DETERMINING THE COST EFFECTIVENESS OF SOLUTIONS TO DIFFUSE POLLUTION: THE CASE OF IN-FIELD MITIGATION OPTIONS FOR PHOSPHORUS AND SEDIMENT LOSS

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Abstract

The European Union Water Framework Directive requires governments to set water quality objectives based on good ecological status. This includes specific requirements to control diffuse pollution. Diffuse phosphorus (P) pollution plays a pivotal role in influencing water quality with losses of P associated with soil particles often linked to soil erosion. The Mitigation Options for Phosphorus and Sediment (MOPS) project in the UK is investigating the cost effectiveness of specific control measures in terms of mitigating sediment and P loss from combinable crops. The measures focus on different cultivation techniques, vegetative barriers, disruption of tramline management and crop residue management. Results from the first year of the project suggest that some mitigation options may not be cost effective in reducing diffuse pollution, however, that other options may be very cost effective.

Keywords: European Union Water Framework Directive, Diffuse phosphorus (P) pollution, Mitigation Options.

Introduction

The European Union Water Framework Directive introduced across Europe in 2003 requires governments to set water quality objectives based on good ecological status (European Parliament 2000; Moss et al., 2003). Given the pivotal role that phosphorus (P) and sediment play in influencing water quality controlling the transfer of these important diffuse pollutants from land to water represents a priority task for catchment managers and stakeholders (Kronvang et al., 2005).

Agricultural systems in most European countries are currently operating at an annual P surplus (Isermann, 1990; Brouwer et al., 1995; Sibbsen and Rung-Metzger, 1995) and, in the UK, this has been estimated to be in the order of 16 kg P ha^{-1} yr^{-1} (Edwards and Withers, 1998; Withers and Jarvis, 1998). P is the key nutrient limiting plant growth in rivers, lakes and reservoirs, and the typical loss of P to water from farming land in the UK is currently estimated at 1 kg ha^{-1} yr^{-1} (Defra, 2002; Heathwaite et al., 2005).

With respect to mitigation, phosphorus losses from agricultural catchments have been shown to be significantly higher than the losses from non-agricultural river basins (Kronvang et al., 1996), thereby further highlighting the need to mitigate agricultural P transfers. Whilst sediment yields in the UK are low by world standards (Walling and Webb, 1987), increased fine sediment loadings are responsible for a range of off-site environmental problems, and the increasing evidence for the role of fine sediment in controlling the transfer and fate of nutrients (Jarvie et al., 2005; Collins et al., 2005) and contaminants (Rees et al., 1999; Collins et al., 2005) serves to emphasize the wider significance of sediment loss and delivery in diffuse pollution problems. A number of studies investigating the provenance of suspended sediment loads in UK catchments have reported the significance of cultivated fields in this process

(Robinson and Naghizadeh, 1992; Chambers et al., 1992; Collins et al., 1997; Collins and Walling, 2004; Walling and Collins, 2005).
An understanding of P and sediment loss pathways is therefore essential for effective targeting of mitigation methods (McDowell et al., 2001). Phosphorus is lost from arable systems via a number of pathways and the most desirable, in environmental terms, is via crop uptake and subsequent removal by harvesting. Less desirable P loss from farming systems can occur from both point and diffuse sources. Surface runoff, as a result of the erosion process, represents the principal pathway for diffuse P loss from many agricultural systems and may, for example, account for 90% of the P transported from arable land in the UK (Catt et al., 1998).

P source management options are typically embodied in nutrient management planning and include: regular soil P testing, matching P applications with crop requirements, incorporation of fertilizers and manures as opposed to broadcasting, and better timing of P applications to coincide with periods of reduced runoff risk (Hart et al., 2004). The timing option alone, however, cannot be relied upon as a principal method of mitigation because weather is highly unpredictable (Hart et al., 2004) and in many areas of England and Wales, there are few windows when optimal soil and weather conditions coincide (Preedy et al., 2001).

Mitigation options focusing upon transport or delivery management are relevant to both P and sediment and primarily concentrate upon topsoil protection and the interception of surface runoff. Transport management options commonly include: the early sowing of winter cereals, delaying tramline establishment, sowing winter cover crops, using rough seed beds, reduced or no-till, and establishment of in-field or riparian buffer strips (see for examples Pierzynski et al., 2000).

The Mitigation Options for Phosphorus and Sediment (MOPS) project (2005 to 2008) is investigating the cost effectiveness of specific control measures, representing different levels of farmer intervention, in terms of mitigating P and sediment loss from combinable crops. This paper outlines the first year of results from the project in terms of P and sediment loss mitigation and the farm management implications of the options examined.

Methodology

Three contrasting case study farms in England covering vulnerable soil types and slope forms are involved in the project to discover which preventative techniques are the most efficient. The three field sites are the Allerton Trust farm in Loddington, Leicestershire which is on clay soils, ADAS Rosemaund in Herefordshire which is on silt soils, and Severn Trent Water's farm at Old Hattons near Wolverhampton which is on sandy soils. At each of the field sites there is a mix of long slopes, convex-concave slopes, and slopes bounded by farm tracks and ditches.

The mitigation options are focused on within field measures and include different cultivation techniques, vegetative barriers, tramline management and crop residue management.

In the first year of the project six treatments were investigated at Loddington: ploughing up and down the slope, across the slope, and across the slope with the establishment, within field, of a beetle bank along the contour; and minimum tillage up and down the slope, across the slope, and across the slope again with a contour beetle bank. Each unbounded plot is 3m wide and about 100m in length. There are three replicates for each treatment.

At ADAS Rosemaund unbounded hill slope plots, each 3m wide and 103m long, were established to examine losses within and between tramlines and specifically tramline wheeling disruption using a cultivator fitted with a ducksfoot tine to disrupt the compacted surface of the wheeling after its establishment in the late autumn. There were four replicates for each treatment.

At Old Hattons farm unbounded hill slope plots each 3m wide and 270m long were established to examine the management of post harvest cereal straw residues which had either been baled and removed or chopped and incorporated into the soil. Again, there were four replicates for each treatment.

To determine the cost effectiveness of the mitigation options, data for each of the case study farms is being collected for each treatment in each year. This focuses on (i) field records on crop establishment, fertiliser and spray applications and harvesting and (ii) the additional costs associated with the mitigation options. Field data from all sites has been collated for the first year of the project. In addition, data on the establishment of the beetle bank and maintenance in the first year was recorded at Loddington. At ADAS Rosemaund, data on the additional time spent in the field disrupting tramlines was recorded. At Old Hattons, data on the time spent baling and removing straw compared with chopping and spreading was recorded.

The resultant costs can then be compared with the runoff, sediment and P loss data from the field monitoring. To examine the potential of the options to mitigate sediment and P loss from combinable crops, surface water runoff from each hill slope plot is channelled, via guttering and plastic pipes, through novel sampling devices which divert a proportion of the run-off into collection tanks. Samples are analysed for P and suspended sediment. As with the tramline disruption treatment at ADAS Rosemaund, losses from tramline and inter tramline areas were monitored separately at both Loddington and Old Hattons.

Results

Farm Management Implications

Table 1 illustrates the cropping pattern and, based upon this, an average ‘operating margin’ per hectare at each of the three sites. This margin is based on a number of assumptions. It goes beyond an enterprise gross margin to include some fixed costs, such as labour and machinery operations, which can be directly allocated to each crop enterprise. It is, however, not a true net margin as certain building, land and general overhead costs are excluded.

Table 1: Case Study Site Cropping and ‘Operating’ Margin

Site	Wheat %	Oats %	Barley %	Rape %	Beans %	Margin £/ha
Loddington	53	8	0	21	14	215
Rosemaund	39	21	0	16	16	197
Old Hattons	41	0	33	26	0	243

To calculate gross output, average crop yields from the 2006 harvest year at each site were multiplied by October 2006 market prices (Farmers Weekly, 2006; Farmers Weekly Interactive, 2007). Variable costs for seed, fertiliser, sprays etc. were taken from Nix (2005). Labour costs were calculated based on average hours to undertake establishment with ploughing, and fertiliser application and spray operations based upon a set number of applications (Nix, 2005). These were then multiplied by an hourly labour rate of £8.50. Similarly, machinery costs were also taken from Nix based on the number of operations and the length of time required to undertake them. This took into account the differences in work rate possible on light and medium/heavy soils. The machinery cost includes fuel, repairs and depreciation but excludes the more general overhead costs.

Actual data from each site, apart from the yield data, was not used due to variability in types of equipment and specific methods of establishment as well as different fertiliser and crop protection regimes. However, imputed costs were compared to given data for validation purposes.

Table 2 shows the impact of the introduction of the various mitigation options. It should be noted that the field records from the first year show that no changes in terms of fertiliser nor agro-chemical applications were required and that there were no impacts on yield.

Table 2: Mitigation Options: Additional Costs and Impact on Margin

Site	Mitigation option	Additional cost	Resultant operating margin
Loddington	Plough	n/a	£215 per ha
	Contour plough	n/a	£215 per ha
	Contour plough with in-field vegetative strip	Year 1: £163/ha Each yr: £21/ha	£213 per ha
	Minimum tillage	n/a	£263 per ha
	Contour minimum tillage	n/a	£263 per ha
	Contour minimum tillage with in-field vegetative strip	Year 1: £163/ha Each yr: £21/ha	£261 per ha
Rosemaund	Plough	n/a	£197 per ha
	Tramline disruption	n/a	£186 per ha
Old Hattons	Plough	n/a	£243 per ha
	Straw bale and removal	n/a	£242 per ha
	Straw chop and incorporate	n/a	£224 per ha

At Loddington there is no explicit impact of switching from up and down slope cultivation to contour cultivation. Moving to a minimum tillage system reduces establishment costs and thereby increases the operating margin. Purchase of new alternative equipment to undertake minimum cultivation is excluded from this calculation. The establishment of a vegetative strip has two costs. There is the initial cost of establishment including land preparation, sowing of grass seed and cutting in the first year, as well as implications in relation to the land taken out of production. The establishment cost given in Table 2 assumes a fully mechanised operation with plough, seedbed cultivation, drill and rolling, and one cut of vegetation in the first year. In practice, areas taken for the vegetative strip would probably be less than one hectare. Costs, however, would not be reduced substantially due to similar ground preparation costs as a result of time and effort taken in setting up the required equipment and travel to and from field sites. Nevertheless, sowing costs could be reduced by half if the area was small enough to be seeded by hand. In subsequent years regular topping of the vegetation may be required. In addition to the direct loss of land, there are additional costs associated with reducing field size and increasing operational costs. Provisional estimates suggests that this could amount to between £1 to £2 per hectare, but this is dependent on farm size, arable area, field sizes, slopes and opportunity to incorporate such strips within field.

The reduced margin for the tramline disruption process at ADAS Rosemaund reflects the labour and machinery cost of an additional pass to disrupt tramlines in cereal crops following the last autumn spray operation. In determining the cost of this operation it was assumed that the machinery and labour costs would be similar to that of spring time harrowing given the similar equipment used. These costs are estimated at £15 per hectare with around 12 hectares being cultivated in an eight hour day (Nix, 2005). In the experiment itself, it took one hour to disrupt four out of the eight tramlines on the experimental area (0.99 ha), using a tractor and cultivator. The equivalent work rate was, therefore, 0.49 ha per hour for disruption compared with 1.5 ha per hour for full width cultivation. However, given the small nature of the plot and the time required for setting up the machinery, an experimental procedure and not applicable to the same extent in commercial practice, the per hectare work rate would probably increase. This cannot be determined until cultivation options have been studied more closely, and it is therefore assumed at this stage that tramline disruption is comparable to full width cultivation. Additionally, increasing or reducing tramline spacing would have implications for the time taken and therefore cost per hectare. This could be quite significant given that 12m tramline spacing is rare, with 18m, 20m and 24m spacing being far more common. With 24m tramline spacing, overall cultivation costs would remain the same, but tramline disruption could reduce by half. It is assumed that there are no additional equipment costs as on the majority of farms the type of kit required would already be available and in use for conventional operations.

The additional cost of baling and removal of cereal straw was deliberately excluded from all of the calculations for operating margin at each of three sites. It would, however, have minimal impact. At Old Hattons, straw baling and removal was undertaken by a contractor. It would typically take 4.8 hours per hectare to bale and cart straw and cost around 25p per bale (Nix, 2005). This gives rise to an additional cost of approximately £1 per hectare, thereby reducing the cereal operating margin by this amount. The average rotational margin would also reduce by a similar amount. The alternative of chopping and incorporating the straw, however, would have a much greater impact. Contractor costs amount to £25 per hectare. If a farmer were to do it themselves the cost would be around 15-25% lower. The implications for the rotational operating margin, using the contractor cost, is an overall reduction of around £19 per hectare.

Mitigation of Sediment and Phosphorus

In the first year, usable data was collected from eight rainfall events at Loddington, two events at ADAS Rosemaund and seven events at Old Hattons across the period from October 2005 to March 2006. It should be noted that the winter of 2005/06 in the Midlands, were all three sites are located, was quite dry compared with long term averages.

Initial results from autumn 2005 to summer 2006 indicate that, at all sites, tramlines are responsible for the majority of run-off, sediment and P lost, and that measures focused on this area as opposed to other within field measures may help in mitigating P losses.

At the Loddington field site tramlines generated five times more runoff than any of the treatments and were responsible for transporting much higher quantities of sediment and P. The results also indicated that the use of beetle banks combined with contour cultivation could reduce runoff, soil and nutrient losses although this effect is not as clear as the difference between tramline and no-tramline areas. Statistical analysis, however, shows no clear differences between treatments, as there was wide variability between the within treatment replicates.

The results from ADAS Rosemaund show that surface run-off from undisrupted tramlines represented between 5-17% of rainfall. On the no-tramline and disrupted tramline areas this was less than 0.6%. Significantly, tramline disruption consistently and dramatically reduced run off and P fluxes to levels comparable to no-tramline areas.

At Old Hattons, as with the other field sites, runoff and nutrient losses were high from tramlines. The results also indicated that the treatments receiving 2.5t/ha straw chopped and incorporated consistently and substantially reduced surface run-off per unit area, typically by 20-40%, and total P loss per unit area, typically by 30-60%, compared with those where straw had been baled and removed.

Discussion and Conclusion

The first year results present some potentially interesting solutions for the mitigation of P and sediment loss from arable cropping.

The potential for contour cultivation and minimum tillage to reduce soil loss has already received considerable attention. The use of these methods of cultivation alongside a within field vegetative strip is less well researched. The impact on the operating margin could be minimal, however, the establishment costs for the vegetative strip are more substantial. Further work on the effectiveness of sediment and P mitigation is needed. Similarly, wider investigation of the potential use of such features on farm is required, examining what would be feasible in terms of field size and positioning on field slopes and how this would impact on the whole farm system.

At the start of the project it was unclear how effective tramline disruption would be in disrupting the compacted surface pathway for runoff and losses of sediment and P. If the disruption was too severe, this procedure could have exacerbated the problem by gouging a channel for runoff leading to rill and gully formation. In fact, however, the concept that breaking up the soil surface compacted by tramline wheelings would increase infiltration and reduce surface runoff potential proved highly effective, and in many cases reduced surface runoff and nutrient losses to levels close to those measured in comparable no-tramline areas. The cost of tramline disruption is comparable with other crop establishment costs and no apparent impact on yield is evident at this stage, suggesting that this method is likely to show considerable promise in terms of cost-effectiveness. Alternative disruption devices (different tines etc) and the effectiveness of the measure on lighter textured soils now need to be explored further before results can be generalised.

The chopping and incorporation of straw, as opposed to baling and removal, was also shown to be effective at reducing surface run-off and total P loss. There was a consistent trend across events, but it is not appropriate at this stage to say conclusively that any reduction from chopping as opposed to baling was real in statistical terms. Further, there is a slightly more substantial cost associated with this operation which suggests that the option may not be as acceptable as the other options identified. There are also agronomic implications relating to long term additions of organic matter and interactions with soil type, and economic implications around farming systems including straw use for livestock and transport costs.

In conclusion, it should be reiterated that the results presented here are from one dry year only and no concrete conclusions can yet be drawn. Further work is ongoing on contour and minimum tillage cultivation with in field vegetative strips and tramline disruption. In terms of cost effectiveness, consideration is also being given to the extrapolation of the case study data to generic farm typologies and from a farm level to regional basis, as well as the potential for the inclusion of mitigation options within agri-environment policy.

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