institute of Freshwater Ecology to relate the development of surface runoff and sediment transport to rainfall, soil, slope and other parameters. In addition to the catchments, a range of representative field-slope sites have been established to examine particulate movement where particulate transport and/or sedimentation has been shown to occur (Chambers *et al.*, 1992).

The collaborative programme is seeking to establish sources for the particulates transported throughout the catchments, the significance of these particles to the transport of pesticides, and the importance of the clay mineralogy (to be investigated by the Postgraduate Research Institute for Sedimentology, Reading University) together with other factors that could influence the bonding process of the pesticides are also being examined. Once a detailed database has been established, which links the mode of particulate transport and pesticide movement to the factors inducing this movement, then modelling studies will be initiated to develop a national understanding of the problem. Finally, the potential to control this loss (e.g. through simple agricultural measures, including buffers) will be determined.

CONCLUSIONS

The potential for pesticide loss to surface waters is considerable in the U.K. because macropore flow can rapidly transport pesticides to the sub-surface drainage system. Combined with autumn applications of pesticides shortly before the first winter drainflows, it is perhaps not surprising that some of the more mobile, widely used pesticides, are found in our water bodies. A number of relatively easy ways to reduce pesticide movement have been outlined.

Although no one measure is likely to eliminate the occurrence of pesticides in water bodies, the combination of the range of opportunities described could offer the long-term potential to minimise the risk of pesticide loss. The new research programme described provides the opportunity to evaluate some of these measures and thus ensure the future co-existence of sustainable farming and the environment.

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PESTICIDES IN DRINKING WATER - CATCHMENT PROTECTION OR WATER TREATMENT ?

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ABSTRACT

The EC standard for pesticide residue in drinking water is effectively zero. Installation of treatment to remove pesticides at water treatment works is extremely costly and cannot always guarantee full compliance if challenged by excessively high raw water pesticide levels. Severn Trent Water actively promotes catchment protection principles within its water source catchments and offers pragmatic help and guidance for pesticide users wishing to develop best practice procedures. A computer-based Catchment Information System has been developed as a management tool for focusing this campaign.

INTRODUCTION

Water companies in the United Kingdom have a statutory obligation from the Water Supply (Water Quality) Regulations 1989 to meet a very stringent pesticide standard. These Regulations are derived from the European Commission (EC) Directive which sets a standard for all pesticides, irrespective of their toxicity, of 0.1µg/L - effectively a surrogate standard for zero and is based on the thesis that "pesticides have no place in drinking water". Severn Trent Water supplies approximately 2,000 megalitres of water per day to its customers. To contaminate our raw water resources to the level of the standard it would take approximately 200g of active ingredient or the equivalent of just 5 drops of pesticide in an Olympic-sized swimming pool.

IS THERE A PESTICIDE PROBLEM ?

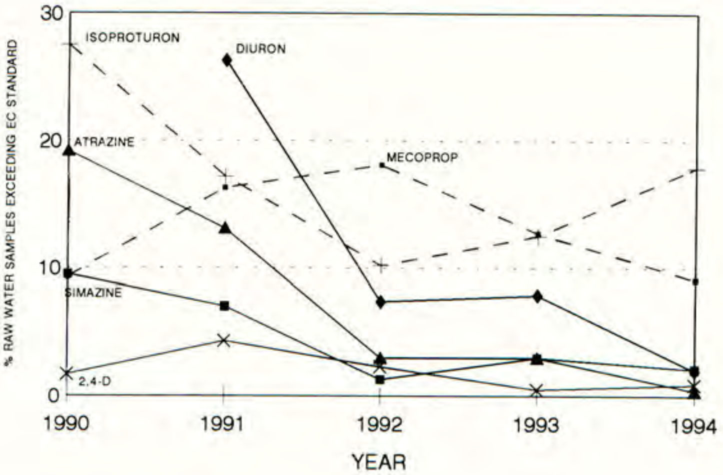
The Catchment

Severn Trent Water treats and supplies drinking water to over seven million customers in the Midlands. Around 2,000 megalitres per day is derived from both surface and groundwater abstractions in the ratios 40% groundwater, 30% lowland surface water and 30% upland surface water. Our operational boundary encloses a variety of topographical features - from the upland peaty hills and mountains of Wales and the Peak District to lowland flood plains in Gloucestershire and Shropshire encompassing a total of around 21,000 km^2. Therefore, land use within our catchments varies depending on the area concerned and this is reflected in the types and quantities of pesticides found in the rivers and reservoirs.

The company has regularly monitored water for pesticides for a number of years and contamination far exceeding the EC standard is frequently seen in untreated lowland river water. More recently, contamination of a few of our groundwater sources has also been revealed. The failures are typically seasonal in nature and tend to reflect peak pesticide usage and rainfall events. Over the past few years, up to 10% of sourcework treated water samples have exceeded 0.1µg/L, the greatest majority of failures being associated with our lowland river-derived sources (Breach & Porter, 1993). This percentage is gradually improving as we commission our major treatment works improvement programmes. The most commonly detected herbicides are the cereal herbicides mecoprop, isoproturon and MCPA and the non-agricultural herbicide diuron. Atrazine and simazine, until recently, were also seen quite regularly in high concentrations but with the implementation of the ban on local authority use of triazines in August 1993 and our Spraysafe campaign, monitoring results have shown an encouraging improvement in raw water compliance (Figure 1).

Figure 1 - Pesticide levels in Severn Trent raw waters

(Comparison against EC Drinking Water standard)



The Reasons

Although non-agricultural pesticide usage is more than thirty-four times less by weight than that of agricultural usage within our region, non-agricultural pesticides have previously been found as frequently as agricultural products and often in very high concentrations. This is primarily due to the use of residual compounds (that by their nature break down very slowly) on hard surfaces which are washed off into surface water sewers and thus directly into watercourses following rainfall. Other contributory factors can also be related to fissuring of the ground surface and incorrect use or disposal. Many non-agricultural users are now changing their weed control policies and, by working with advisory organisations, are developing more environmentally friendly policies. Unfortunately, due to the large quantities of agricultural pesticide used within our region we still experience problems - predominantly with the older products that have high application rates and are very mobile . We are now looking at ways of promoting safe pesticide use in agriculture to minimise pesticide levels in water resources whilst maintaining their effectiveness in farming practices.

ANALYSIS OF PESTICIDE RESIDUES

In addition to prescribing water quality standards that water utilities are obliged to meet, the UK Regulations require utilities to develop strategies for monitoring pesticides in water, based on local use patterns and the risk that any particular product may be present in the water sources.

It is well known, however, that it is extremely difficult to carry out reliable and accurate analysis of pesticides in water when many other organic constituents are also present in very low concentrations. For example, for UK regulatory purposes, laboratories must be able to analyse pesticides at a level of 0.1 of the standard, i.e. 0.01μg/L, with a maximum total tolerable error of +/- 20%. There are still a number of pesticides in use for which reliable methods are not available, although further development of new analytical procedures is continually taking place.

It is important to emphasize that, because of the complexity of modern pesticide analysis, it is a very expensive exercise. During 1993 alone, Severn Trent Water spent over £1 million on pesticide analysis. An onerous burden for any utility, this reinforces the need to target the monitoring effort very precisely to ensure that maximum benefit and information is generated for this investment.

WATER TREATMENT TO REMOVE PESTICIDE RESIDUES

To meet the stringent UK pesticide standard, additional treatment to conventional methods must be employed. Conventional water treatment works apply coagulation, filtration and disinfection which ensures that most impurities are removed but this is not sufficient to remove trace organics such as pesticides. For this purpose, Granular Activated Carbon (GAC) and/or ozone may need to be installed. In Severn Trent Water, GAC treatment is being installed at all of our surface water works which are susceptible to considerable pesticide contamination.

GAC adsorbs small organic molecules into pores on its surface. However, saturation of these active sites will eventually occur and the carbon must be regenerated to recover its effectiveness. This process is costly and may ultimately increase production costs by around £8 million per annum depending upon raw water quality. Frequency of regeneration is subject to the organic loading in the water. If no action is taken to protect water catchments, frequencies can be expected to increase and, therefore, the revenue costs too. In badly contaminated areas, treatment, even with GAC, cannot guarantee full compliance on an absolute basis.

More importantly, sole reliance on treatment does not reflect the "polluter pays" concept which recognises that the prime objective in such situations is to control the problem at source by catchment protection rather than attempt to clean up degraded water resources.

CATCHMENT PROTECTION

The Spraysafe Campaign

Within the Severn Trent Water region, one of the major sources of pesticide contamination was known to be from the use of residual herbicides to control weed growth on hard surfaces, particularly roads and railways. We therefore initiated a major campaign entitled Spraysafe, to persuade all users to significantly modify weed control practices in order to minimise or even eliminate pesticide leaching into catchments. The Spraysafe campaign was carried out with the support of the agrochemical industry, and was generally well received by herbicide users as being positive and constructive.

The campaign included a number of co-ordinated and compatible actions that took place initially over an eighteen month period, namely;

User surveys via mail shots to ascertain the extent and trends in herbicide use and the attitude of users; this has the added advantage of enabling a database of contact names both of pesticide users and other relevant parties to be created

Conferences attended by herbicide users, contractors, research agencies and agrochemical companies. The proceedings included both water industry and agrochemical experts describing the scale of the pesticide problem and practical ways to avoid such pollution

Press campaigns in a variety of press, radio and TV reports of the conferences to highlight the problem and to encourage users that had not already adopted good practice to follow the example of those who had

Promotion of detailed advice as some users wanted to change their practices to avoid water pollution but had limited access to expert advice. We therefore provided contact names and addresses for centres of advice and worked with a number of major agrochemical companies to encourage the development of training packages using video and other techniques. Concurrently, the government produced simple codes of good practice on herbicide use. At the same time a specialist independent advice agency developed a commercial consultancy service.

The main messages in the campaign were published in our Spraysafe charter which included a simple eight-point checklist of ways to avoid or minimise water contamination.

Since then, Spraysafe has continued to develop and recently another survey was sent to our contacts to determine latest trends in policy and usage. The response was very encouraging with representatives from almost 100% of those organisations and municipalities contacted responding. Nearly 80% of authorities now review their weed control policies on an annual basis. This allows changes in statutory requirements to be implemented quickly and prevents the use of inappropriate or environmentally harmful herbicides. Over 70% of local authorities quoted Spraysafe as an influencing factor in reviewing their policies.

We are now working closely with railway representatives and the National Rivers Authority to determine ways in which track spraying procedures can be modified in areas where a perceived risk to water resources exists. This includes use of non-residual herbicides in pesticide-sensitive areas and complete exclusion of pesticides from small sections of track close to water abstraction points for example, bridges over rivers etc.. A pilot study is being developed to look at the practicalities and benefits of implementing these measures.

Catchment Protection Policy Documents

Land use activities in areas close to a water treatment works abstraction point can significantly affect raw water quality both in terms of pesticides and other contaminants such as farm slurry, chemicals and fertiliser use. In the case of upland catchment areas, land use activities around impounding reservoirs are likely to have the greatest influence upon water quality. In addition to agricultural pollution, water quality problems arise from soil erosion, deforestation and tourism. For each of its upland impounding reservoirs, Severn Trent Water is producing a Catchment Protection Policy Document. The document assesses potential pollution risks and provides pragmatic advice to minimise these risks. Areas addressed in the document include the definition of catchment boundaries and the landowners involved and the control of risks from the various sources already mentioned. In many areas the land is not controlled by the water company and it is then that the advice should be practical and where possible save the private landowner expense and protect him from risk of prosecution from pollution control agencies. Assistance from experts in agriculture and land management is sought to enable a realistic and sensible approach to policy formulation.

Catchment Information System (CatchIS)

To determine the need and benefit of carrying out catchment protection initiatives a risk assessment of the individual catchments is essential. By looking at the prevailing soil types and the physicochemical characteristics of pesticides used in the catchment in combination with the historical agroclimatic variables, a vulnerability assessment of the area can be made. In order to carry out these detailed assessments computer-based models are essential.

We recognised this need at an early stage and undertook a joint research project with the Soil Survey and Land Research Centre (SSLRC) to develop CatchIS (Catchment Information System) (Breach *et al,* 1994). It is operated on a powerful IBM RISC RS/6000 workstation using an object-orientated spatial application development environment produced by APIC Systems which allows high performance handling of large volumes of spatial and non-spatial data.

To perform the assessment, CatchIS uses a number of GIS and non-GIS core databases:

GIS databases

Agroclimatic data at 5km resolution based on long term averages between 1941 and 1978 for start, end and duration of field capacity periods and volume of excess winter rainfall.

UK National surface hydrological network as part of the Ordnance Survey 1:250,000 scale hydrological database.

River catchments and sub-catchment boundaries as standardised by the National Rivers Authority (NRA).

Ordnance Survey 1:250,000 Strategi vector map with features including roads, railways, urban areas etc.

Soil data from the SSLRC 1:250,000 scale data which is down to 100m resolution derived from the SSLRC 'LandIS' Land Information System and is based on the National Soils Map held by SSLRC. This includes soil type and run-off and leaching potential and associated soil parameter database comprising of chemical and hydraulic characteristics and relative depth of the unsaturated zone.

Digitised reservoir catchment boundaries.

Non-GIS databases

Pesticide characteristics for over 100 of the most commonly used products within the Severn Trent region including information on average application rates, target crops and application dates, likely crop interception factors and physicochemical properties such as measured ranges of degradation rates and Koc.

Surface and groundwater abstraction points for Severn Trent water treatment works and boreholes including licence details and abstraction rates and relevant surface and groundwater details.

The system uses two models for evaluating risk - Aquifer Attenuation Model (AQUAT) and Surface Water Attenuation Model (SWAT).

Aquifer Attenuation Model (AQUAT)

This model has been developed by SSLRC (Hollis, 1991) based on the attenuation factor concept described by Rao *et al* (1985) and Leonard & Knisel (1988). The mass of pesticide within recharging water impacting on a groundwater surface is only a fraction of that mass originally applied on the soil surface. This fraction represents the amount of attenuation that has occurred during pesticide transport through the various soil sub-levels and can therefore be termed the Attenuation Factor. This will vary depending on the rate of degradation of the pesticide due to chemical and biological means and the time of travel from the surface to the groundwater. Further attenuation is caused by the partitioning of the compound into gas, liquid and solid phases.

Surface Water Attenuation Factor (SWAT)

Based on an adaptation of the attenuation factor concept used in AQUAT this model predicts the average pesticide concentration entering streams in the peak drainage from fields following the first rainfall event that initiates run-off after pesticide application. The concentration is calculated by assuming that during the rainfall event, all rainfall interacts with the upper part of the topsoil by displacing and mixing with the mobile water fraction. It is this displaced and diluted soil water fraction that moves rapidly to streams, either via surface flow or through the soil fissure/macropore systems and field drains.

Vulnerability Assessment

By comparing the 'best' and 'worst' case scenarios for either the Attenuation Factor (AQUAT) or the average pesticide concentration (SWAT) against a threshold value such as the UK standard for pesticides (0.1µg/L) - a vulnerability assessment of HIGH, MODERATE/HIGH, MODERATE, LOW/MODERATE or LOW can be made. It is essential to use the best (high rate of degradation, highest adsorption) and worst (low rate of degradation, lowest adsorption) cases as the environmental fate of a pesticide can vary from year to year depending on the soil and climate conditions. If the models predict that under worst case conditions the estimated pesticide concentration will be less than the threshold value then the assessment will be LOW (pesticide unlikely to contaminate source unless misapplied) but, conversely, if with the best case the estimated concentrations are greater than the threshold then the assessment will be HIGH (frequent contamination of the resource is likely). All other results will be between these two extremes as is appropriate.

Use of Vulnerability Assessments

There are probably around 20,000 farmers and landowners within the Severn Trent region. All land users have the potential to influence drinking water resource quality but it is important to target practices in the most critical land areas first. Through use of CatchIS these users can be identified and any contact can be more cost effectively focused. Trials of different products on CatchIS have shown that pesticides which show up most frequently in water at present can still be used but in areas where geology, soil type and proximity to water courses would not present a risk. By liaising closely with land management consultants and agrochemical companies minimisation methods may be developed that are acceptable to all concerned.

Future Developments

Work is in progress to incorporate land use information into the models which will enhance CatchIS and allow a more accurate vulnerability assessment to be made. Field work to validate the models with real-time data is also ongoing. The results from this sampling is compared with data from our routine monitoring of raw waters and initial results have confirmed that CatchIS risk assessments are appropriate.

We are also incorporating Ordnance Survey 1:50,000 raster data for areas of maximum risk which will enable us to identify more clearly the activities and land ownership within our catchments. We are looking at the best way of incorporating other land-use sensitive areas such as Nitrate Sensitive Areas, Nitrate Vulnerable Zones and groundwater recharge areas and there is the potential to use CatchIS for compounds other than pesticides e.g. sludge application to land and fertiliser applications.

CONCLUSIONS

The development and use of CatchIS provides a useful tool for the management of water resources by water utilities and regulatory authorities. It provides an improved understanding of the environmental fate of different pesticides, particularly from the water supply perspective. Through the use of such tools, expert agricultural advice and the co-operation of local landusers our current objective is to facilitate improved environmentally friendly weed control practices, to promote the use of non-chemical methods of weed control whenever possible and, when pesticides are absolutely necessary, to ask pesticide users to consider carefully which product and application rate they employ .

Management and protection of water resources is a very complex and expensive task but with the co-operation of land users and agrochemical companies we aim to minimise contamination of water resources through pesticide use and achieve an appropriate balance of catchment protection and robust water treatment.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the use of licences for various databases and software used within CatchIS, namely: Soilmap and Soil Properties Database - SSLRC; 1:250,000 Ordnance Survey Strategi digitised data; Surface Water Catchments - NRA; APIC Software - APIC Systems. The CatchIS software is the copyright of Severn Trent Water and SSLRC. CatchIS is being registered as a Trade Mark.

The authors acknowledge permission from Severn Trent Water to publish this paper, but any views expressed are personal and not necessarily those of the company.

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GOOD FARMING PRACTICES TO REDUCE RESIDUES OF ATRAZINE IN GROUND AND SURFACE WATER

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ABSTRACT

Atrazine was among the first herbicides to provide selective weed control in maize. It has been used extensively and at high rates in agriculture and for non-agricultural weed control. In the 1980's, the application of sensitive analytical methods revealed the presence of residues of atrazine in ground water and drinking water.

As a consequence, Ciba successively eliminated those uses of atrazine contributing most to residues in water. In the late 80's, the "Good Farming Practice Programme" was introduced in Switzerland (and subsequently throughout Europe), limiting the use of atrazine to maize only, at a maximum rate of 1.5 kg AI/ha once a year. The objective of this programme was to reduce residues of atrazine in water substantially, while retaining the uses with highest benefit to the farmer and minimal risk to the environment.

Results from various monitoring programmes clearly illustrate decreasing trends of residues in ground and surface water. The abandonment of non-agricultural uses, especially uses on railway tracks, contributed most to the significant reduction of residues in water.

Agricultural practices favoring surface run-off and erosion as well as crop production systems badly adapted to local conditions (hydrology, climate, soil type etc.) lead to residues of various pesticides and nitrates in ground- and surface water. A sustainable solution to the problems of agrochemicals in water must therefore include an adaptation of agricultural practices to local conditions.

INTRODUCTION

Former use areas for herbicides containing atrazine

In the fifties, atrazine was one of the first herbicides to provide selective weed control in maize. On account of its effectiveness and low price, the product was used not only in agriculture but also to control weeds in non-agricultural areas (railways, road embankments, open spaces) at frequent intervals and high dosage rates. In maize atrazine was applied in autumn for dealing with couch grass at dosage rates of up to 5 kg AI/ha and in spring for the control of various weeds at dosage rates of between 1 and 3 kg AI/ha. For controlling weeds in non-agricultural areas (including railway embankments), dosage rates of up to 9 kg AI/ha were used regularly, some times even several times per year.

In 1979 the laboratory of the Canton of Fribourg detected atrazine in ground water in the rural district of Courtepin. Up to that time, drinking water had scarcely ever been tested for atrazine, as nobody expected to find residues of plant protection products. At the beginning of the 1980's, tests were made more frequently, and the sensitivity of the analytical methods was improved. The intensified monitoring revealed that traces of atrazine can move to ground water.

Restrictions on the application of herbicides containing atrazine

In 1987 restrictions on the application of atrazine were imposed in Switzerland. In maize, atrazine was restricted to 1.5 kg AI/ha. On railway lines the dosage rate was reduced by 50% in 1988, and in 1989 this use of atrazine was abandoned. These use adaptations, now known as "Good Farming Practice Programme", was subsequently adopted by the registration authorities. Since 1990 atrazine may be used in Switzerland as follows:

- application only in maize;
- dosage rate: 1 - 1.5 kg AI/ha;
- application only post-emergence, but before the 30th of June.

In order to assess the effectiveness of the implemented measures and in order to identify causes of atrazine residues in water, a comprehensive investigation was carried out. This paper summarises the results.

DATA BASE

Tests by the cantonal laboratories

The laboratories of the Cantons of Aargau, Basel-Land, Bern, Solothurn, Fribourg and Ticino contributed some of their data from the years 1987 - 1994 to this publication. Seventy eight sampling sites of ground water were selected in agreement with the Swiss Association for Chemical Industries. In addition to the data on ground water, the laboratories of the Cantons of Basel-Land and Solothurn monitored various bodies of surface water with regard to atrazine.

Atrazine in ground water - a model study

A model study was carried out with the aim to investigate the causes of atrazine residues in ground water at the Kaltenstein pumping station of Küsnacht ZH (Rick, 1993).

Monitoring of the River Rhine

Ciba has been analysing monthly samples from the River Rhine for their atrazine contents. Sampling sites were upstream and downstream of their former atrazine production plant at Schweizerhalle.

Importance of individual values

In spite of analytical fluctuations (experience has shown that the standard deviation can be 10 - 20%) it was possible to record representative values at concentrations in the range of

0.1 µg/L. Each individual value gives the content of atrazine at the moment of sampling and is strongly affected by current climatic conditions. Heavy precipitation after application can carry plant protection products into surface waters and into deeper soil layers. If such short-lived events take place between samplings, they may possibly remain unrecorded. Consequently, not very much importance is attached to the absolute value of individual samples, but the data are interpreted in relation to the trends observed.

RESULTS

Ground water

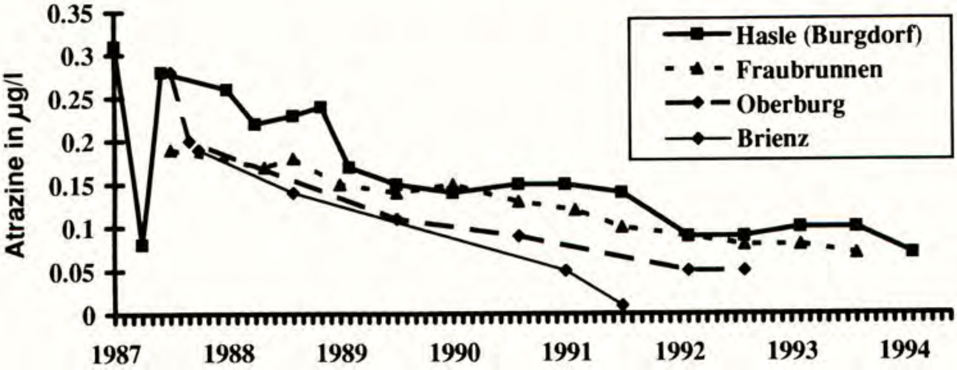
General trends

In most cases concentrations of atrazine dropped significantly as a result of the restrictions on use (Figure 1), not only where the initial concentrations were relatively high but also where they were low (Table 1). In cases where the concentrations did not drop considerably, the initial concentrations were in most cases already below 0.5 µg/L.

TABLE 1. Changes in atrazine concentrations in 78 wells: Wells grouped according to the initial concentration and the decrease observed.

Initial concentration	Decrease, in % of the initial concentration			
	0-25%	25-50%	50-75%	75-100%
> 1.0 µg/L	2 wells		1 well	3 wells
0.5 - 1.0 µg/L	1 well		2 wells	3 wells
0.1 - 0.5 µg/L	10 wells	14 wells	15 wells	9 wells
< 0.1 µg/L	15 wells	2 wells	1 wells	

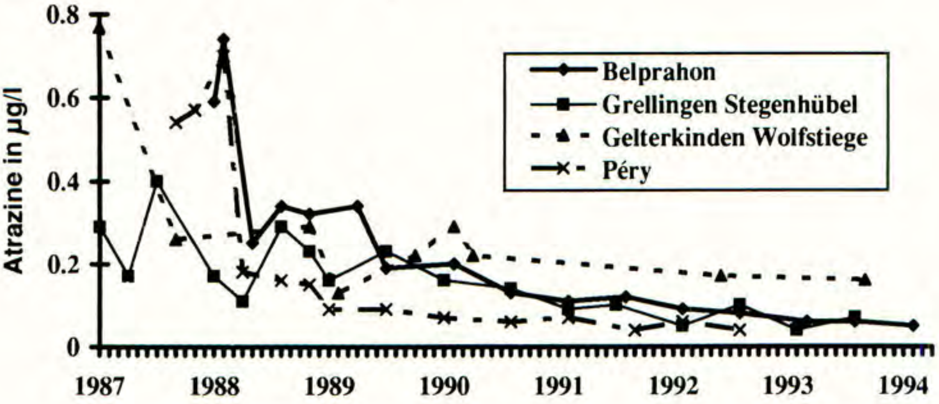
FIGURE 1. Reduction of atrazine concentration in 4 wells of the Canton of Bern



Catchment areas around railways

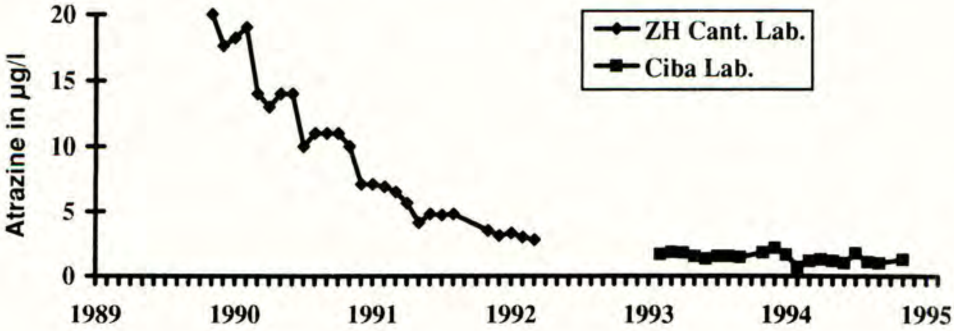
For weed control along railway tracks, application rates were reduced by 50% in 1988, and eliminated in 1989. At sampling sites close to railway installations, concentrations of atrazine dropped significantly as a consequence of the use restrictions (Figure 2).

FIGURE 2. Catchments close to railways



Particularly high values (around 20 µg/L) were measured in the ground water of Kaltenstein ZH at the end of 1989. After a comprehensive investigation of all possible causes (use of atrazine for weed control on railway embankments, roadsides and in agriculture), the use of atrazine on railway embankments was identified as the main cause. During the first three years after the phasing out of atrazine for this use, concentration in ground water dropped by approximately 90% (Figure 3). Since 1992, this trend slowed considerably, which is probably due to residues in the soil that stem from former applications on railway tracks. Test drilling has shown an atrazine content of 15 - 20 µg/kg soil at a depth of 7 - 12 m.

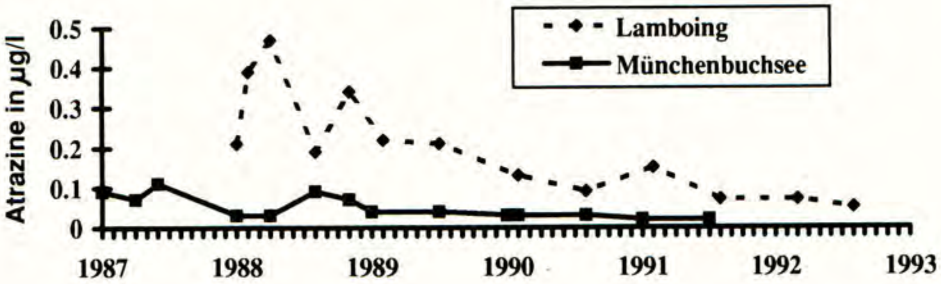
FIGURE 3. Catchment in the area of the railway at Kaltenstein ZH



Catchment areas in agricultural regions

Two catchment areas (Münchenbuchsee and Lamboing) are located in purely agricultural regions. The respective concentrations of atrazine decreased significantly after the implementation of the modified use pattern in 1987 (Figure 4).

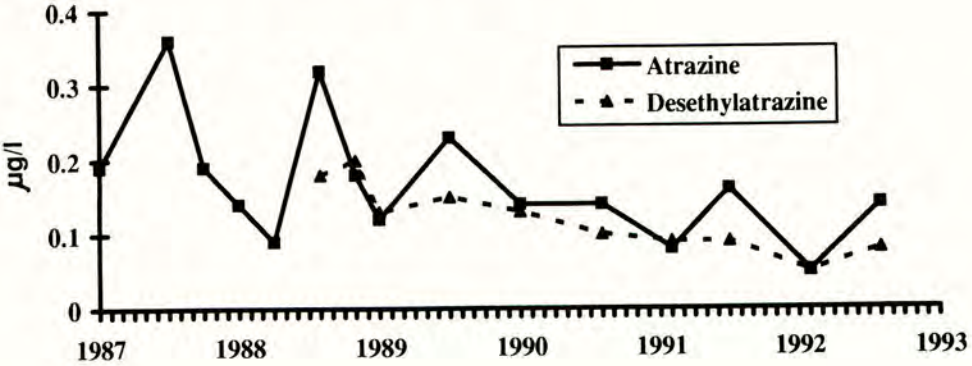
FIGURE 4. Catchments in agricultural regions



Catchment areas in karstic regions

Some catchment areas in karstic regions regularly show higher concentrations of atrazine in summer than they do in winter (Figure 5). Nevertheless, in these cases a constant downward trend can also be observed, with concentrations between 0.1 and 0.4 µg/L in 1987 and between 0.05 and 0.15 µg/L in 1993. The annual fluctuations indicate that traces of atrazine seep rapidly into the ground water, without substantial degradation. This conclusion is supported by the fact that, in proportion, more atrazine than desethylatrazine (atrazine's first degradation product) is found. This indicates that because of the immediate and rapid seeping into the underground, there was not enough time for a (microbial) degradation in the top soil.

FIGURE 5. Catchment in a karstic region (Liesberg)

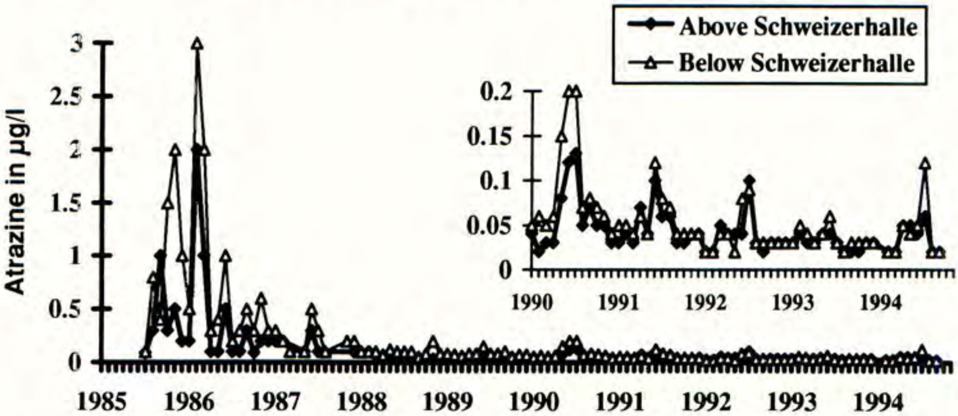


Surface water

Investigation of the river Rhine

Since 1985 Ciba has monitored the water of the River Rhine upstream and downstream of its former atrazine production plant in Schweizerhalle. The data show a steep reduction in atrazine residues between the years 1985 and 1988 (Figure 6). This reduction is due to the fact that atrazine was no longer produced at Schweizerhalle after 1987 as well as the use restrictions implemented during this period. The downward trend continued in the following years with seasonal peaks most likely caused by surface run-off and erosion.

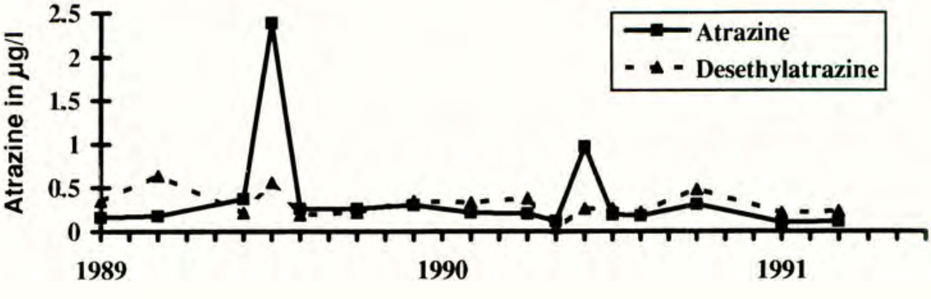
FIGURE 6. Tests on Rhine water above and below Schweizerhalle



Tests on the Ergolz, a tributary of the river Rhine

The laboratory of the Canton of Basel-Landschaft collected data on the Ergolz (a creek in a rural area) for the years 1989 and 1990. On July 6th, 1989 a substantial increase of atrazine concentrations, exceeding 2 µg/L was observed (Figure 7). Most likely, these high temporary residues result from run-off or erosion, caused by the heavy rainfall (66.3 mm) on July 1st, 1989. Based on the ratio of the metabolite desethylatrazine to atrazine it can be concluded that these residues reached the creek shortly after application, without substantial previous degradation.

FIGURE 7. Atrazine content in the Ergolz



THE QUALITY OF DRINKING WATER

In Switzerland, the water companies are responsible for the quality of the drinking water they supply to the consumer. In addition, the supervising authorities (Kantonschemiker) regularly check the quality of the drinking water. The legislation regulating the quality of food and water states a quality objective (Toleranzwert) of 0.1 µg/L for residues of individual pesticides in water and 0.5 µg/L for the sum of all pesticides. The laws use the tolerance level to lay down the standard for the purity of drinking water and to meet consumers' rightful expectations.

If the concentration of a pesticide is below the quality objective, the water is considered of high quality. If the supervising authorities detect more than 0.1 µg/L of a pesticide in drinking water, it raises objections. However, concentrations below the Guideline Values proposed by the World Health Organisation (2.0 µg/L in the case of atrazine according to WHO, 1993) are not considered a health concern. Nevertheless, the causes for the elevated concentrations have to be investigated and remedial actions implemented.

CONCLUSIONS

The adapted and improved use recommendations for atrazine, known as "Good Farming Practice Programme", have resulted in a marked decrease of atrazine concentrations in the River Rhine and almost all catchment areas (ground water) examined. The decrease is most noticeable in the years after the introduction of the restrictions (1986-88) but then slows down in most cases.

Application of high concentrations of atrazine around railways not only leads to high residues of atrazine in the ground water, but also to residues in the soil profile. During the first years after the phasing out of the use of atrazine on railway tracks, concentrations of atrazine in ground water decreased significantly. However, it must be assumed that residues in soil, stemming from former uses, successively leach into the ground water and are responsible for slowing down the decrease in a second phase.

The investigation on catchment areas in karstic regions give rise to the assumption that in such areas the use of atrazine in agriculture results in residues entering the ground water in the same season.

OUTLOOK

A sustainable reduction of residues in water can be achieved for pesticides in general and for atrazine in particular by means of the following measures:

Ground water: In areas with thin layers of humus and with fissured subsoil (e.g. karstic regions) the cultivation of maize often leads to residues of pesticides (with atrazine being investigated the most frequently) and nitrates in the ground water (Flury *et al.*, 1994; Shipitalo *et al.*, 1990). It is questionable whether intensive cultivation of maize in these regions is respecting the requirements of a good agricultural practice since it might not be adapted to local conditions.

Surface water: Many investigations show that erosion and the consequent entry of soil, nitrates, fertilisers and pesticides into surface water can effectively be reduced by cultivation techniques. Reduced soil cultivation or even living cover-crops and planted buffer strips along the banks of stretches of water can lead to a steep drop or even complete prevention of erosion and subsequently protect surface water (Norris, 1993; Jones, 1993; Dillaha *et al.,* 1988).

Sensitive areas: In "sensitive areas", e.g. on steep hillsides or on very porous soils, no intensive cultivation should be carried out because the characteristics of the site might not be suitable for it. In such areas, sustainable agriculture would mean to reduce the use of agrochemicals, fertilisers and liquid manure or to refrain from intensive cultivation of crops that require substantial inputs of fertilisers and agrochemicals.

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GRASSED BUFFER STRIPS TO REDUCE HERBICIDE CONCENTRATION IN RUNOFF - PRELIMINARY STUDY IN WESTERN FRANCE.

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ABSTRACT

The effectiveness of grassed buffer strips in decreasing isoproturon (IPU) and diflufenican (DFF) contents in surface runoff was investigated. Three winter wheat plots (125 m^2) were treated, for two successive years (1993, 1994), with Quartz GT (3 and 2.5 l/ha) and runoff was obtained with natural rainfalls. Runoff from each plot B0, B6 and B12 was collected after filtration through a 0, 5.7 and 11.1 m wide grassed buffer strip, respectively. During the two cropping periods, runoff volumes were reduced by 8 and 88 % in the 5.7 m strip and by 37 and 92 % in the 11.1 m strip, respectively. During the same periods, total solids transported in runoff were reduced by 81 and 93 % in the 5.7 m strip and by 92 and 99 % in the 11.1 m strip, respectively. Of total IPU and DFF lost from the plots in runoff, during the first period, 97 and 90 % were removed in the 5.7 m strip, respectively.

INTRODUCTION

During rainfall events, transfer of agricultural pesticides from treated areas to surface water is mainly under the control of runoff processes. Non point source pollution caused by pesticide losses is responsible for surface water quality degradation. In order to mitigate adverse impacts of agricultural practices, grassed buffer strips used for controlling suspended solids (Neibling & Alberts, 1979; Young *et al.* , 1980; Parsons *et al.* , 1991) and nutrient transport from feed lots (Dillaha *et al.* , 1986/1988/1989; Vought *et al.* , 1991; Magette *et al.* , 1989; Osborne & Kovacic, 1993) have been studied in the USA since 1965. However, efficacy of grassed buffer strips in restricting pesticide transfer in runoff is still not well documented.

Using simulated rainfall, Asmussen *et al.* (1977) found that suspended sediment reduction in a 24.4 m grassed waterway was 94 and 98 % of the total amount moving from the plot in the wet and dry waterway conditions, respectively. Under the same conditions the waterway removed 69 and 71 % of 2,4 D lost from the plot in solution. In fact, 2 and

25 % of retention of 2,4 D in the waterway were attributed to infiltration and 67 and 46 % of removal were attributed to adsorption on vegetation, organic matter, etc. under wet and dry conditions, respectively. Rohde *et al.* (1980), using a similar 24.4 m grassed waterway, found that trifluralin lost in the simulated rainfall runoff was reduced by 86 and 96 % under wet and dry conditions, respectively. Under the same conditions, 29 and 43 % of retention of trifluralin in the waterway were attributed to infiltration.

The 24.4 m grassed waterway used in these studies was responsible for the 2,4 D and trifluralin content reduction in runoff irrespective of significant differences between pesticide mobility properties. 2,4 D is moderately water soluble (890 mg/L) and slightly adsorbed (K_{oc} = 20 cm^3/g) whereas trifluralin herbicide is slightly water soluble (0.3 mg/L) and strongly adsorbed on soil (K_{oc} = 8000 cm^3/g). We can therefore make the assumption that grassed buffer strips of sufficient width could be efficient in decreasing herbicide content in runoff. However, possibilities of implementation need to be assessed in various conditions.

In a recent study, Michenfelder & Schramm (1992) outlined the importance of soil surface conditions in the transfer of isoproturon and pendimethalin in runoff. The study reported here was conducted by Cemagref, I.T.C.F. and Rhône-Poulenc Agrochimie and was sponsored by the French Ministry of Agriculture. It aimed at determining the effectiveness of grassed buffer strips in reducing isoproturon (a substituted phenylurea) and diflufenican (a phenoxynicotinanilide) concentrations in runoff from treated wheat plots.

MATERIALS AND METHODS

The study was carried out at the I.T.C.F. research farm at "La Jaillière" located near Nantes, France. The experimental site included three winter wheat plots (25 x 5 m) bordered by a rill and a plastic sheet. Soil was a silt loam prone to runoff generation. Winter wheat was directly sown (along plot lengths) for the two cropping periods (1992/1993 and 1993/1994) on November 11, 1992 and October 26, 1993, respectively. A 12 m wide grassed buffer strip (rye-grass sown on September 25, 1992, at 20 kg/ha, perpendicularly to the slope) was established below the three winter wheat plots. Plot slope was approximately 6 % for the first 17 m and 10 % for the bottom of the plots and the grassed buffer strips. Runoff was collected from each plot B0, B6 and B12 in a gutter and drained into a tank after filtration through a 0, 5.7 and 11.1 m wide grassed buffer strip, respectively (Figure 1).

Two herbicides, isoproturon (IPU) and diflufenican (DFF), were applied on winter wheat plots. IPU is moderately water soluble and slightly adsorbed on soil, whereas DFF is very low water soluble and strongly adsorbed (Table 1). Quartz GT (DFF: 62.5 g/L, IPU: 500 g/L) was applied by manual spraying on January 15, 1993 and December 14, 1993 at 3 l/ha and 2.5 l/ha for the two cropping periods, respectively. A Pulval sprayer equipped with red "ALBUZ" nozzles was used to spray a width of 2.50 m with a spray angle of 80°, an operating pressure of 1.8 bar and a flow rate of 0.74 l/min.

Four soil cores (length: 10 cm, diameter: 7.3 cm) were taken on each plot before the first herbicide application so as to define the initial soil residue level. Rinses of each tank were also analysed to determine their contamination level before application and the first runoff event.

Figure 1. Experimental design at the research farm "La Jaillière" (near Nantes, France).

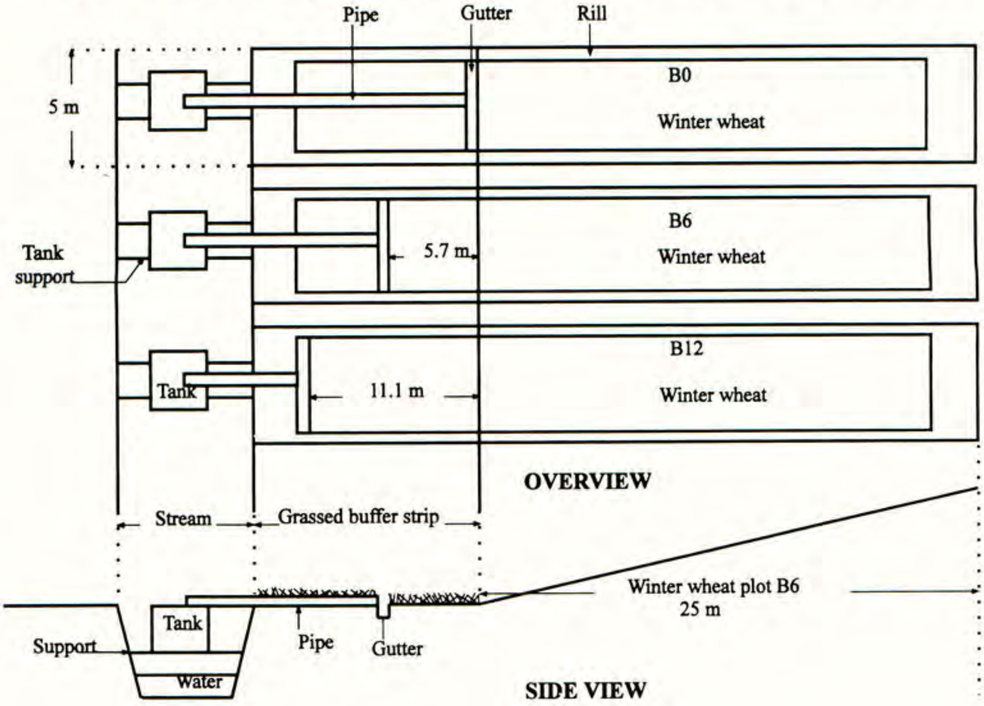


Table 1. Physico-chemical properties of isoproturon and diflufenican.

	diflufenican	isoproturon
Vapor pressure (Pa)	4.3 10^{-6} (25 °C)	8.1 10^{-6} (25 °C)
Water solubility (mg/L)	0.05 (25 °C)	65 (22 °C)
Koc (cm^3/g)	1990	120

from Rhône-Poulenc Agrochimie (Lyon, France).

Four glass Petri dishes were placed on each plot just before application and their IPU and DFFcontent was analysed immediately after treatment to determine actual application rate. Four soil cores (length: 10 cm, diameter: 7.3 cm) were taken on each plot immediately after application and one, four and eleven months later for the first cropping period and immediately after application and 3 months later for the second period. Soil samples were analysed to check IPU and DFF application rates and to determine the herbicide half-lives under the experimental conditions.

After each rainfall event, runoff volume was measured. After homogenization of the tank content, runoff samples were taken from each tank and stored at -18°C. Analytical conditions will be described in a separate paper (in preparation). The rate of suspended solids and the particle size were determined for each runoff sample sieved through a 500 µm mesh. Then, runoff samples were divided into two parts. The first part was extracted by liquid-liquid extraction with dichloromethane (method I). The second part was separated into liquid and solid phases by continuous flow centrifugation (40000 rpm). Runoff liquid phase was extracted by liquid-solid extraction on C18 Empore disk (method II). Runoff solid phase and soil samples were extracted with acetone followed by solvent partition between dichloromethane and water (method III and IV). The different extracts were purified on Sep-Pak Florisil cartridges. IPU and DFF concentrations were determined respectively by high performance liquid chromatography and electron capture gas chromatography.

Mean recovery rates of isoproturon from runoff (method I), runoff liquid phase (method II), runoff solid phase (method III) and soil (method IV) were 87, 88, 87 and 83 % respectively. For DFF the results were 94, 87, 96 and 84%, respectively. The validity limits ranged between 0.01 to 0.1 µg/L and 0.1 to 30 µg/kg (dry) for the different methods.

RESULTS AND DISCUSSION

Soil and tank initial residue concentration

Soil samples and tank rinses collected before application were free of residues (below the detection limit).

Herbicide application

Average application rates for both treatments (determined using Petri dishes) were 89 and 75 % of theory for IPU and DFF, respectively (Table 2). Recoveries in soil samples collected immediately after treatments were 76 and 68 % of theoretical rates for IPU and DFF, respectively. Therefore IPU and DFF mean amounts actually applied on each wheat plot were 18.7 g and 2.3 g for the first and 15.2 g and 1.8 g for the second application.

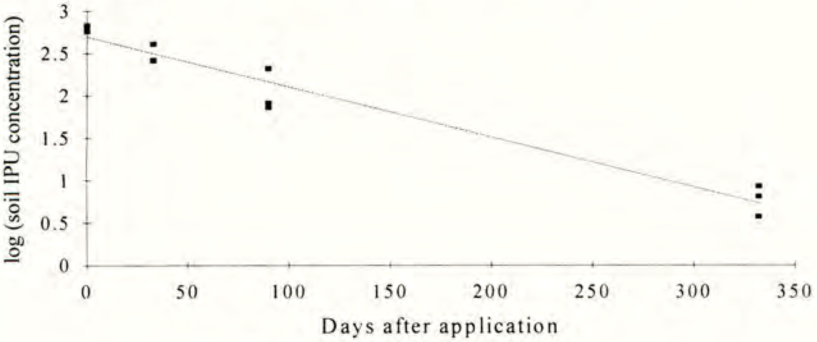
Table 2. IPU and DFF amounts (g) applied on winter wheat plots for the two cropping periods at "La Jaillière" research farm, France (i: theoretical rates; ii: Petri dishes analysis; iii: soil analysis).

Application date	Wheat plot	IPU amount applied (g)			DFF amount applied (g)		
		i	ii	iii	i	ii	iii
January 15, 1993	B0	17.9	19.0	13.4	2.20	1.80	1.60
	B6	18.7	17.9	12.3	2.30	1.70	1.50
	B12	19.6	18.6	12.8	2.40	2.10	1.50
December 14, 1993	B0	15.2	14.4	15.5	1.80	1.50	1.50
	B6	15.2	10.3	13.0	1.80	1.10	1.50
	B12	15.3	11.1	9.50	1.80	1.10	0.80

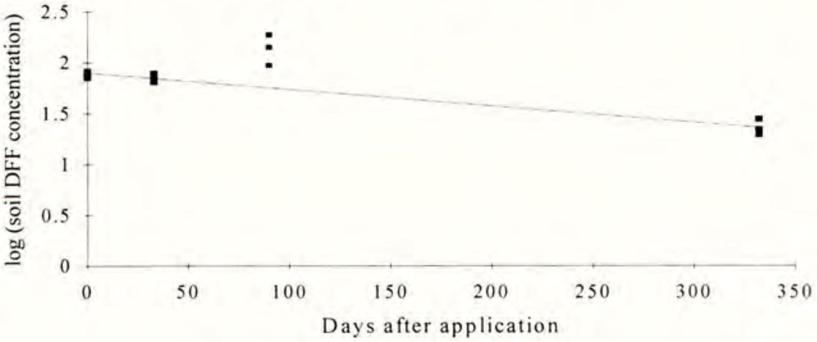
IPU and DFF half-life estimation

The total residues in soil cores collected during the 1992/1993 cropping period are presented in Figure 2. Logarithm of herbicide concentrations (C) in soil are plotted versus time after application (t) and IPU and DFF half-lives in soil (0-10 cm) derived from linear regression coefficients were determined to be 31 and 192 days, respectively.

Figure 2. IPU (a) and DFF (b) residues in "La Jaillière" soil (0-10 cm) during the 1992/1993 period, after application of Quartz GT (3 l/ha).



(a) Equation : log C = -0.006 . t + 2.7 (r^2 = 0.9569)



(b) Equation : log C = -0.002 . t + 1.9 (r^2 = 0.9668)

These results are quite consistent with the values published in the literature. Half-lives obtained by Rhône-Poulenc Agrochimie varied between 12 and 32 days for IPU and 175 and 294 days for DFF in field conditions (France). Mudd *et al.* (1983) reported that the IPU half-life was approximately 40 days in field conditions (England). Kyndt *et al.* (1985) pointed out that in a clay loam soil (Essex, England) DFF half-life varied between 112 and 140 days. Soil laboratory studies conducted by Blair *et al.* (1988) and Mudd *et al.* (1983) showed a 35 days and a 14-21 days half-life for IPU, respectively.

Grassed buffer strip studies

Various runoff analytical results are presented in Table 3. Runoff losses decrease with time and grassed buffer strip width (Figure 3). The first rainfall event which occured after application was responsible for the highest runoff herbicide losses. But, grassed buffer strips appeared to be efficient in restricting the IPU and DFF transfers in runoff to surface water.

Table 3. Residues in runoff collected from wheat plots B0, B6 and B12 during the 1992/1993 and 1993/1994 cropping periods at "La Jaillière" research farm, France.

Runoff event: date and rainfall (mm)	Wheat plot	Suspended solids rate (mg/L)	Runoff volume (L)	Total solids (g)	IPU in runoff (µg/L)	DFF in runoff (µg/L)	IPU in runoff liquid phase (µg/L)	DFF in runoff liquid phase (µg/L)	IPU in runoff solid phase (µg/kg dry)	DFF in runoff solid phase (µg/kg dry)
April 15, 1993 (51.6)	B0	1804	19.2	34.6	59	17	110	1	307	2440
	B6	1504	12.2	18.3	2.2	1.8	2.3	< 0.1	< 30	130
	B12	1086	8.2	8.9	0.6	0.2	< 0.1	0.4	< 30	38
May 14, 1993 (12.2)	B0	369	8.9	3.3	4.4	7	2.8	1.5	*	3735
	B6	215	10.9	2.3	< 0.1	3.4	< 0.1	0.7	*	486
	B12	116	7.9	0.9	1.2	0.2	1	0.1	*	*
June 15, 1993 (57.2)	B0	1079	20	21	0.8	3.5	1	1	*	553
	B6	21	33	0.7	< 0.1	0.07	*	*	*	*
	B12	30	20	0.6	< 0.1	< 0.02	*	*	*	*
September 17, 1993 (38.9)	B0	1410	17.5	24.7	0.2	4.8	< 0.1	1.5	*	514
	B6	410	4.5	1.8	0.3	0.2	< 0.1	0.2	*	*
	B12	140	2.5	0.35	< 0.1	0.15	< 0.1	0.2	*	*
October 04, 1993 (25.8)	B0	2532	11.1	28	0.26	4	< 0.1	1	< 30	307
	B6	306	8.1	2.5	< 0.1	0.1	< 0.1	0.1	*	192
	B12	32	6.1	0.19	< 0.1	0.04	< 0.1	< 0.1	*	*
October 18, 1993 (43.7)	B0	6046	9.1	55	< 0.1	3	*	*	*	*
	B6	630	10.1	6.3	< 0.1	0.04	*	*	*	*
	B12	276	9.1	2.5	< 0.1	< 0.02	*	*	*	*
January 06, 1994 (72.2)	B0	6800	29.5	200	60	2.7	*	*	*	*
	B6	2800	10	28	< 0.1	0.02	*	*	*	*
	B12	282	6	1.7	< 0.1	< 0.02	*	*	*	*
February 03, 1994 (35.4)	B0	961	55	52.8	9	2	9	0.7	*	279
	B6	80	6	0.48	< 0.1	0.04	< 0.1	< 0.1	*	*
	B12	500	4.5	2.25	< 0.1	0.02	< 0.1	< 0.1	*	26
March 08, 1994 (10.9)	B0	1070	41	43.9	4	2	4	0.6	33	294
	B6	128	2.5	0.32	< 0.1	< 0.02	*	*	*	*
	B12	245	4	0.98	< 0.1	< 0.02	< 0.1	< 0.1	*	113
April 12, 1994 (41.4)	B0	764	15	11.5	0.40	1.8	0.30	0.5	< 30	330
	B6	152	5	0.8	< 0.1	< 0.02	*	*	*	*
	B12	474	2	0.9	< 0.1	0.2	*	*	*	*
April 26, 1994 (4.4)	B0	1686	38	64	0.15	3	< 0.1	0.5	< 30	472
	B6	0	0	0	0	0	0	0	0	0
	B12	0	0	0	0	0	0	0	0	0
August 01, 1994 (31.8)	B0	5366	5	27	< 0.1	3	< 0.1	0.6	< 30	392
	B6	0	0	0	0	0	0	0	0	0
	B12	0	0	0	0	0	0	0	0	0
August 05, 1994 (30.1)	B0	264	5	1.32	< 0.1	5.6	*	*	*	*
	B6	0	0	0	0	0	0	0	0	0
	B12	0	0	0	0	0	0	0	0	0
August 16, 1994 (24.9)	B0	2108	10	21.08	< 0.1	3.7	*	*	*	*
	B6	0	0	0	0	0	0	0	0	0
	B12	0	0	0	0	0	0	0	0	0

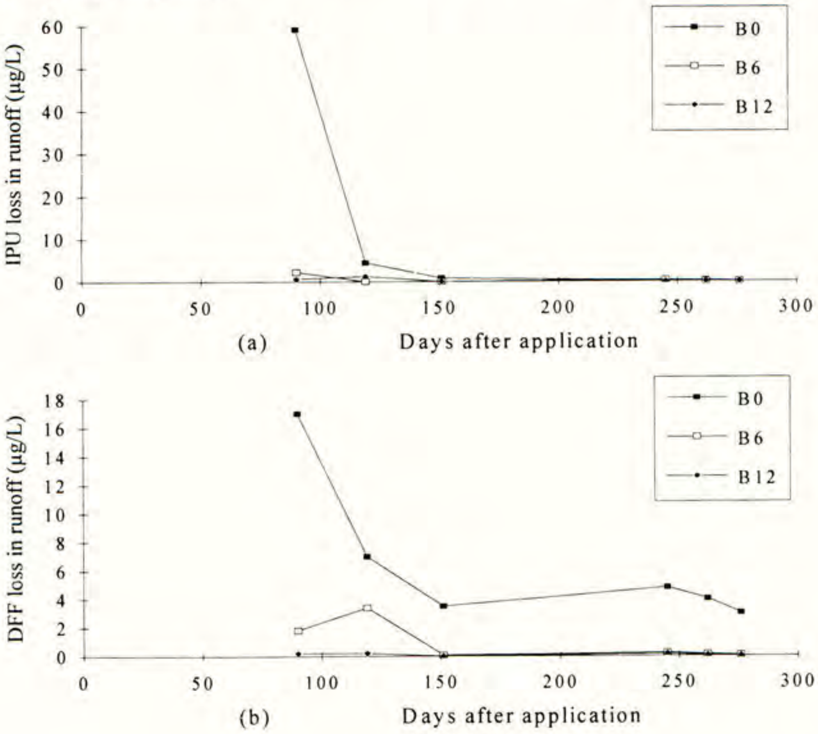
* : Insufficient sample size for residue determination.

In order to determine grassed buffer strips effectiveness, we made the assumption that the three winter wheat plots B0, B6 and B12 had the same hydrological behaviour.

As expected, solid particle load in runoff was greatly reduced by sedimentation in the grassed buffer strips. In fact, solid particle content in runoff was decreased by 81 and 93 % in the 5.7 m wide grassed buffer strip and by 92 and 99 % in the 11.1 m strip during the 1992/1993 and 1993/1994 cropping periods, respectively (Table 4).

Runoff generated by the wheat plots was approximately 0.3 and 0.6 % of the total rainfall received during the 1992/1993 and 1993/1994 cropping periods, respectively. Runoff volumes were reduced by 8 and 88 % in the 5.7 m wide grassed buffer strip and by 37 and 92 % in the 11.1 m strip during the same cropping periods, respectively (Table 4).

Figure 3. Concentration of IPU (a) and DFF (b) in runoff from wheat plots B0, B6 and B12, during the 1992/1993 cropping period at "La Jaillière" research farm, France.



IPU residues exported from wheat plots in runoff were approximately 0.006 % of total amount applied during the 1992/1993 cropping period. The 5.7 and 11.1 m wide grassed buffer strips removed, respectively, 97 and 98 % of IPU lost from the plots in runoff during the same period (Table 4). DFF losses from wheat plots in runoff were approximately 0.03 % of total amount applied during the two periods. Of the total DFF lost from the plots in runoff, 90 and 99 % were removed, respectively, in the 5.7 and 11.1 m wide grassed buffer strips during the 1992/1993 cropping period (Table 4). During the 1993/1994 cropping period, the 5.7 and 11.1 m strips removed more than 99 % of IPU and DFF lost from the plots in runoff. Therefore, small amounts of IPU and DFF moved from the treated wheat plots in the grassed buffer strips and only traces were transported from the grassed buffer strips to surface water.

IPU losses from the plots in the runoff liquid phase were approximately 0.01 % of total amount applied during the 1992/1993 cropping period. The 5.7 m wide grassed buffer strip removed 98 % of IPU lost from the plots in the runoff liquid phase during the same period (Table 5). DFF losses from the plots in the runoff liquid phase were approximately 0.004 % of total amount applied during the 1992/1993 cropping period. In the same time, the 5.7 m wide grassed buffer strip removed 90 % of total DFF lost from the plots in the runoff liquid phase (Table 5).

Table 4. Runoff, solid particles and herbicide residues movement from wheat plots through the grassed buffer strips.

Cropping period	1992/1993		1993/1994	
Runoff	Volume (L)	% of B0	Volume (L)	% of B0
Effluent from B0	85.8		198	
Effluent from B6	78.8	92	23	12
Effluent from B12	53.8	63	16	8
Water retention in the:				
5.7 m grassed buffer strip (B6)	7	8	175	88
11.1 m grassed buffer strip (B12)	32	37	182	92
Solid particles	g	% of B0	g	% of B0
From B0	166.6		422	
From B6	31.9	19	30	7
From B12	13.4	8	6	1
Solid particles retention in the:				
5.7 m grassed buffer strip (B6)	134.7	81	392	93
11.1 m grassed buffer strip (B12)	153.2	92	416	99
IPU in runoff (1992/1993)		g/ha	% applied	% of B0
From B0		0.096	0.0064	
From B6		0.003	0.0002	3
From B12		0.0014	0.000097	1.5
Total retention in 5.7 m grassed buffer strip (B6)		0.093	0.0062	97
Total retention in 11.1 m grassed buffer strip (B12)		0.0946	0.0063	98
DFF in runoff (1992/1993)		g/ha	% applied	% of B0
From B0		0.05	0.027	
From B6		0.005	0.0027	10
From B12		0.00035	0.00019	0.7
Total retention in 5.7 m grassed buffer strip (B6)		0.045	0.024	90
Total retention in 11.1 m grassed buffer strip (B12)		0.0496	0.0268	99

In the 5.7 m wide grassed buffer strip, 8 and 88 % of retention of herbicides were attributed to infiltration during the 1992/1993 and 1993/1994 cropping periods, respectively. But infiltration in the grassed buffer strip was not responsible for the large reductions in herbicide concentrations in the runoff liquid phase. Sorption onto organic matter and vegetation probably occured during runoff filtration through the grassed buffer strips.

Very small amounts of IPU were lost from wheat plots in the runoff solid phase during the first cropping period and only traces moved from the grassed buffer strips (Table 5). DFF losses from wheat plots in the runoff solid phase were approximately 0.006 % of total amount applied during the 1992/1993 cropping period. The amount lost in the runoff solid phase was consistent with the expected pesticide behaviour because, unlike IPU, this herbicide is strongly adsorbed onto soil. The 5.7 m wide grassed buffer strip removed 96 % of DFF lost from the plots in the runoff solid phase during the same period. In the grassed buffer strip, 81 % of retention of DFF was attributed to sedimentation. The difference between 96 and 81 %, may be caused by approximations in calculations and by exchanges which may occur between runoff liquid and solid phases during runoff filtration through the grassed buffer strips (Table 5).

Table 5. Herbicide residues movement in runoff liquid and solid phases from wheat plots through the grassed buffer strips (1992/1993 cropping period).

Runoff liquid phase	IPU			DFF		
	g/ha	%applied	% of B0	g/ha	%applied	% of B0
From B0	0.173	0.011		$7.2\ 10^{-3}$	0.004	
From B6	$2.4\ 10^{-3}$	0.00016	1.4	$8\ 10^{-4}$	0.00043	11
From B12	$7.7\ 10^{-4}$	0.00005	0.46	$4.1\ 10^{-4}$	0.00022	5.6
Total retention in:						
5.7 m strip (B6)	0.171	0.0108	98	$6.4\ 10^{-3}$	0.0036	90
11.1 m strip (B12)	0.172	0.0109	99	$6.8\ 10^{-3}$	0.0038	94
% of retention attributed to infiltration	8(B6),37(B12)			8(B6),37(B12)		
% of retention attributed to sorption	90(B6),62(B12)			82(B6),57(B12)		
Runoff solid phase	**IPU**			**DFF**		
	g/ha	%applied	% of B0	g/ha	%applied	% of B0
From B0	$9\ 10^{-4}$	0.00006		$10.4\ 10^{-3}$	0.0056	
From B6	$4\ 10^{-5}$	0.0000027	4.5	$3.2\ 10^{-4}$	0.00017	3
From B12	$2\ 10^{-5}$	0.0000014	2.3	$2.7\ 10^{-5}$	0.0000018	0.03
Total retention in:						
5.7 m strip (B6)	$8.6\ 10^{-4}$	0.000057	95	$10.1\ 10^{-3}$	0.0054	96
11.1 m strip (B12)	$8.8\ 10^{-4}$	0.000059	97	$10.37\ 10^{-3}$	0.00559	99.9
% of retention attributed to sedimentation	81(B6),92(B12)			81(B6),92(B12)		

Due to the lack of several runoff analysis results (Table 3) and the low runoff rates observed in this study, caution should be exercized in considering the effectiveness of the grassed buffer strips in restricting herbicide transfer in runoff liquid and solid phases. More comprehensive results are necessary to evaluate the performance of grassed buffer strips in various hydrological conditions. To better control the runoff generation, a rainfall simulator will be used in the future. Grassed buffer strips relative performances in conditions of intense runoff will be estimated for both herbicides.

CONCLUSION

Although it requires more intensive work in analytical method development, residue monitoring in runoff solid and liquid phases for two chemicals with a different environmental behaviour has produced valuable information with respect to the efficacy of grassed buffer strips. In fact, the preliminary study showed that grassed buffer strips were efficient in decreasing IPU and DFF contents in runoff. Grassed buffer strips proved to be efficient in removing water soluble pesticides from runoff and sorption onto organic matter appeared to be important in restricting herbicide transfer in runoff liquid phase. Due to the low runoff rates observed under the experimental conditions, a rainfall simulator will be used for the next cropping period to generate a larger range of rates.

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MANAGEMENT PRACTICES TO REDUCE PESTICIDE MOVEMENT TO WATER.

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ABSTRACT

Pesticide movement to water, both drinking and non-drinking sources, causes real public concern. However, what is the real situation; at what levels is this pollution; who is causing it and what steps are farmers taking to ensure that where they use pesticides their environmental impact is kept to a minimum? Clearly farmers see any pesticides that do reach water as a waste of resources and carefully planned management can reduce this risk. Integrated Crop Management (ICM) is a system of farming that can help to address the practical processes to minimise the use of agrochemicals and thus reduce their impact on the water resources. Good agricultural practices, the LEAF Environmental Audit, record keeping and a well defined management system, all backed up by research and development and a regular flow of information can play an active role in reducing the risk of pesticide movement to water.

INTRODUCTION

The EC limit for pesticide levels in drinking water is 0.1 μg/l, and treatment to reduce pesticide concentration in water is expensive (OFWAT, 1993). The National Rivers Authority (NRA) do not see farmers as the main problem for causing contamination, and the water companies bring the same message. However, that does not mean we should be complacent about potential risks that may arise on account of pesticides in water. Three years ago the water authorities launched a campaign with the British Agrochemicals Association (BAA), to encourage Local Authorities to be more vigilant in their use of pesticides. The campaign was a success and the percentage of incidents of pesticides in water above compliance, were shown to be falling dramatically (figure 1). This is a very encouraging sign. These pesticides are removed from drinking water sources by activated carbon filters which is one of the principal costs for the water service companies. These filters are also used for improving taste and the odour of water, but if the concentration of pesticides does increase the running costs for regenerating the carbon filter also increases. So, the farming industry has their part to play by adopting the best agricultural practice.

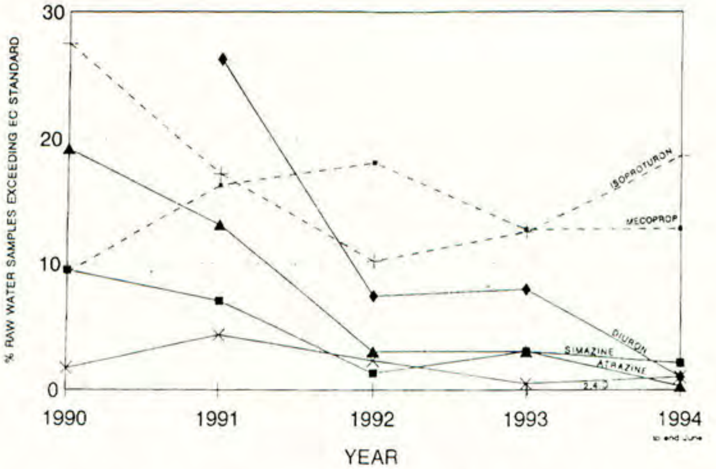

Figure 1. Number of samples exceeding EC Standards in Severn Trent Raw Surface Waters.

(Source: Severn Trent Water)

This is where the LEAF (Linking Environment And Farming) project fits in. It is through demonstrating and promoting Integrated Crop Management (ICM) that we are encouraging systems that can reduce the potential incidence of pollution and reduce the associated risks to both health and the environment.

ICM is a mixture of the best of traditional methods with the best of modern technology resulting in a system of farming that is economically viable, environmentally responsible and attractive to the customer. Within an integrated approach, attention to detail is of upmost importance and an area where pollution risks can be reduced. Not only are there financial benefits to be gained through reducing wastage by being more accurate and targeted with application rates and amounts, but there are also environmental benefits through minimising the long term liability for pollution and opportunities to reduce public pressure.

LEAF is addressing this by encouraging the uptake of ICM. This is particularly illustrated by the LEAF Environmental Audit (LEAF, 1994). A self assessment approach, this documentation questions farmers about all aspects of their farm practices. It includes areas such as the choice of pesticides, threshold levels, accuracy of application, correct and up to date record keeping, calibration of machinery, training of staff and safe and appropriate disposal of pesticides and containers. It is through the integrated approach that a full understanding of disease minimisation, for example, by varietal selection, sound rotations and appropriately planned cultivations can contribute to a reduction in pesticide use. All this conforms with the requirements of the Control Of Substances Hazardous to Health (COSHH) 1994 regulations and the essential 'due diligence' clause of the Food Safety Act 1990. The audit becomes both the farm conscience and the sensible trigger mechanism for areas that require investment in both financial and management terms.

However, it is essential that we do not lose sight of the practicality of these systems. We must ensure that good common sense and good housekeeping lead to management practices which minimise the movement of pesticides. Technology is becoming increasingly refined, for example pesticides are being developed which are more environmentally benign, and we are able to assess their impact on the environment with increasing precision. We are able to predict threshold levels more accurately through computer models and machinery applications are becoming more targeted.

THE SITUATION AS IT STANDS

The Drinking Water Inspectorate (DWI) in England and Wales and the Scottish Office annually reports on the quality of drinking water, including the monitoring of pesticides. In 1993 in England and Wales, 72.1% of Water Supply Zones complied with the Prescribed Concentration or Value (PCV) of 0.1 μg/l for individual pesticides and in most cases the PCV was much lower (HMSO, 1994) (NRA, 1994).

About 400 pesticides are approved for use in the UK, and some of these have the potential to reach drinking water sources. Research funded by the Department of the Environment has investigated the uses and occurrences of pesticides in a river catchment used as a source of drinking water (Cable *et al,* 1994). It found that both agricultural and non-agricultural uses of pesticides contributed to the contamination of drinking water. Nevertheless, the 1993 annual report for the Drinking Water Inspectorate showed that standards for drinking water quality, as far as pesticides were concerned, were markedly improved. Of the 1 006 458 tests made for individual pesticides in 1993, 30% fewer breached the standard of 0.1 parts per billion compared to the 1992 tests.

Compliance with the EU pesticide standard is a significant component of the total increase in water and sewerage bills predicted for England and Wales in the next ten years (an estimated average household increase of up to £77 per year). It is thus important that each sector that does contribute to water contamination takes on board positive steps to deal with the situation. It must be remembered that 0.1 parts per billion is the equivalent to one second in 320 years. Alongside this, industry's ability to detect this is becoming more effective all the time.

ADDRESSING THE PROBLEM

The question arises whether it would be better to restrict pesticide use to ensure that pollution does not arise, on the basis that prevention is better that cure. Indeed, some countries operate protection zones for sources of drinking water, so that pesticide use in the zone is restricted or event prohibited. However, it has been shown that voluntary agri-environmental schemes have achieved the widest compliance and the encouragement of good agricultural practice and market forces will be the most appropriate in the UK.

The first step in reducing any potential risk from pesticides is the precise application of least harmful chemicals, minimising emission of pesticides and correct targeting.sound and sensible application of them. This step is relatively easy to take and the benefits for the environment are considerable.

Coupled with this, there is also a communication role to play to show how the agricultural industry is addressing the situation. We cannot alleviate the 'not in my back yard' attitude, but we can make people recognise that there is only a certain amount that technology can do in this area, and that the risks are minimal.

OVERVIEW OF AN EFFECTIVE APPROACH

LEAF's approach to encourage farmers to adopt ICM has been very much through demonstration and the development and dissemination of information. To date there are 17 LEAF Demonstration Farms which have been chosen against specific criteria. These farms comply with the Guidelines for LEAF Farms, carry out the LEAF Environmental Audit and host visits to a wide range of groups, including farmers, industry representatives, MPs, MEPs and opinion formers and concern groups. It is these visits that act as a useful information exchange and talking point to address public concerns and develop practical solutions.

The LEAF Environmental Audit is a management tool to address the concerns of the consumer through good agronomic and environmental practices. It offers a unique way for farmers to assess their farming operations against the principles of ICM - a whole farm policy which draws together the best of traditional methods with appropriate modern technology.

The audit is a practical, non-prescriptive way for farmers to look objectively at their business, assess strengths and weaknesses and identify cost saving operations and capital expenditure to minimise long term risk; it shows how the integration of the environment with food production can be profitable as well as desirable. The audit is a series of self assessment forms and provides a convenient and structured way which, when carried out on an annual basis, will monitor progress and help in determining priorities on the farm. It addresses 8 principal areas.

These are:

- Landscape features;
- Wildlife and habitats;
- Management of the soil;
- Crop protection;
- Conservation of energy;
- Pollution control;
- Organisation and planning;
- Animal welfare.

As well as taking stock and giving credit to existing practices and identifying areas for future improvement, there are many long term benefits which can result from carrying out the audit.

These include:

- improving economic performance;
- ensuring environmental protection;
- enhancing environmental performance;
- meeting legislative requirements;
- meeting insurance requirements;
- addressing public concerns;
- gaining a marketing edge;
- ordering of capital investment.

The starting point of the audit is the management policy statement which sets out the goals for the whole farm. From there the series of self assessment sheets assists farmers in looking at their farm objectively. Many of the questions are based on standard good agricultural practice but with the rapid advancement of technology there are other areas that can assist farmers in addressing and targeting situations where greater attention to detail is required. The audit makes people think and with increasing pressure on farmers to address both environmental and economic criteria it is a useful management aid.

For example, when the use of pesticides is inevitable, it questions methods that can be developed and adopted in order to ensure pesticides are used rationally. These include more exact timing of applications eg. crop walking, crop growth stage observation, pest, weed and disease identification; more exact placement of pesticides eg. inter-row and spot applications and more exact dose rate and application systems, eg. low dosages, improved application techniques. Furthermore, there are other practical steps that are being developed such as the inclusion of buffer zones around water courses which can reduce the risk of any surface run-off of pesticides.

KEEPING MY FARM CLEAN

Over the last twenty years, on the chalk downland farm in Wiltshire, we have developed a whole farm approach - very much in line with the Integrated Crop Management philosophy. Indeed, the farm principles set as the initial management policy for the farm include:

- promotion of 'environmentally friendly' farming systems which must be profitable to provide a secure future for the farm and those who live and work on it. These systems must in themselves maintain and enhance the land, its flora and fauna;

- running an integrated and diverse cropping system which is market led;

- 'adding value' wherever possible to farm products;

- producing high quality commodities.

THE MANAGEMENT

The staff is one of the most important assets on the farm and it is in situations where they are well trained and motivated by opportunity for responsibility that they can best contribute to the farm.

It is the sprayer operator who has grasped the full understanding of his or her responsibilities, that can recognise the importance of accurate applications, for example not spraying the hedgerow bottoms or ensuring that the weather conditions are suitable. Accurate local weather forecasting is still one of the biggest single problems.

With detailed records there is the opportunity to look at historic information, monitor the effectiveness of the system and address the "due diligence" clause. All these are areas that are becoming increasingly important in order to reach the market requirements. We already see the UKASTA passport system for cereals in store and soon records may be required for the whole growing process.

Then there is the advice. The agronomist has an important role on the farm and regular crop walking is an essential part in the decision making process. Locally based research such as that carried out by the Arable Research Centres may be particularly valuable for certain decisions eg. varietal choice. Historically research has been geared towards maximum yields and only now is a more integrated approach linking together the varietal choice, the crop nutrient requirement and the pesticide application being used. The satellite systems used to target localised fertiliser applications are already in use and will soon be available for spraying allowing even greater precision.

The buying policy is more than often linked in with agronomy advice and many companies are gearing their sales towards offering a service rather than a maximum sell. Furthermore we link this to choice of chemical looking at both economic and environmental criteria. Last summer I was particularly concerned about the pesticide applications for the control of orange wheat blossom midge. Having put a lot of effort into enhancing the biodiversity on the farm, one application of some chemicals can wipe out something that will take at least five years to repair. This is where MAFF has a part to play in research providing an early warning of pest infestations of national importance.

The Food and Environment Protection Act (FEPA) 1985 and Control of Substances Hazardous to Health (COSHH) 1994 were both appropriately timed in that they ensured that risks were not taken in the field and that there was a better knowledge of the risks actually associated with the pesticide being used. As a result we have addressed the storage situation and have much tighter rules on stock control with purchase on the basis of use or return. Computer systems give us an up to date record of what is in the store. Data entry can of course be the problem and is being addressed by the RDS transfer system.

On a practical scale, the disposal of empty containers is not an easy one to address but we have tackled it by the use of a very effective bottle washer on the sprayer hopper. However, there is much scope for development in this area, with for example, the use of recyclable containers or more accredited disposal sites and more easily washed containers.

PLANNING

This is to perhaps the most important part. Knowing the cropping system, the field size, the area to be sprayed enables proper calibration of the sprayer, with due regard to droplet size, the target and the weather conditions, both forecasted and previous. Mixing up of the right amounts, based on good advice, on our sprayer is through the induction hopper and with liquids this is a clean process, with powders less so.

Low volume applications using low drift nozzles allow reduced water volumes and if there is any excess, tank washings can take place in the field. The ultimate system here is the carbon water filters.

Reduced rates should be considered and used where appropriate. Integrated Farming research projects provide an interesting opportunity to see first hand the ICM results which can be used to fine tune our own applications.

IN THE LONG TERM

In the future there is much scope for the satellite location, radar and spot treatment developments. By mapping the weed populations on the combine, monitoring yield (to see if there is a problem) and targeting application to specific areas in the field, the technology in the future looks set to ensure that there is minimal input.

There are several additional areas in which there is still room for improvement:

- a more efficient mixing container system;
- spot spraying;
- better plastic disposal;
- the development of direct injection systems;
- the development of better weather forecasting techniques;
- a market place that enforces these standards through compliance and not legislation.

This relatively high technology route may well be the way forward in the world market of tomorrow, giving us low unit cost as well as high probity of production.

CONCLUSION

The growth of environmental management systems and environmental audits has been a valuable discipline for industry, forcing companies to consider the environmental impact of the whole of their operations, identify options to reduce this, and set in place systems and targets to implement and monitor improvement. Indeed, the LEAF Environmental Audit is a step towards introducing such management aids in agriculture to ensure that farmers can reduce pesticide movement to water as effectively as possible. They should also allow us to maximise our climatic and soil advantages, thus allowing us to compete more effectively in world markets.

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