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Determining The Cost Effectiveness Of Solutions To Diffuse Pollution: Developing A Model To Assess In-Field Mitigation Options For Phosphorous And Sediment Loss

Alison Bailey[1], John Quinton[2], Martyn Silgram[3], Carly Stevens[4], Bob Jackson[3]

[1] University of Reading
a.p.bailey@reading.ac.uk
[2] Lancaster University
[3] ADAS
[4] Open University

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 phosphorous (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, using three case study sites, is investigating the cost effectiveness of specific control measures in terms of mitigating sediment and P loss from combinable crops. The analysis is conducted at the farm level using a simple spreadsheet model. Further development of the model will allow the results to be extrapolated to generic regional farm typologies. Results from the initial farm level analysis suggest that some mitigation options may not be cost effective in reducing diffuse pollution, however, that other options may be very cost effective.

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). 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).

Phosphorous 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 and erosion represents the principal mechanism of 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).

Phosphorous source management options are typically embodied in nutrient management planning and include: regular soil P testing, matching P applications with crop requirements, incorporation of fertilisers 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 reducing both sediment and P loss 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 development of the spreadsheet model and data requirement for the cost effectiveness analysis, and presents results from the first year of the project at the farm level as an illustration of the model's application. The paper concludes with a discussion on the potential policy options that could result from this work.

Project Outline

Three contrasting case study farms in England covering vulnerable soil types (clay, silt, sand) and slope forms (long slopes, convex-concave slopes, slopes bounded by farm tracks and ditches) 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.

The mitigation options, on unbounded hill slope plots, 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.

At ADAS Rosemaund plots 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.

At Old Hattons farm plots 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.

Cost Effectiveness Analysis

To determine the cost effectiveness of the different 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.

The analysis involves the construction of a simple spreadsheet model to examine impacts on individual cereal crop margins and thence the overall arable rotation. In the first instance, three farm level versions of the model have been developed to represent each of the three case study farms. The model includes both gross margin calculations and an 'operating' margin based upon labour and machinery costs which can be directly allocated to each crop enterprise. The operating margin goes beyond an enterprise gross margin as it includes some fixed costs, however, it is not a true net margin as certain building, land and general overhead costs are excluded.

To calculate gross output, average crop yields from the 2006 harvest year at each case study farm were multiplied by October 2006 market prices (Farmers Weekly, 2006; Farmers Weekly Interactive, 2007). In subsequent analyses, a range of prices can be used to reflect fluctuations in the market over time. Similarly, a range of yields will also be used to reflect differing climatic conditions. Variable cost data has initially been based upon standard costs taken from Nix (2005). However, farm records on seed rates and fertiliser and agro-chemical applications is being collected from each of the case study farms for each of the different mitigation options. Typical prices for these products will be used in the final analyses.

Machinery costs have been calculated based upon the number and type of operations undertaken at each site, and as with the variable cost data, have initially been based upon average farmer cost data taken from Nix (2005). The calculations take into account the differences in work rate possible on the light and medium/heavy soils that occur at each of the three case study farms, and include fuel, repairs and depreciation but exclude the more general overhead costs. Labour costs have been calculated assuming a set number of hours to undertake the operations identified (Nix, 2005). These were then multiplied by an hourly rate of £8.50. Full records are being kept on crop establishment, fertiliser and agro-chemical applications, and harvesting and the length of time required to undertake them. This data, as with the variable cost data, will be used in the final analyses.

The resultant gross and operating margins will reflect the impacts of the different mitigation options on the costs of crop establishment and fertiliser and agro-chemical applications. The additional costs associated with the mitigation options also need to be considered and deducted, where relevant, from the appropriate crop margins.

At Loddington, the switch to minimum tillage and contour cultivation is explicitly included in the model within the crop operating margins. Additional costs associated with the purchase of new alternative equipment to undertake minimum cultivation would not be included here. The establishment of the vegetative strip has two costs. First, there is the initial cost of establishment including land preparation, sowing of grass seed and cutting in the first year. As a one-off capital cost, it is not recorded in the resultant margins within the model. This is also the case for the annual maintenance costs. Second, are the costs associated with the reduction in arable area which will need to be recorded. In addition to the direct loss of arable land, there are potential additional costs associated with reducing field size and increasing operational costs. This is dependent on farm size, arable area, field sizes, slopes and opportunity to incorporate such strips within field.

At ADAS Rosemaund, the additional time spent in the field disrupting tramlines in cereal crops following the last autumn spray operation is a cost which needs to be deducted from the relevant crop operating margins. In determining the cost of this operation it was assumed that the machinery requirement would be similar to that of spring tine harrowing given the similar equipment used. 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.

In setting up the spreadsheet models, the additional cost of baling and removal of cereal straw, one of the mitigation option comparisons, was deliberately excluded from all of the calculations for each of three case study farms. It is separately identified as a deduction from the relevant cereal operating margins in the farm case study model for Old Hattons where the option was investigated. In this way, the cost for the straw baling and removal provides a direct comparison to the other cereals straw option of chopping and incorporation. In both cases, it was assumed that the work would be undertaken by a contractor as was the case at the case study farm.

Once impacts on individual crop margins have been calculated, the impact on the overall arable rotation can be determined. To do this, each crop margin is multiplied by the percentage area that is grown on the farm taken from the 2006 harvest year farm records. The resultant rotational farm operating margin for each of the mitigation options then need to be compared with data on the runoff, sediment and P loss to determine how effective and hence cost effective the options are. Data for this has been collected over the winter period, October through to March, when erosion risk and hence soil and diffuse P loss is at its highest.

Results

Table 1 illustrates the 2006 cropping areas and, based upon this, an average 'operating margin' per hectare at each of the three case study farms. 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. In the long term, this may not be the case.

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

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, the switch to minimum tillage system, as is to be expected, reduces establishment costs and thereby increases the operating margin. The additional capital cost for the establishment of the vegetative strip at Loddington 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. Provisional estimates regarding the additional costs associated with reducing field size and increasing operational costs amount to between £1 to £2 per hectare.

The calculation for the resultant operating margin for the tramline disruption option at ADAS Rosemaund was derived from the assumption that spring tine harrowing costs would be £15 per hectare with around 12 hectares being cultivated in an eight hour day (Nix, 2005). This equates to 1.5 hectares per hour. The experimental plot at ADAS Rosemaund is 0.99 hectares with eight 12m tramlines. It took one hour to disrupt four out of the eight tramlines on the experimental area using a tractor and cultivator. The equivalent work rate was, therefore, 0.49 hectares per hour for disruption compared with 1.5 hectares per hour for full width cultivation. Given the small nature of the plot and the time taken for setting up the machinery, and that the process was an experimental procedure and not perhaps 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. It is therefore assumed, at this stage, that the tramline disruption work rate 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. Overall cultivation costs would remain at £15 per hectare but tramline cultivation could reduce by half for 24m tramlines.

Straw baling and removal would typically take 4.8 hours per hectare to bale and cart straw and using a contractor, as was the case at Old Hattons, 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.

In the first year, usable data to examine the effectiveness of the different mitigation options for reducing sediment and P loss were 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, where all three case study farms are located, was quite dry compared with long term averages.

Initial results from autumn 2005 to summer 2006 indicate that, at all case study farms, 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 per hectare 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.

Future Work

If practical mitigation measures are to be adopted by farmers they will need to be effective in mitigating sediment and phosphorous, but be at worst cost-neutral to the farmer. The first year results of the MOPS project 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 oppose 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, straw use for livestock, and transport costs.

In light of these initial results, further work is currently ongoing on contour and minimum tillage cultivation with in field vegetative strips at Loddington, and tramline disruption is continuing at ADAS Rosemaund and has also been incorporated within the treatments at Old Hattons, which has a lighter soil than that at ADAS Rosemaund.

In addition to the continued experimental work on the examination of the mitigation options, further development is ongoing with the cost effectiveness analysis and expansion of the spreadsheet model. The next stage of the analyses is to extrapolate the results beyond the farm level to generic farm typologies at a regional level. In the regional spreadsheet model, typical financial crop enterprise data for the region will be taken from the relevant Farm Business Survey and used as the baseline level for the analyses. At this level it is envisaged that the model will incorporate a wider range of crops than those that are used within the farm models. Impacts found at the farm level will then be incorporated within the regional model for the different crops for which data is available using the full three years of results. To move from the individual crop margins to the rotational arable margin, the percentage area of crops grown within a region will be taken from Defra census data based upon the year prior to and three years of the project (2005 to 2008).

Policy Options for the Mitigation of Sediment and P Loss

The potential for the mitigation options to be included within existing agri-environment policy frameworks is also being considered. Within England and Wales, the mid term review of the EU's Agenda 2000 has provided the opportunity to introduce mitigation measures at a variety of levels: cross compliance, Entry and Higher Level Stewardship.

Cross compliance is linked to the Single Payment Scheme. In order to receive payment under this scheme farmers must meet the cross compliance requirements, keeping their land in Good Agricultural and Environmental Condition (GAEC) standards, set by each Member State individually, and meeting Statutory Management Requirements (SMR), set by the European Union. In England there are four GAEC standards for soil management and protection: preparing and implementing a soil management plan, post-harvest management of the soil, mechanical field operations on waterlogged soil, and burning of crop residues. It is suggested that the mitigation options being considered within the MOPS project would not become a requirement under GAEC standards other than identification within the soil management plan. The SMRs cover 'environment' and 'public and animal health'. Within this, and with regard to diffuse pollution, there is a current requirement to manage the application of nitrogen fertilisers and manures. Potentially, similar measures for the control of diffuse phosphorous pollution could be introduced. Again, the mitigation options within the MOPS may not be relevant here.

It is therefore more likely that the MOPS mitigation options, in the current policy climate, could be incorporated within Environmental Stewardship, potentially, at both the Entry and Higher Levels. Entry Level Stewardship (ELS) is a whole farm scheme open to all farmers and land managers with an agreement term of five years. Higher Level Stewardship (HLS), which is combined with ELS, aims to deliver significant environmental benefits in high priority situations and areas and has an agreement term of 10 years.

Under ELS farmers need to reach a points target related to their farm size, normally 30 points per hectare. Farmers complete a simple record of features on their farm and choose options to reach their points target. There are over 60 management options to choose from and each option is worth a certain number of points. Once their target is reached farmers receive a flat rate payment of £30 per hectare per year related to the amount of land they enter into the scheme. Effectively, points per hectare are equivalent to pounds per hectare. Current ELS options which could help minimise soil sediment and P loss include buffer strips (from 300 to 400 points per hectare), beetle banks (580 points per hectare), and soil and nutrient management plans (three and two points per hectare respectively).

HLS requires farmer to produce a whole farm environmental audit to identify environmental features, their condition and environmental risks, and thence proposed management options. These may include non-rotational, rotational, management plan, access and capital works options. Payments are based upon the type of work undertaken. Farmers may therefore receive both annual land management payments and payments for capital works. Current HLS options of relevance to minimising soil and P loss are crop establishment by direct drilling (£370 per hectare) and in-field grass areas covering up to 30% of the field to prevent erosion or run-off (£350 per hectare).

There are similar options in other schemes across Britain providing payments for grass margins, restrictions on cultivations and applications of agro-chemicals, and nutrient planning.

Considering the MOPS mitigation options, it is evident that, to some extent, two similar options are already incorporated within Environmental Stewardship, the vegetative strip and contour ploughing. The MOPS vegetative strip mitigation option could feature at Entry Level, where there is currently a beetle bank option, and also at the Higher Level, where there is an in-field grass area option. These options would need to be revisited in relation to findings from the MOPS experimental work and cost-effectiveness analysis. Contour ploughing already occurs within the ELS soil management plan. The purpose of the plan is to detail how land will be managed to reduce the risk of erosion. Cultivating along field contours is one example of the management that can be adopted.

The minimum tillage, tramline disruption and straw incorporation options do not explicitly feature in Environmental Stewardship currently. There is a direct drilling option at Higher Level and a similar option, with lower payment, could be introduced for minimum tillage. This would allow for some cultivation, but place restrictions in terms of deep ploughing and sub-soiling. Tramline disruption could be introduced at

Entry Level whereby a commitment is made to undertake the operation on vulnerable fields in each year in return for the award of a small number of points per hectare. Alternatively, an option could be introduced at Higher Level whereby the first 20 hectares, for example, receive a higher payment and subsequent hectares receive a lower payment rate. The initial higher rate would reflect the additional 'fixed' costs of setting up the machinery to undertake the operation. Finally, a straw incorporation option could be introduced at Higher Level. Farmers would receive a fixed payment per hectare to incorporate the straw following cereal harvest.

It is important to reiterate at this point that the above are initial suggestions. Further analysis using the full three years of the results is required before conclusive recommendations could be made.

Conclusion

The control of diffuse pollution is receiving considerable research and policy interest. One of the key policy drivers is the introduction of the Water Framework Directive which requires that all Member States' surface waters must attain 'good chemical and environmental status by 2015'. The UK governments current approach is to achieve this through cross compliance measures, including soil management and the control of nitrates through Nitrate Vulnerable Zones, and through incentive based policy under Environmental Stewardship, again with land management options. The emphasis within ES is on vegetative buffer strips and crop cultivation options, as well as through consideration of soil and nutrient management.

The MOPS project reviewed in this paper highlights a number of additional in-field mitigation options that could be introduced and the development of a simple model to analyse the implications of undertaking these new, as well as existing, options for the farm manager. Currently, the analysis has been at the farm level only with future expansion to generic farm typologies planned. Nevertheless, the initial results from the farm level analysis are encouraging in that there are a number of potential options to reduce sediment and P loss that could be introduced cost-effectively through existing policy measures.

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