ROTHAMSTED RESEARCH

The Brimstone Farm Experiment

7: Phase III

Rothamsted Research

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7. PHASE III

7.1 BACKGROUND

The results for pesticide and nitrate leaching in earlier phases of the experiment suggested that both might be influenced beneficially by restricting drainflow. By preventing rapid flow through the mole and pipe drainage system, degradation and sorption of pesticides should be increased by prolonged contact with the soil. In addition, raising the water table in the plot should cause the clay soil to swell, thereby closing the desiccation cracks and other macropores responsible for rapid transfer of pesticides to the drains. It should also decrease losses of nitrate by encouraging denitrification and possibly by limiting the rate of mineralization of organic matter. Decreasing the rate of water flow through macropores and mole drains should also limit losses of phosphorus in particulate material.

7.1.2 Phase III objectives

7.1.2.1 To investigate the effects of temporary restriction of drainflow in autumn on leaching of pesticides, nitrate, nitrite and phosphorus.

7.1.2.2 To assess the effect of decreased application rates on leaching and degradation of pesticide residues.

7.1.2.3 To study the effect of late summer cover crops, sown before harvest of the preceding main crop, on turnover of organic matter and leaching of nitrate.

7.1.2.4 To assess the effect of a reduced P fertilizer rate on P losses.

7.1.2.5 To study the effects of a finer surface tilth and subsoil (30-45 cm depth) loosening on macropore water movement and leaching of pesticides, nitrate and phosphorus.

7.1.2.6 To utilize the various databases in parallel collaborative modelling exercises, to develop models which accurately predict the losses of nutrients and pesticides from cracking clay soils.

7.2 SITE CHANGES FOR PHASE III

In winter 1992/93 rotatable U-bends (Fig. 18) were installed in the pipework leading from the main collector drain to the weir box and flow recorder on twelve of the drained plots. The number of programmable EPIC water samplers was increased to 17 at the same time, and Plots 5, 6, 10, 19 and 20 were re-moled to maintain effective drainage systems. Plot 14 remained undrained to provide a control linked to the previous phases of the experiment.

The EPIC samplers were linked to an upgraded data logging and telemetry system, allowing flow proportional water sampling, which takes samples more frequently as flow

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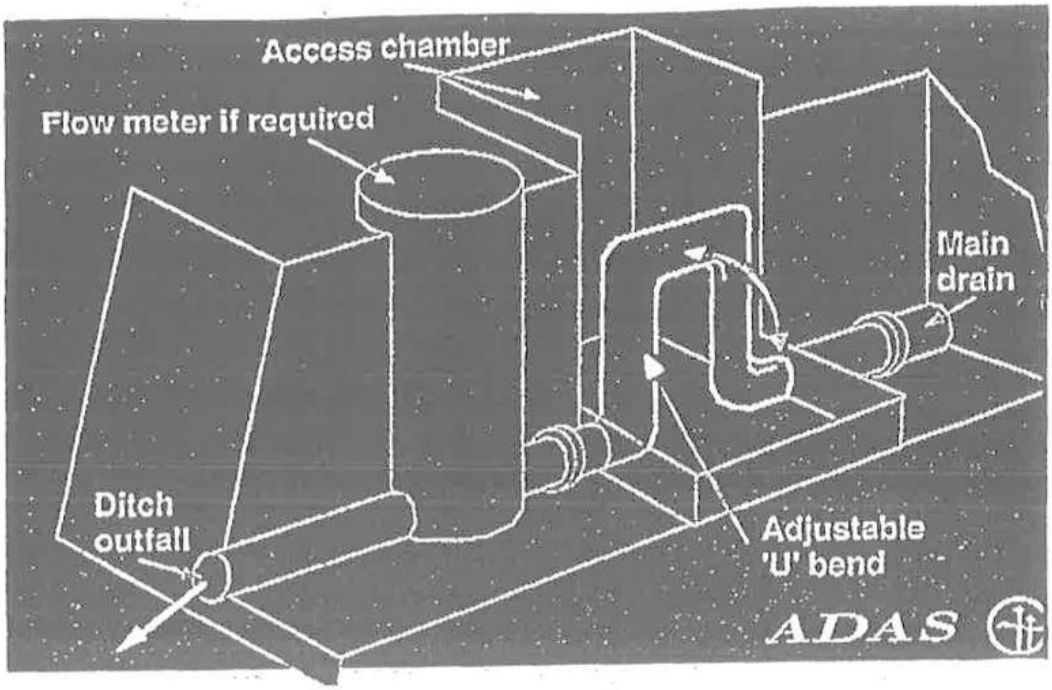

Fig. 18A. Drainage valve installation in upright position - drainage restricted.

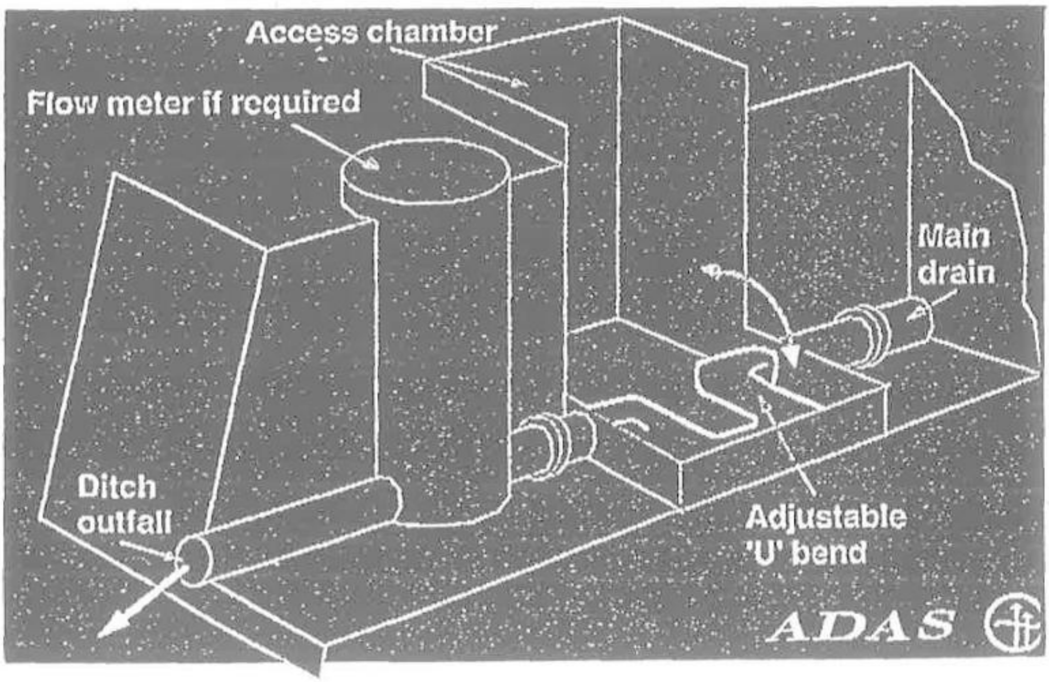

Fig. 18B. Drainage valve in lowered position - free drainage.

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increases. Sample size is 1 litre, and the programme provides for an automatic flushing routine before sampling. A flagging system is used to initiate sampling remotely from ADAS Cambridge at the start of major autumn/winter flow events. Alternatively daily sampling can be initiated remotely until 16 bottles are filled out of the 24 available on each EPIC; thereafter samples are taken every 48 hr. A manual override is also available, for example in the event of a system failure.

7.3 SITE UNIFORMITY

The final crop of Phase II (unfertilized spring oats following a winter fallow) was chosen to assist removal of the variable amounts of pesticide and nitrate in the soil following the different treatments of Phase II. Water samples for nitrate analysis were taken throughout the winter of 1992/93 and samples for pesticide analysis in late March and early April 1993.

The peak nitrate concentrations for runoff events in the autumn and early winter were much greater on some plots than on others (e.g. 30-120 mg NO_3-N/l in September and October). However, the variation decreased over the winter, and in a runoff event in early April the range was only 26-39 mg/l; the N loadings for April for the different plots ranged from 0.07 to 1.63 kg N/ha, whereas those for the early winter (August - January incl.) were much more variable (1.84-14.55 kg N/ha). The pesticide concentrations in March/April 1993 were also uniformly small; isoproturon (last applied April 1992) ranged from < 0.1 to 0.3 μg/l, and pendimethalin (not applied in the previous 5 years (Table 13), and possibly derived by spray drift from adjacent fields) ranged from < 0.1 to 0.4 μg/l. These data suggested that the site had almost returned to a uniform condition by spring 1993. Nevertheless, the growth of spring oats in 1993 was very variable, though this would have further decreased the variability of soil mineral N.

7.4 CROPPING IN PHASE III

Winter wheat has been grown in every year of Phase III, except that winter oats were grown as a break crop in 1995/96 to avoid disease problems. This provided an opportunity to test a wider range of pesticides.

7.5 EFFECTS OF DRAINFLOW RESTRICTORS

7.5.1 Water table

Brief tests of the U-bend restrictors or valves in January 1993 showed that they are effective at ponding water in the plots, though there was considerable variation between plots in depth to the raised water table. A further test between April 2 and 22, 1993 again showed some variation in depth to the water table and in persistence of the raised water table level after a dry period of weather began in mid-April. The most problematic plots were those known to be affected by a lystric periglacial slip surface in the deep subsoil, which probably allowed loss of water beneath the peripheral polythene barriers and gravel-filled trenches containing the plot drains.

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7.5.2 Pesticide losses

In the winter of 1993/94 the restrictors were raised on November 3 on four plots: 1 (gravel-filled moles), 6 and 10 (conventional moles) and 7 (close-spaced perforated plastic pipes). The remaining 8 plots fitted with U-bends had unrestricted drainflow, and were divided between full-rate (label instructions) applications of the pesticides isoproturon and pendimethalin (Plots 15 - gravel-filled moles, 5 and 20 - conventional moles and 9 - plastic pipes) and half rate applications (Plots 4, 16, 18 and 19 - all conventional moles). The pesticides were applied on November 2.

The first major flow event on November 13/14 produced flow from all plots, though this was delayed on the four plots with restricted drainflow by a maximum of 4 hr compared with the plots with unrestricted drainflow. Subsequent rainfall and flow events occurred on December 7-8, December 18-19 and January 5.

The peak concentrations of isoproturon in November 1993 were typically 200-500 μg/l, several times those found in drainflow in Phase II. Although drainflow was held up for no more than 4 hr in the first event on the plots with restricted drainflow, the isoproturon (full rate) concentrations in this event were decreased from a mean of 465 μg/l on plots without restriction to a mean of 190 μg/l on plots with restriction. In subsequent drainflow events the mean concentrations of isoproturon decreased progressively to 130 μg/l (unrestricted) and 115 μg/l (restricted). Over the four main events in 1993/94 total losses of isoproturon were approximately 20 g from unrestricted plots, 15 g from restricted plots (4% and 3% of the amounts applied, respectively).

Application of isoproturon at half rate (unrestricted drainflow) decreased the concentrations for the same flow events to 140-30 μg/l, i.e. there was a greater than 50% decrease in the drainflow concentrations. In the cultivated layer flow of Plot 14 the peak concentration of isoproturon was nearly four times greater than in the drainflow (unrestricted) in the first event, but it decreased very rapidly to $<$ 100 μm/l in subsequent events.

Concentrations of pendimethalin were much less than for isoproturon under all conditions. Losses from the half rate treatment were especially small. Laboratory studies showed that pendimethalin is quite stable in the Brimstone soil; more than half of an application can be recovered after 32 weeks for incubations at 15°C or less. However, the sorption coefficient (K_d) for pendimethalin (87.7 l/kg) in Brimstone topsoil is much greater than that of isoproturon (2.9 l/kg), and this may account for the much lower concentrations in the drainwaters.

In the winter of 1994/95 the concentrations and loadings of isoproturon were much less than in 1993/94, and were similar to those measured in Phase II. Peak concentrations in the first drainflows (in early December) were 53 μg/l on unrestricted plots and 36 μg/l with restricted drainage. Restriction decreased the winter loading by 33%, from 1.2 g to 0.8 g.

In 1995/96, when oats were grown, isoproturon was applied at 10% rate to minimize potential damage to the crop. Drainflow began much later than in 1994/95, and isoproturon was consistently detected in only the first drainflow event (19-23 December). Peak concentrations adjusted to account for the reduced application rate were 100 μg/l

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on unrestricted plots, 11 μg/l on restricted, and loadings were 0.04 g (unrestricted) and 0.03 g (restricted), equivalent to < 0.1% of applied.

Over the three winters of Phase III the losses of isoproturon (g/ha), standardised to unit volume of drainflow (100 mm) to eliminate the effects of variable drainflow between plots and seasons, were decreased by 19% by drainflow restriction. In 1994/95 and 1995/96 triasulfuron was applied as the second target pesticide instead of pendimethalin, and the losses of these two over the three winters (again expressed per unit volume of drainflow) were 20% less with restricted drainflow than with unrestricted.

7.5.3 Nitrate

In the three winters of Phase III drainflow restriction has decreased mean annual nitrate concentrations by 1-21%, mean nitrate loadings by 7-69% and losses per unit volume of drainflow by 11-27%. The smallest decreases were in 1995/96 when the rainfall was close to the long term mean but the soil was often drier than usual following the very dry summer of 1995 and several dry periods during the winter. As drainflow restriction probably decreases nitrate by increasing the period of winter waterlogging and thus enhancing denitrification, the weak effect in 1995/96 can be attributed to the unusually dry soil conditions. Evidence for increased denitrification with restricted drainage is provided by increases with restriction in nitrite concentrations (26-54%), loadings (44-143%) and losses per unit volume of drainflow (9%). However the actual as opposed to percentage increases in nitrite loadings (usually in the range 10-22 g/ha/yr) are much too small to account for the actual decreases in nitrate loadings (5-11 kg/ha/yr).

Figure 19 shows the overall effect of drainflow restriction on nitrate loadings per unit volume of drainflow for the three year period 1993/94 to 1995/96. The decrease attributable to restriction is 14%. Figure 20 shows that drainflow restriction has not affected crop yields in any year of Phase III.

7.5.4 Phosphorus

Phosphorus losses in Phase III are determined as either soluble (molybdate reactive) P or total P (i.e. including particulate P). MRP has been measured in all three years of Phase III, but to date TP has been determined only in samples taken in 1994/95. Both are assessed in drainflow and cultivated layer flow, but at present MRP and TP data are available only for 1994/95.

Over the three winters of Phase III (1993/94 to 1995/96) drainflow restriction has decreased mean annual MRP concentrations by 25-73%, annual loads of MRP by 25-50% and annual losses per unit volume of drainflow by 24-52%. Mean concentrations have ranged from 0.003 to 0.158 mg P/l, and annual loads from 0.004 to 0.26 kg/ha/yr. The lowest values were in the winter of 1995/96 when the soil was unusually dry for much of the season. Figure 19 shows the effect of drainflow restriction on MRP losses per unit volume of drainflow averaged over the three years of Phase III. 37

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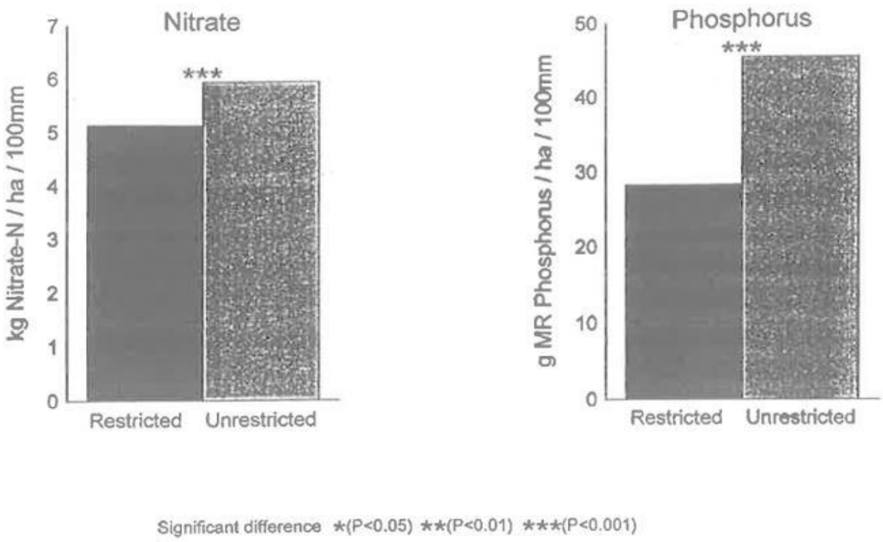

Fig. 19. Effect of drainflow restriction on losses of nitrate and soluble (molybdate reactive) phosphorus at Brimstone Farm 1993/94 - 1995/96.

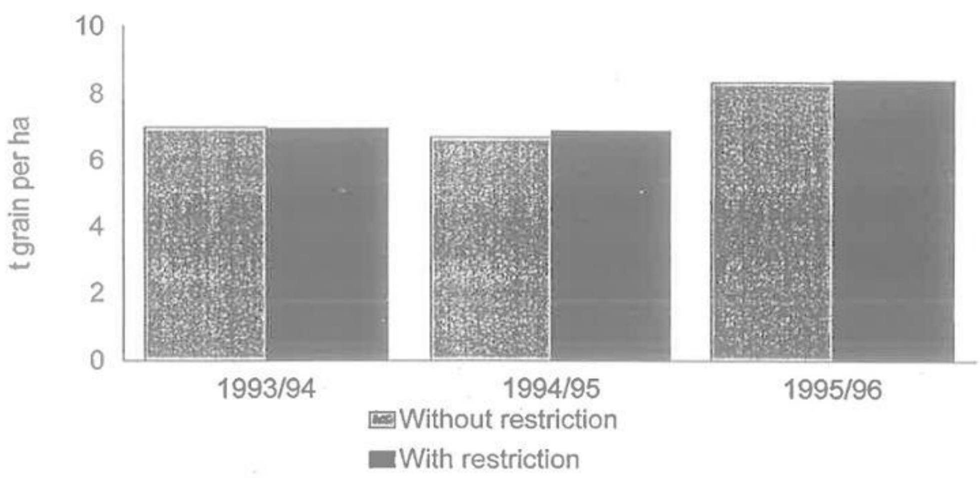

Fig. 20. Effect of drainflow restriction on crop yields at Brimstone Farm, 1993/94 - 1995/96.

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In 1994/95 drainflow restriction decreased mean annual TP concentration by 26% (from 0.382 to 0.284 mg P/l), annual TP loading by 26% (from 0.503 to 0.370 kg P/ha) and TP loss per unit volume of drainflow by 29%. In the same year the concentrations of MRP were increased in cultivated layer flow by 63% and the loading of MRP was increased by 323%. Similarly the mean concentration of TP in cultivated layer flow was increased by 153% (from 0.980 to 2.483 mg P/l) and the TP loading was increased by 880% (from 0.048 to 0.470 kg P/ha. The increased loading was largely attributable to increased cultivated layer flow on the plots with restricted drainage, but even after allowing for this by standardising to unit volume of flow, the TP loss was 124% greater with drainage restriction. So, although drainage restriction decreases MRP and TP losses in drainflow, it can increase the volume of cultivated layer flow and also increase the concentrations of MRP and TP in it, so that loadings of MRP and TP in cultivated layer flow are greatly increased.

7.5.5 Effect of P fertilizer rate on P losses

Because of wet soil conditions, the first application of P fertilizer (at rates equivalent to 32 and 16 kg P/ha) in Phase III was not made until early December 1994, shortly before the first winter drainflow event. For approximately four weeks the concentrations of MRP in drainflow were greatly increased, but by early January they had returned to the levels measured during other periods. The effect was much greater at the higher P application rate, with the result that over the winter of 1994/95 as a whole the mean annual MRP concentration in drainflow was 290% greater at the higher application rate, and the annual MRP loading was 73% greater. However there was almost no effect on TP, the concentrations of which were slightly less in drainflow from the plots given the higher P fertilizer rate, and the loadings were increased by only 3%. However, drainage restriction was quite effective in decreasing the MRP concentration in drainflow from the high P plots; it decreased the mean annual MRP concentration by 82% on the high P plots, but by only 16% on the low P plots. The results for 1994/95 show that P fertilizer applications should be made in spring, summer or autumn to a dry soil, and that applications in excess of crop requirements do increase P losses to surface waters.

In 1995 the P fertilizer was applied at the same two rates in late summer between harvest and ploughing. It had no effect on concentrations in the first drainflows in late December, but over the 1995/96 winter as a whole MRP concentrations in drainflow were 70% greater and MRP loadings 73% greater at the higher P rate.

7.6 LATE SUMMER COVER CROPS

Forage rape was broadcast on four plots on 15 August 1995 after harvest of winter wheat and shallow power harrowing to prevent the seed falling down the wide desiccation cracks that had formed during the dry summer. Germination and growth were very slow in the dry conditions, and together with volunteer wheat plants gave total dry weights on September 27 (just before autumn ploughing) of only 105-157 kg/ha. The amounts of N taken up were very small (4-6 kg/ha). In the winter of 1995/96 the mean concentration of nitrate in drainwater from the plots that had grown the cover crop was 4% less than where no cover crop was sown; the daily loading of nitrate was 2% greater; the loss per unit volume of drainflow was 11% more. The yield of oats at harvest 1996 was 10% greater where cover crops had been grown and the N uptake over the season was 11% greater. These results suggest that summer cover crops have little or no effect on nitrate leaching in the subsequent winter, but may increase the yield of subsequent winter crops slightly. However,

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a second summer cover crop (again forage rape) was planted in 1996 and grew better; its effects are still being assessed.

7.7 FINE TILTH

This was tested in 1994/95, but was difficult to create because the soil was too wet, and numerous passes with a power harrow were required. Its effect on nitrate losses was small; mean annual nitrate concentration was decreased by 15%, loading by 23% and loading per unit volume of drainflow by 8%. The effect on nitrite losses was even less.

However, fine tilth decreased MRP concentrations by 74%, MRP loading by 24% and MRP loss per unit volume of drainflow by 29%, presumably because the slower water flow allowed more time for sorption of soluble P on soil mineral particles. In contrast, TP was increased; mean concentration was increased by 37%, loading by 81% and loss per unit volume of drainflow by 57%. The increase in TP can probably be attributed to the large energy input in repeated harrowing, which would have dispersed fine soil particles that were subsequently transported to the mole drains during periods of heavy rain and more rapid, turbulent water flow through the soil profile. Probably for the same reason, the loss of TP in cultivated layer flow was also increased by the fine tilth treatment: mean annual TP concentration was increased by 330%, annual TP loading by 1044% and loss per unit volume of drainflow by 289%.

7.8 SUBSOIL LOOSENING

This was tested on three plots (8, 11 and 12) in 1995/96. It increased mean annual concentration of nitrate by 56%, loading by 44% and loss per unit volume of drainflow by 50%. It also increased nitrite by 42%, 38% and 71% for the same three factors. The slower water movement through the profile to the mole drains on plots with loosened subsoil probably allowed greater uptake of the nitrate formed during the autumn and winter by mineralisation of organic matter, and may also have created more anaerobic zones for production of nitrite by denitrification, though this was insufficient to compensate for the increased nitrate.

7.9 WIDELY SPACED MOLE DRAINS

A treatment with widely spaced (4 m) mole drains was tested on four plots (4, 16, 18 and 19) in 1995/96 as a simple alternative method of restricting drainflow. However, it had little effect on nitrate losses in drainflow, yet increased nitrite by 45% (mean annual concentration), 38% (loading) and 71% (loss per unit volume of drainflow), probably by slightly increasing sites for denitrification. It also increased MRP losses by 171% (concentration), 43% (loading) and 53% (loss per unit volume of drainflow), especially on plots given the higher rate of P fertilizer (240% concentration, 52% loading, 98% loss per unit volume of drainflow). Therefore it does not seem to be a useful technique for reducing nutrient losses.

7.10 ABSORBENT MATERIALS IN MOLE DRAINS

A carbonaceous material (Jimsorb), which sorbs pesticides more effectively than the Brimstone subsoil, was tested in selected mole drains of two pilot plots in the winter of 1995/96. It proved successful in removing almost all the pesticides from drainwater, but increased the mean annual concentration of nitrate by 40%, the loading of nitrate by 35% and the loss of nitrate per unit

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volume of drainflow by 64%. The increased nitrate losses could have resulted from partial mineralization of the Jimsorb or from increased mineralization of soil organic matter through the greater disturbance of the soil during insertion of the Jimsorb into the mole drain channels.

Although the Jimsorb was softened slightly by immersion in the mole channels over winter, it recovered its hardness and structure in the summer of 1996 and is being retested in 1996/97. Likewise, an ironstone gravel is being tested in 1996/97 for sorption of soluble P from the drains.

7.11 DISCUSSION OF PHASE III RESULTS

Of the various strategies for limiting pesticide and nutrient losses from the Brimstone soil tested in Phase III, the most consistently successful has been drainflow restriction by the use of rotatable u-bends in the collector drains. By raising the watertable in the plot and increasing contact time with the subsoil, this has had a beneficial effect on nitrate, MRP, TP and pesticide losses without adversely affecting crop growth and yield. It has increased denitrification and this is partly reflected in the increased amounts of nitrite in drainage water, though concentrations of nitrite are rarely enough to cause problems with fish stocks in surface waters. The extent to which enhanced denitrification is also increasing emissions of nitrous oxide (a greenhouse gas) to the atmosphere is currently being addressed by a new programme monitoring gaseous emissions from selected Brimstone plots, which began in 1996. A further adverse effect is the increase in cultivated layer flow with drainage restriction and the large increases in MRP and TP losses by this route, though these are usually less in absolute terms than the decreased MRP and TP losses in drainflow. Nevertheless, the enhanced movement of water and pollutants on or just below the surface in winter is a matter of concern, and will be addressed in future work at Brimstone.

The contrasting influence of the natural carbonaceous material Jimsorb on pesticide and nitrate losses, together with the above considerations relating to drainflow restriction, emphasize the need for an holistic approach to diffuse pollution of surface waters by agriculture. Treatments that decrease one pollutant may increase another in the water or cause greater pollution of the atmosphere. The correct balance for sustainable agriculture can only be achieved by carefully integrated studies on a fully instrumented site such as Brimstone Farm.

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