A FRAMEWORK TO ANALYSE THE INTERACTIONS OF WHOLE FARM PROFITS AND ENVIRONMENTAL BURDENS

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A model is described that analyses both the economic and long-term environmental performance of whole farms. The Silsoe Whole Farm Model was combined with mechanistic calculations of environmental burdens (nitrate, ammonia and nitrous oxide and methane) to produce the MEASURES Framework. MEASURES responds to changes in soil type, rainfall and farm size and calculates the optimal crop rotation (using linear programming), profitability and environmental burdens, under external constraints. The impact on cropping, profit and environmental burdens from policies to reduce ammonia emissions were determined. Covering slurry stores to reduce ammonia emissions can increase profitability by excluding rainwater and reducing spreading costs in wet areas, but ammonia emissions increase unless low-loss application techniques are used. Farmers' responses to reduced profitability can result in changed cropping that may increase environmental burdens. The cost of compliance with regulations to reduce ammonia emissions varies greatly with soil type and rainfall.

1. INTRODUCTION

Policies to reduce environmental emissions from farms need to be analysed in the context of whole farms and their responses and in the context of long-term emissions. This work analyses interactions between the many environmental burdens and the impact on sustainable farm profitability. It is important to consider the behaviour of whole farms rather than just individual technologies or regulations in isolation as the response of farmer may not yield the results expected by researchers or policymakers.

The approach taken was to extend the Silsoe Whole Farm Model (SFARMMOD) to include estimates of several environmental burdens associated with farming as well as to include a balanced N cycle within rotations. SFARMMOD began life as a farm-planning tool (Audsley, 1981). It was extended to include environmental burdens and so form the MEASURES (Multiple Environmental outcomes from Agricultural Systems) Framework (Annetts and Audsley, 2002). A major feature of this framework is that environmental equations are entered as data that can be viewed and edited by others, somewhat like the formulae in a spreadsheet. Also, additional environmental burdens can be added and existing equations modified. The model aims to impose a mass balance on main plant nutrients in order to ensure sustainable solutions and eliminate short-term environmental effects.

The MEASURES framework is unique in that it combines economic and environmental assessments of farms, so allowing interactions between economic and environmental aspects and interactions between different environmental aspects to be assessed simultaneously. In this paper, we summarise how the MEASURES Framework was constructed and give some results from the application of it, particularly for manure management on farms.
2. METHODS

2.1. Outline description of SFARMMOD

A whole farm is described within SFARMMOD in terms of its area, the nature of the soil (sandy to heavy clay) and the climate (annual rainfall). A set of possible arable and animal enterprises can be defined together with an inventory of farm machinery and labour. SFARMMOD uses linear programming to optimise farm profitability by selecting the best production system from the range of possibilities, subject to any constraints. It thus attempts to mimic farmers' behaviour by maximising farm profit within constraints. There are many activities and interactions within the SFARMMOD, which is at the centre of the MEASURES Framework (Figure 1).

An example of economic optimisation is timeliness. There is an ideal time to establish a crop for maximum yield. If established earlier, diseases may affect the crop, while if established later, the growing season is shortened, so reducing yield. Establishing all crops on the farm at their ideal time, however, requires much machinery and labour and hence a high cost. Establishing at non-optimal times can be traded off against using a smaller (thus cheaper) set of possible machinery and labour (Figure 2). All capital costs are converted to annual equivalents.
Pig and cattle enterprises are the livestock enterprises currently modelled. All pig feed is bought in and all manure is used on the farm. Cattle food is partly bought in (concentrates) and partly obtained by summer grazing and forage conserved as silage. The land allocated to forage crops must be enough to support the numbers of cattle on the farm. SFARMMOD contains many constraints and assumptions about farming practices, such as largely following the UK Government’s Codes of Good Agricultural Practice (MAFF, 1998a,b). Also, fertiliser use follows the UK Government’s recommendations for fertiliser use (MAFF, 2000).

2.2. Environmental burdens in the MEASURES Framework

The main focus of the environmental burdens concerns the N cycle. Methane emissions were also included, but only from animal agriculture. Sources of information include inventories (Chadwick et al, 1999; Pain et al, 1997 and Sneath et al, 1997); experimental data and mechanistic models (MAFF, 2000; Smith, et al, 1996; Chambers, et al, 1998; Scholefield, et al, 1991; Bouwman, 1996). Some could be used directly (e.g. ammonia emission from animal houses), but others required considerable adaptation to meet the long-term needs of the MEASURES framework (e.g. nitrate leaching).

2.3. Base cases

The base case for a pigs and arable farm is 250 ha with 2000 fattening pigs. Manure N is valued at 50% (which means that the farmer reduces mineral fertiliser application by 50% of the expected plant available N value of manure). All manure is handled as slurry, which is stored uncovered and spread by a splash plate tanker. The dairy base case included 150 cattle and followers on 250 ha. The forage requirement is met by rotational grass from the farm (about 65 ha). Most manure is handled as slurry (87%) with the rest as farmyard manure (FYM).

Options for ammonia abatement, such as are required under Integrated Pollution Prevention and Control (IPPC) rules were explored with covering a slurry store and using two low-loss application systems (injection and rapid incorporation after broadcasting).

3. RESULTS

The results of the base cases are presented as the mean of the combinations of light, medium and heavy soil under three levels of rainfall (Table 1). The values are broadly similar for cattle and pigs, but the larger emission of methane from cattle results from enteric fermentation. Net profit is crop gross margins less the labour and machinery costs. Net profit does not include the general overheads, which are typically £200-315 ha$^{-1}$.

Table 1. Base case performance of mixed farms

<table>
<thead>
<tr>
<th>All values are annual per ha</th>
<th>Dairy</th>
<th>Pigs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net profit, £</td>
<td>328</td>
<td>306</td>
</tr>
<tr>
<td>Ammonia, kg N</td>
<td>15</td>
<td>23</td>
</tr>
<tr>
<td>Nitrous oxide, kg N</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Nitrate leaching, kg N</td>
<td>78</td>
<td>74</td>
</tr>
<tr>
<td>Methane, kg CH$_4$</td>
<td>108</td>
<td>41</td>
</tr>
</tbody>
</table>
3.1. Ammonia abatement on mixed farms

On the pig farm, covering a store alone caused 6% more ammonia to be volatilised, while net profit increased by £6 ha$^{-1}$. The effect on net profit resulted from the exclusion of rainwater in wetter areas so that less slurry required spreading, but ammonia losses increase from spread slurries containing relatively more dry matter (Chambers et al, 1998). Slurry injection reduced ammonia volatilisation by 7% and net profit by £13 ha$^{-1}$, but also slightly increased leaching (2%). Rapid incorporation after broadcasting was more effective and reduced ammonia emissions by 17%, but at the expense of reducing net profit by £17 ha$^{-1}$ and increasing leaching and nitrous oxide emissions by 3% and 2%. Covering combined with rapid incorporation reduced ammonia emissions by 23% although net profit was depressed by £11 ha$^{-1}$ and leaching increased by 4%. The same reduction was achieved by also raising the manure N valuation to 75%, and this helped recover net profit, but this was still £9 ha$^{-1}$ below the base case, while nitrous oxide emissions and nitrate leaching both fell by 3%.

On the dairy farm, covering a store alone caused 3% more ammonia to be volatilised, while net profit increased by £7 ha$^{-1}$, for the same reasons as with pig slurry. Slurry injection on grass and arable land reduced ammonia volatilisation by 3% and net profit by £16 ha$^{-1}$. Rapid incorporation after broadcasting on arable land combined with injection on grassland was more effective and reduced ammonia emissions by 8%, although reducing net profit by £14 ha$^{-1}$ and increasing leaching by 2%. The combination of covering with rapid incorporation was more successful and reduced ammonia emissions by 10% while increasing net profit by £3 ha$^{-1}$. The same reduction in ammonia emissions was achieved by also raising the manure N valuation to 75%, and this raised net profit to £4 ha$^{-1}$ above the base case.

Unlike the pigs with arable scenario, there are some solutions here that can reduce nitrogenous pollution while increasing net profit, although the potential reductions in pollution are not very large.

3.2. Valuation of manure N

In the analysis above, recovery of profit was made possible by also raising the valuation of manure N. In MEASURES, this means that the farmer is assumed to substitute plant available manure N for mineral fertiliser. The effects of changing manure N valuation are powerful (Figure 3). Increasing the valuation of manure N decreases nitrate leaching and nitrous oxide emissions, by reducing mineral fertiliser applications. This also reduces costs and so increases net profit. So, the simple approach to increase the utilisation of manure N benefits farm profit and the environment. The increase in farm profits not massive, but it is in the right direction.
3.3. Effects of soil and rainfall on abatement costs

IPPC rules are principally intended to reduce ammonia pollution, but the costs of achieving abatement varied under a combination of three soil types and three rainfall levels. The costs of ammonia-N abatement consistently fell (and indeed became profitable) as rainfall increased across all soil types and with both pigs and cattle (Figure 4).

4. DISCUSSION

Estimates of net profit do not include the transitional capital costs of moving from one system to another. While covering a cattle slurry tank can save farmers money in the long term, the capital costs of changing system may restrain farmers from changing systems.

A concern arising from our analysis is that farmers may keep within the regulations, but not abate ammonia. Dairy farmers in wetter areas could be tempted to cover slurry stores to save money by excluding rainwater. This will help the farm economy, but ammonia
emissions will be increased compared with uncovered storage if conventional slurry spreading systems are kept in use owing to the dry matter effect on field volatilisation.

The variability of implementation costs with soil type and rainfall is of concern, as uniform rules will apparently penalise farmers on heavy land. The high cost of abatement could put such farmers out of business unless much cheaper technical solutions can be found.

The scope for reducing nitrogenous pollution from dairy with arable farming is limited as only half the manure is under managerial control, the rest being excreted directly on fields. Indeed, the magnitude of the responses at the whole farm level for all farm types was relatively small. Part of this was because good practices were coded into MEASURES. It does show the importance of considering how constraints or new technologies will affect farming at the whole farm level. Constraints can have unexpected consequences as farmers try to recover lost profit and many interacting factors produce effects. Increasing livestock stocking density, for example, increases the workload, as more manure must be spread. This affects periods of peak activity, such as harvest and autumn crop establishment, and causes the cropping to change to grow more spring crops. It is not necessarily an intuitive expectation, but is a solution that provides the best use of resources of the farm.

Increasing the valuation that the farmer places on manure has good effects on both farm profit and the environment. It can cost nothing more than a change in attitude by farmers and the use of free advisory publications or decision support systems. Maximising the use of manure N is helped considerably (although at greater expense) by the use of chemical analysis of ammoniacal-N, on-farm N meters for slurry analysis or, potentially, in-line meters on slurry tankers. Changing the valuation of manure had no direct effect on ammonia emissions, but contributes to the overall benefit of reducing ammonia emission by other techniques by increasing net profit.

5. CONCLUSIONS

1. A unique framework (MEASURES) has been produced that analyses the interactions between environmental performances and profit of whole farm systems under constraints such as IPPC rules.
2. The maximum overall reduction of ammonia emissions on pig farms by manure management was 23%, but this decreased profit and increased nitrate leaching.
3. Applying the same IPPC rules to reduce ammonia emissions is very costly for farms on heavy land, while farms on lighter land may increase profit.
4. Some components of possible regulations can have a negative effect if not fully analysed.
5. Increasing the valuation that farmers place on manure has a positive effect for both the environment and profit.

6. ACKNOWLEDGEMENTS

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