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Hillslope scale surface runoff, sediment and nutrient losses associated with tramline wheelings

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Abstract

Research in the Mitigation of Phosphorus and Sediment (MOPS) project on arable sandy loam and silty clay loam soils on moderate 4° slopes in England has shown that *tramlines* (i.e. the unseeded bought lines used to facilitate spraying operations to combinable crops) can represent the most important pathway for phosphorus and sediment loss from moderately (4-5º) sloping fields under combinable cropping. Detailed monitoring from the first two winters of this project included event-based sampling of surface runoff, suspended and particulate sediment, and dissolved and particulate phosphorus from hillslope segments (each around 300-800 m^2) established in a randomised block design with four replicates of each treatment at each of two sites with lighter and heavier soils.

Research on both sandy and silty clay loam soils across two winters showed that tramline wheelings represented the dominant pathway for surface runoff and transport of sediment, phosphorus and nitrogen from combinable crops on moderate slopes. Results indicated 5.5-15.8% of rainfall lost as runoff, and losses of 0.8-2.9 kg TP/ha and 0.3-4.8 T/ha sediment in tramline treatments, compared to only 0.2-1.7% rainfall lost as runoff, and losses of 0.0-0.2 kg TP/ha and 0.003-0.3 T/ha sediment from treatments without tramlines or those where tramlines had been disrupted. The novel shallow disruption of tramline wheelings using a tine once in the autumn following the autumn spraying operation consistently and dramatically reduced ($P<0.001$) surface runoff and loads of sediment, total nitrogen and total phosphorus down to levels close to those measured in vegetated areas between tramlines. Such effective options for managing tramline wheelings warrant further refinement with a view to incorporating them into spatially-targeted farm-level management planning using national or catchment-based agri-environment policy instruments aimed at reducing diffuse pollution from land to surface water systems.

Keywords: runoff, phosphorus, sediment, tramlines, mitigation

Introduction

This paper addresses the need for practical, affordable, and targeted management of fields with combinable crops to help reduce losses of soil, phosphorus and nitrogen from land to water courses. Inputs of nutrients from agricultural land are a significant contribution to the measured riverine loads in UK rivers (Defra, 2002; Defra, 2006; Environment Agency, 2007) and at European scale (Kronvang *et al.*, 2005). Enrichment of surface waters with sediment, phosphorus (P) and nitrogen (N) is problematic as siltation restricts fish spawning and excess nutrients encourage the development of algal blooms toxic to animals. As a result, reducing sediment, P and N losses from land to water is a priority associated with implementation of the Nitrates Directive, Water Framework Directive (WFD), and Freshwater Fish Directive. Reducing these losses from fields to surface waters benefits farmers as well as the environment by retaining plant nutrients on fields, thereby maintaining soil fertility and limiting the need for fertiliser inputs.

EU Member States have implemented a wide range of agri-environment policies aimed at achieving these policy objectives. In England, the Environmental Stewardship scheme awards points for specific environmentally beneficial activities ranging from maintaining hedgerows to the use of vegetated headlands around field margins. The scheme initially focused on improving biodiversity and limiting the ecological impacts of land management. However, recent attention has turned to how this agri-environment scheme might be modified to incorporate practical and cost-effective management techniques for controlling diffuse pollution to water. The research outlined in this paper explores specific potential pollution mitigation options for reducing surface losses under combinable cropping systems, all of which have the potential to be incorporated into commercial farming practices.

Tramline wheelings are the unseeded bout lines left bare in autumn and used to facilitate spraying operations in combinable cropping systems. Recent research has identified that tramlines can represent an important pathway in the loss of sediment and phosphorus from a silty clay loam soil under arable management on a 7º slope in western England (Silgram, 2004; Silgram *et al.*, 2008). The project reported here extends this work to confirm (i) whether tramline wheelings are important across a broader range of soil textures and on longer slopes and shallower slope angles, and (ii) whether relatively simple tramline management and/or crop residue management can function as effective mitigation techniques suitable for integrating into agri-environment schemes aimed at reducing erosion and loss of sediment and phosphorus from land to surface water systems in order to achieve water quality targets. This work is relevant to a wide variety of stakeholders, including scientists involved in developing and evaluating pollution mitigation options, and government and agency staff concerned with making, implementing and evaluating agri-environment policy measures at farm and catchment scale linked to the EU Water Framework Directive.

Methodology

This paper focuses on the first two years of results from two of the three experimental sites in the Mitigation of Phosphorus and Sediment (MOPS) project. On a uniform 4º slope on a sandy soil at Old Hattons farm in Staffordshire, England with erodable sandy loam soils, unbounded long hillslope segments were established to quantify surface runoff and diffuse pollutant loss. Similar unbounded hillslope segments were established at a second site at Rosemaund in Herefordshire, England, in a slightly wetter area 100 km southwest of the first site on a uniform 5º slope and contrasting silty clay loam soils. Hillslope segments were 3.5 m wide at both sites, and were 270 m long at Hattons and over 100 m long at Rosemaund.

In Year 1 at Hattons, treatments included areas where post-harvest cereal straw residues had either been baled and removed, or had been chopped and incorporated into the soil. Losses from tramline areas and the conventionally planted area between tramline wheelings were monitored separately. The resulting split-plot design consisted of four treatments, each with four replicates.

In Year 1 at Rosemaund, treatments measured surface losses in tramlines and in the conventionally planted area between tramlines. In addition, one treatment explored the effect of using a cultivator fitted with a tine to disrupt the compacted surface of the wheeling (to 6cm depth) after its establishment in the late autumn. There were four replicates of each treatment

In Year 2, treatments were identical at both sites, and involved: (i) vegetated areas between tramlines ("no tramline"); (ii) areas with conventional tramlines ("tramline"); (iii) areas where a cultivator fitted with a ducksfoot tine were used to disrupt (to 6cm depth) the compacted surface of the tramline wheeling ("tramline disrupted"); and in year two only, (iv) areas where the crop sprayer was run over the emerging crop during the autumn ("tramline offset"), rather than running on the unseeded tramline area. This was undertaken to identify whether any effect of the presence of tramlines was driven primarily by the compaction caused by the sprayer machinery used following crop emergence in the autumn, or by the lack of vegetation cover in the wheeled areas.

Surface runoff from each hillslope segment was channelled via guttering and plastic pipes through novel sampling devices which diverted a user-defined proportion of the total runoff into collection tanks. Event-based samples were analysed for total phosphorus (TP), total dissolved phosphorus (TDP), particulate phosphorus (PP), total nitrogen (TN), total dissolved nitrogen (TDN), and suspended sediment (SS).

Results

Year 1 – Hattons site

At Hattons, eight events were monitored between October 2005 and March 2006. Overall results across these events are summarised in Table 1. Treatments receiving 2.5 t/ha straw chopped and incorporated had substantially lower ($P<0.01$) surface runoff, sediment, TP and TN fluxes than those where straw had been baled and removed. It can be inferred that the presence of vegetation cover would reduce the kinetic energy in incident precipitation reaching the soil surface, and would act to increase the storage capacity of the soil surface area before runoff would be promoted.

However, superimposed on this residue management effect was a more dominant effect associated with the presence or absence of tramline wheelings (Table 1). Results demonstrated the dominant effect ($P<0.001$) of the presence of tramlines as transport pathways for the loss of surface runoff, sediment, and phosphorus to field margins, showing that this mechanism is important on lighter sandy soils as well as the heavier silty clay soils at Rosemaund (e.g. Silgram, 2004; Silgram *et al.*, 2008). Over all monitored events and treatments at Hattons, >90% of TP was present in particulate form and a similar proportion of TN was present as insoluble N.

Year 1 – Rosemaund site

At Rosemaund only four events were captured in this first winter of monitoring. Surface runoff from undisrupted tramlines represented 5-17% of rainfall, but only <0.6% of rainfall from both the cropped area between tramlines, and from the disrupted tramline areas. Results shown in Table 2 illustrate the dominant effect of tramlines as pathways for the transport of surface runoff, sediment, and phosphorus to the edge-of-field area.

Across all monitored events and treatments at Rosemaund, 77-85% of the TP in runoff was present in particulate form. Overall results for TN reveal 71% was present as organic N on disrupted tramlines but only 54-57% of TN present as organic N where there were no tramlines or where tramlines had been disrupted. Most importantly, tramline disruption consistently and dramatically reduced ($P<0.001$) runoff and N and P fluxes to levels comparable to non-tramline areas, supporting its use as a practical mitigation tool.

Year 2 – Both sites

In the wetter second year of the project, treatments were identical at both sites. The rainfall and sampling regime are shown in Figure 1. At both sites, tramline wheelings once again proved an extremely significant ($P<0.001$) pathway for surface runoff, sediment, phosphorus and nitrogen losses to edge-of-field (Table 3). Diffuse pollutant losses from treatments with tramlines were typically an order of magnitude greater than from treatments without tramlines, for each pollutant. Measurements indicated 5.5-15.9% of rainfall was lost as surface runoff containing 0.30-4.82 T/ha sediment, 0.8-2.9 kg TP/ha, and 1.1-5.4 kg TN/ha in treatments with tramlines; but only 0.5-1.7% of rainfall was lost as surface runoff containing 0.02-0.07 T/ha sediment, 0.0-0.2 kg TP/ha, and 0.0-0.3 kg TN/ha on treatments without tramlines and treatments where tramlines had been disrupted. Results from offset tramlines suggest the majority of the enhanced losses observed from tramline areas may be related to surface compaction rather than to a lack of vegetation cover.

Losses were notably greater from the silty clay loam soils at the slightly wetter Rosemaund site. To demonstrate that these broad effects were evident in data from individual events, plots for a typical event from each site are shown in Figure 2. With the exception of the offset treatment, individual replicates produced relatively tightly clustered results, especially given the variability inherent in soils and that additionally introduced through land management activities (Figure 3).

Reductions of 86-97% were therefore achieved in losses from disrupted compared to undisrupted tramlines, effectively bringing over-winter losses close to “background” levels measured in the cropped areas between tramlines. In contrast, results from the offset tramlines were inconsistent and extremely variable, with this treatment actually *increasing* losses slightly at the Rosemaund site (Table 3). Although losses of 0.8 and 2.9 kg TP/ha from conventional tramline wheelings on these moderate slopes would not be considered agronomically significant (relative to the errors associated with fertiliser spreading, for example), these losses are *highly ecologically significant* and equate to flow-weighted concentrations in surface runoff of >3000 µg TP/l (whereas limits for eutrophic status in freshwaters are *ca.* 60-100 µg TP/l (e.g. Environment Agency, 2000)).

Discussion

Evidence from both sandy and silty clay loam soils across two winters has shown that tramline wheelings can represent the dominant mechanism for surface runoff and transport of sediment, phosphorus and nitrogen from arable fields with shallow to moderate slopes. These findings support recent reports identifying tramline wheelings as a potential pollutant pathway in a number of recent studies (e.g. Silgram, 2004; Withers, 2006; Silgram *et al.*, 2008), and this is acknowledged by virtue of their inclusion as a mechanism of loss in the final report from the UK government’s recent Diffuse Pollution Inventory project (Cuttle *et al.*, 2006). These results also suggest that estimates of whole-field losses of diffuse pollution (typically based on small plot studies) may have been significantly under-estimated the role of tramlines as rapid pollutant pathways (e.g. during the calibration of models used to estimate field, farm and catchment scale diffuse pollution losses).

Apart from delaying tramline establishment, until now no specific practical methods have been proposed to mitigate losses from this pathway until this project's exploration of the potential for disrupting tramlines once with a tine in the autumn. Most other options for tramline management are problematic. For example, delayed establishment of tramlines is usually considered to be agronomically unacceptable due to the risks of disease, weeds, and associated yield penalty. Controlled Traffic Farming (CTF) (e.g. Chamen, 2006), where a semi-permanent roadway is used for traversing fields for spraying, uses a gantry system and hence CTF is a more expensive option which limits itself to the largest of fields and agricultural operators. Furthermore, CTF tends to compact the soil in the semi-permanent trackway, which consequently has the potential to increase runoff, and increase the risk of rill formation and associated diffuse pollution loss in the adjacent area.

In contrast to these less practical options for mitigating losses from tramlines, results presented in this paper demonstrate that a single shallow disruption of a tramline wheeling using a tine once in the autumn following the spraying operation can consistently and dramatically reduce ($P<0.001$) surface runoff and loads of sediment, total nitrogen and total phosphorus to levels close to those measured in vegetated areas between tramlines. These conclusions are specific to fields with combinable crops on moderate slopes. Results have been presented as the mass of pollution prevented per unit area, for different treatment plots. Upscaling these effects to estimate whole-field impacts is required to generalise these results and integrate them into modelling assessments, but is dependent on the tramline spacing which typically varies from 18 m to 24 m in arable farming systems in England. Bailey *et al.* (2007) estimated the costs (including fuel, labour and equipment) associated with implementing these pollution mitigation measures in commercial farms, and concluded that at £11/ha tramline management compared favourably to the £19/ha cost of chopping and spreading straw residues.

As the evidence presented here shows that tramline disruption reduced diffuse pollution losses from tramline areas by >85%, and with no discernible effect on yield, we conclude that this measure appears very promising as a practical pollution mitigation measure for specific arable areas identified as at high risk of runoff and soil erosion. The modest cost which farmers would incur when implementing tramline disruption could be offset, for example, by awarding points under agri-environment policy instruments (such as the Environmental Stewardship scheme in England). The requirement to achieve good water quality objectives as laid down in the Water Framework Directive, together with the Freshwater Fish Directive limits on sediment concentrations in freshwaters, impose a regulatory framework which means that if measures with demonstrable effectiveness - such as tramline management - are not integrated into commercial farming operations under voluntary arrangements, then there is the real possibility of such measures (or more onerous ones) being imposed as compulsory in the future as Member States strive to achieve these demanding water quality policy objectives over the next decade.

Further work

Further work is now needed to explore other tramline management options; to assess the most appropriate method (e.g. tine type, depth, timing) for disrupting tramlines on different soils; to determine how tramline management can best be integrated into commercial farming operations (e.g. trafficability of land in spring); to identify the area where this mitigation option might be most effectively targeted in different catchments (e.g. moderate to steeply sloping arable fields within 250 m of a water body); and to explore through modelling the potential impact of introducing tramline management as a practical management option in targeted areas in lowland England.

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Table 1. Summary results from runoff events at Hattons, winter 2005/6

		Runoff mm	Runoff litres	% rainfall as runoff	Sediment kg ha^{-1}	TP kg ha^{-1}	TN kg ha^{-1}
Baled/removed	No tramline	0.4	312	0.2	21	0.06	0.09
Baled/removed	Tramline	8.4	6802	6.8	499	1.52	1.83
Chopped/spread	No tramline	0.2	172	0.1	12	0.03	0.04
Chopped/spread	Tramline	6.4	5056	4.4	298	0.99	1.17

Table 2. Summary results from runoff events at Rosemaund, winter 2005/6

		Runoff mm	Runoff litres	% rainfall as runoff	Sediment kg ha^{-1}	TP kg ha^{-1}	TN kg ha^{-1}
No tramline		0.3	63	0.5	3	0.01	0.03
Tramline	Not disrupted	5.8	1807	10.9	357	1.32	1.32
Tramline	Disrupted	0.3	105	0.6	6	0.02	0.06

Table 3. Summary results for winter 2006/07 for surface runoff, sediment, total phosporus and total nitrogen losses from Hattons (sandy loam) and Rosemaund (silty clay loam) sites under contrasting tramline management treatments.

		Runoff mm	Runoff litres	% rainfall as runoff	Sediment kg ha^{-1}	TP kg ha^{-1}	TN kg ha^{-1}
Hattons	No tramline	3.2	3024	1.0	30	0.1	0.1
	Tramline	16.0	15120	5.5	296	0.8	1.1
	Disrupted tramline	5.0	4725	1.7	73	0.2	0.3
	Offset tramline	10.1	9545	3.5	133	0.4	0.5
	P	<0.001	<0.001		0.003	0.001	<0.001
Rosemaund	No tramline	2.0	722	0.5	21	0.0	0.0
	Tramline	78.1	28194	15.8	4820	2.9	5.4
	Disrupted tramline	2.7	975	0.6	40	0.0	0.1
	Offset tramline	94.7	34187	19.1	6360	3.7	6.5
	P	<0.001	<0.001		<0.001	<0.001	<0.001

Figure 1. Cumulative rainfall and sampling at Hattons and Rosemaund, 2006/07

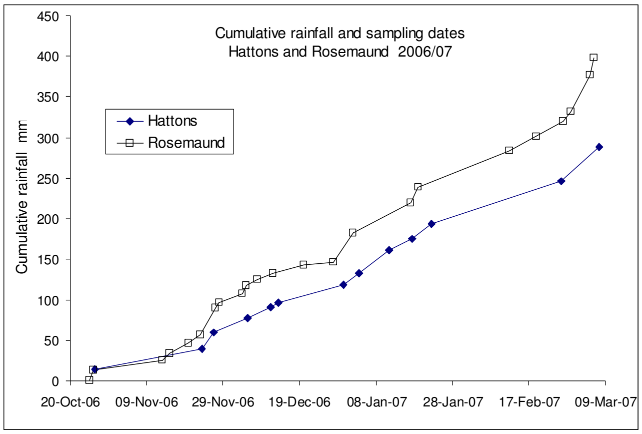

Figure 2. Example event-specific runoff. Left: Hattons 30/12/06; total rainfall 23 mm; maximum intensity 2 mm/hr; maximum runoff 17.3 l/min. Right: Rosemaund 04/12/06; total rainfall 11 mm; maximum intensity 4.6 mm/hr; maximum runoff 20.3 l/min

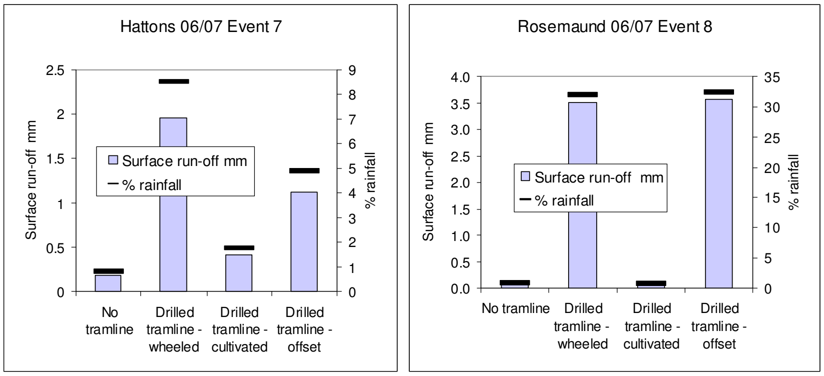

Figure 3. Total over-winter surface runoff at Hattons 2006/07 showing replicate data