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Environmental policy measures for livestock production An integrated economics and natural science analysis[*]

By

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Abstract

In this paper we analyze the effect of different policy measures on the pollution from livestock farms. We have used a modelling system called EcEcMOD, which integrates economics and ecology in a consistent way. A main emphasis of the paper is on the choice of manure handling technologies, and its effect on the pollution. The choice of technology is handled within EcEcMOD in a sub model called MASH (manure application, storing and handling).

Policy measures considered are: taxes on mineral nitrogen (50, 100 and 200%), reduction in nitrogen content in feed and mandatory 12 months manure production storage capacity. The command and control measures are also combined with a 100% tax.

The main conclusion regarding measures is that they will all on average reduce the pollution level. However, there is a large variation both between measures and among the model farms. We also show that changes in technology induced by the measures might have effects which work in opposite direction of each other regarding pollution. These effects are "visible" since EcEcMOD is a micro base eco-eco modelling system. In some cases we find that results are sensitive to the assumption made about the model farms. This especially important with respect to choice of technology, since expected profit for the different options do not differ much.

Key words: pollution from livestock farms, policy measures, economics and ecology, manure handling technologies

1 Introduction

1.1 Background

There has been a growing concern about pollution over the last decades. In the case of pollution from agriculture, this growing concern stems from at least two factors. First we have got more information about the negative effects of pollution. We have more knowledge about the systems, and we have seen indications that various compartments of nature is stressed. In 1987 10 countries around the North Sea signed an agreement, whereby the countries committed themselves to reduce the nitrogen and phosphorous load to the North Sea by 50%. In addition to this, nitrate contamination of ground water is a serious problems in Europe, at least locally. In Norway this is not a big problem, mainly of two reasons: we use ground water only to a small degree, and the fertilization levels (esp. animal manure) are lower. Due to this, the policy measures in Norway should differ from the ones used elsewhere in Europe. While a reduction in the animal density, transportation of manure to less dense areas or large scale processing of manure may be the solution in countries like the Netherlands, better utilization of the manure should be the aim in Norway.

The research program Economics and Ecology, Resource Management and Pollution from Agriculture (EcEc/RMPA) was established in 1991. The main aim of the program was to integrate problems and insights from both economics and ecology, and to provide knowledge contributing to a more sustainable use of terrestrial biological production systems. A main focus of the program was studies of policy measures towards reduction of non-point source pollution from agriculture, and a model called EcEcMOD was developed. This paper presents results from some of these analyses for a set of livestock farms with focus on the loss of nitrogen. Results for other types of farms are presented in Vatn et al. (1996).

1.2 Aims of the paper

The primary aim of this paper is to study the effect of different policy measures on nitrogen pollution (nitrate leaching and ammonia losses to air) from livestock farms. There is a link between manure handling and pollution from livestock farms, and by implementing policy measures farmers may be given incentives to change the manure practice, hopefully for the better.

A secondary aim is to show how economical and environmental factors interplay. It has been important to incorporate these complexities into the analysis to get a better foundation for policy evaluations.

The paper is organized as follows. First there is a discussion of the manure handling chain and effects on the environment at different stages in the chain. This is followed by a short review of some studies analyzing choices of manure handling technologies. Thereafter the modelling framework is presented, with emphasis on the model dealing with choice of manure handling technology. Then data and policy measures are presented, and in remainder of the paper results from the analysis are presented and discussed.

1.3 The manure handling chain and environmental effects

The manure handling chain consist of different elements, from storage facility via spreading technology to incorporation into the soil. The choice of technology at each of these stages will affect the emissions of N (and P) to the environment. The losses of nitrogen when dealing with manure occur in two forms, air losses and leaching. Manure contains ammonia, and like other volatile gases it easily escapes to the air. The rest ends up in the soil and enters complex processes, and some of it may eventually leach to the groundwater.

The manure storage capacity determines how much manure that can be spread in the growth season. In Norway the average storage capacity is 8 - 9 months of manure production. This means that some manure must be spread in fall, when no plant growth can utilize the nutrient spread. When increasing storage capacity, more manure can be spread in the growth season and thereby reduce the need for purchased fertilizer. By reducing the sum of nitrogen applied, the total loss of N is reduced. Leaching will be reduced, but there may be a slight increase in losses to air since these are higher in the growth season. The reason for this is higher temperatures and less precipitation.

The conventional way of applying manure in Norway is by using tank trailer and semi liquid manure, but there are other options. One is to spread water added manure through pipes which has two effects compared to the tank trailer solution. First, application using pipes requires far less trafficking on the fields. Everything else held fixed, the yields will increase due to less direct damages to the plants and less soil compaction, i.e. the fertilizer level necessary to reach a given yield will be reduced. The other effect is reduced losses of ammonia to the air, mainly because adding water the ammonia infiltrates the soil easier. In other words, the effective nitrogen from a given amount of manure will increase, reducing the need for artificial fertilizer.

Manure is normally incorporated into the soil after some time. In this time lag it is exposed to the air, yielding losses of ammonia. By reducing this period of time the losses will be reduced, but the leaching may increase since the amount of nitrogen in the soil increases.

1.4 Previous studies

In a situation with no environmental policies (e.g. tax on fertilizer nitrogen) previous studies in the Nordic countries have shown that no shift towards better utilization of manure are profitable (Mattsson 1986; Skjølberg 1988; Tveitnes 1993). Mattsson (1986) found that a 170% tax on mineral N would make it profitable to invest in increased storage capacity and thereby increase the amount of manure applied in the spring. Christoffersen & Rysstad (1990) and Simonsen et al. (1992) have analyzed the effect on manure handling technologies and pollution under different tax rates on fertilizer nitrogen. They found that a nitrogen tax would induce the farmers to invest in storage and change spreading technology. At which tax level these changes occurred, where found to differ among model farms due to different productions and intensities. However, they found that even low levels of the tax had a clear effect.

2 An overview of EcEcMOD

As mentioned above, a modelling system - EcEcMOD - has been developed in order to analyze farmers response to environmental policies and the change in non-point source pollutions following these changes in farming practices. A more detailed description is given in Vatn et al. (1996). Here we will just give a brief overview of the modelling concept. The model is a watershed model with a set of representative model farm representing the economic agents. The model may be divided into two spheres: one economic sphere and one environmental sphere. EcEcMOD consists of several sub models with various number of modules. The main aim has been to develop a model that integrates both economics and natural sciences in a consistent way.

In the economic sphere, farmers' choices are modelled, given the resource base on the farm (area, soil types, main production, etc) and political frame conditions (regulations, taxes, prices which are politically set, etc). The farmers are assumed to maximize expected profits. The main choices modelled are: crop rotation, tillage system, manure handling practice (described below) and optimal level of fertilizer. The upper part of figure 1 shows the interactions between the different choices in the economic sphere.

Due to the micro approach chosen, the model do not handle structural changes, e.g. changes in main production. However, as mentioned above, the pollution problem in Norway is not as severe as in other countries in Europe. The need for a model handling structural changes are therefore not that important in this case.

In the environmental sphere the effects on the environment, i.e. pollution, given the farmers choices are modelled. This is done by the use of a set of natural science models. This part of EcEcMOD consists of two major elements, one dealing with leaching of nitrogen and one where phosphorus losses and soil erosion are modelled.

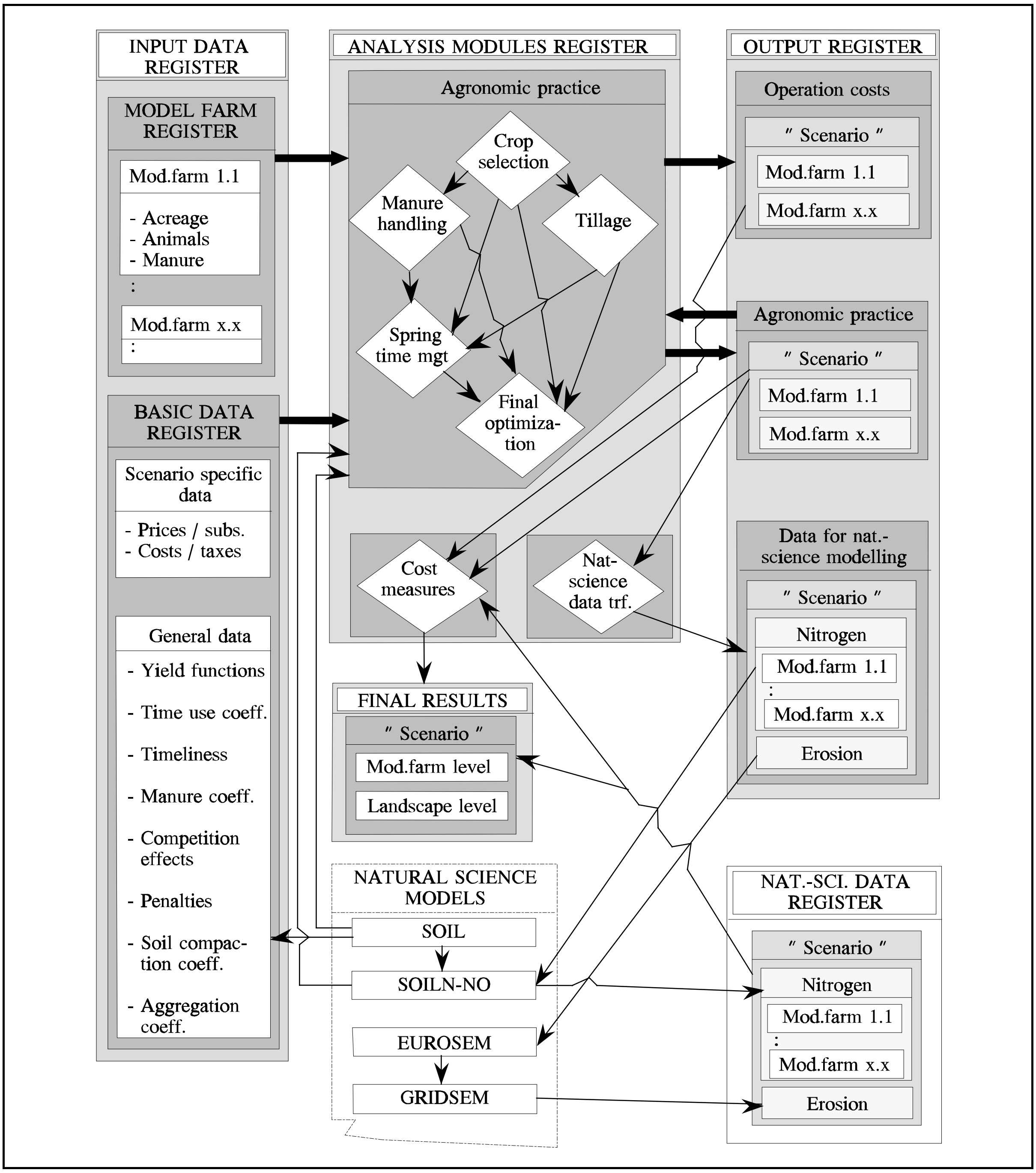

Figure 1. An overview of the EcEcMOD with emphasis on the economic sphere.

In order to cover a reasonably variation in weather, which is important in the natural science modelling, a period of 20 years was chosen. EcEcMOD does not model transitions, meaning that we are modelling different stable situations. This also mean that under the different scenarios the farmers are not bound by current (base line technology) investments, with a few exceptions. Loosely speaking, this means that farmers adapt to the new frame conditions in year 0 in the 20 years scenarios. All results presented here are average over the 20 year sequence.

3 The MASH model

3.1 Introduction

MASH (Manure Application, Storing and Handling) is part of EcEcMod. In figure 1 the interaction between MASH and the other parts of the economic sphere can be seen. Given the frame conditions on the model farm, a optimal crop rotation plan is found. Combining these two elements, the optimal choice of manure handling technology is found using the procedure described below. The choice of technology affects the spring time management (when to do sow bed preparations, sow, etc) and the final optimization (where optimal level of fertilizer, etc are found). The choices in the economic sphere are then fed into the natural science models, where nitrogen leaching and soil erosion/phosphorous losses are estimated. There is also a feedback loop form the environmental sphere to the economic sphere.

3.2 Modelling principles

Like the other elements of the economic part of EcEcMod, MASH is a farm level model where the farmer is assumed to maximize expected profit. The purpose of MASH is to model the optimal choice of technology for each model farm. These farms are described by, among other things, the total amount of manure and a given number of fields with certain characteristics such as size and soil type. This is combined with the crop rotation plan for each field and optimal application of manure is found for each field. It is assumed that the farmers do not differ the application of manure between for groups of crops, i.e.

grains except winter wheat are treated as one group, winter wheat as one and meadow as one.

The set of technologies the farmer can choose from is rather large, and it would be almost impossible to model all of them. The set we have chosen consists of well established and working technologies.

Since storage capacity determine how much can/must be applied in the different season, esp. in fall, we are modelling three sizes of storage: 8, 10 and 12 months storage capacity. In order to meet the current regulations, no application on frozen soil, a storage capacity of at least 8 months is needed. The standard solution in Norway regarding application of manure, is to spray semi liquid manure using tank trailer. In addition to this we have modelled two other options: tank trailer spreading semi liquid manure added 100% water and application of the same manure type using a system of pipes/hoses. The different application technologies yield different losses of ammonia to air and different soil compaction losses. On grains, the manure is incorporated into the soil after application. The loss of ammonia depends on the period of time between application and incorporation. We have modelled an average time lag between application and incorporation of one and two days.

Since non of the technologies at different stages are mutually exclusive, we end up with a set of 18 technologies.

The choice of technology combination is modelled in two steps. For each technology combination the expected profit is estimated. The chosen technology combination is then the technology yielding the highest expected profit.

Formally the model can be expressed by:

$$\mathrm{MAX}\{E[\pi^{*1}],. .., E[\pi^{*j}],. .., E[\pi^{*J}]\} \qquad [1]$$

where J is the total number of technologies (18), and $E[\pi^{*j}]$ is the expected profit when using technology j. For a given year and technology this is defined by

$$E[\pi^{*j}] \equiv \underset{\beta}{\mathrm{MAX}} \left\{ E[\pi^{j}] = E\left[\sum_{i=1}^{I} \left(a_i \left[p_i f_i(N_i) \Omega_i^j(N_{i1}, N_{i2}, N_{i3}) - \sum_{k=1}^{3} v_{ik}^j N_{ik} - v_m N_{im} \right] \right) - FC^{j} \right] \right\} \qquad [2]$$

where	j	is the technology index
	i	is the crop group index
	k	is the manure spreading season index
	β	is a vector of choice variables (N_{ik} and N_{im} $\forall i,k$)
	N_i	is the total amount of nitrogen available to the plants during the growth season ($N_i = N_{i1} + N_{i2} + N_{im} + N_{ic}$)
	N_{i1}	nitrogen from manure applied in spring, kg N/ha
	N_{i2}	nitrogen from manure applied in summer (set = 0 for small grains), kg N/ha
	N_{i3}	nitrogen from manure applied in fall (assumed to have no effect on the current growth), kg N/ha
	N_{im}	nitrogen applied as mineral fertilizer, kg N/ha
	N_{ic}	carry over effect from manure applied previous years, kg N/ha
	a_i	area of field i, ha
	p_i	price of crop on field i, NOK/kg
	$f_i(\bullet)$	product function for crop on field i, kg/ha
	$\Omega_i^j(\bullet)$	correction factor due to soil compaction/trafficking (a function of manure applied in different seasons) and date of sowing
	v_m	price of mineral fertilizer, NOK/kg N
	v_i^j	variable costs for technology j, NOK/kg N
	FC^j	fixed cost associated with technology j, NOK

Equation [2] may look complicated, but it just an ordinary direct profit function. $p_i f_i(\bullet)\Omega_i^j(\bullet)$ is the gross income per ha for field i. $\Sigma v_{ik}^j N_{ik}$ is the variable costs per ha in connection with spreading of manure, while $v_m N_{im}$ is the variable cost from applying mineral fertilizer. The gross income less the variable costs yield the gross margin per ha. The gross margin multiplied by the area of the field and summed over all fields, give the total gross margin. This less the fixed costs, FC^j, yield the net income, or profit.

In addition to non-negative constraint on all choice variables, equation [2] is maximized subject to the following constraints

$$\sum_{i=1}^{I} a_i \sum_{k=1}^{3} \frac{N_{ik}}{1-\gamma_{ik}^j} = \bar{N} \qquad [3]$$

$$\sum_{i=1}^{I} a_i \frac{N_{ik}}{1-\gamma_{ik}^j} \leq \tau^j \bar{N} \qquad \forall k \qquad [4]$$

where	γ_{ik}^{j}	loss of nitrogen (as ammonia) to the air after spreading for field i in season k when using spreading technology j
	$\bar{N}$	total production of manure-N (ammonia) per year, corrected for losses during storage
	τ^{j}	storage capacity expressed as fraction of year for technology j.

These two constraints are both connected to storage capacity. Equation [3] simply says that all manure produced during a year must be spread (two spreading seasons on pig/grain farms, three on farms with meadow), while [4] puts a limit on how much it is possible to spread in each season.

Since we are not modelling the amount of manure in storage explicitly, we need to make some further assumptions. Applied in spring, manure is a substitute for mineral fertilizer. If the manure is spread in fall, the only fertilizing effect will be the carry over effect next year, which is relative small. Hence, manure has the highest value in spring. We therefore assume that the storage is full when applying manure in spring.

In order to not exceed storage capacity on pig/grain farms the amount in storage in spring plus production during summer less what is applied in spring should be less than the storage capacity. Formally:

$$\tau^{j}\bar{N} - \sum_{i=1}^{I} a_i \frac{N_{i1}}{1-\gamma_{i1}^{j}} + \alpha\bar{N} \le \tau^{j}\bar{N} \qquad [5]$$

Rearranging and canceling terms yield:

$$\sum_{i=1}^{I} a_i \frac{N_{i1}}{1-\gamma_{i1}^{j}} \ge \alpha\bar{N} \qquad [6]$$

where α is the time, expressed as fraction of a year, from spring application to fall.

There are similar constraints for milk/beef farms, but since they have three spreading seasons we need three constraints. The model is programmed in SAS using PROC NLP. An overview of the data flow in the MASH is shown in figure 2.

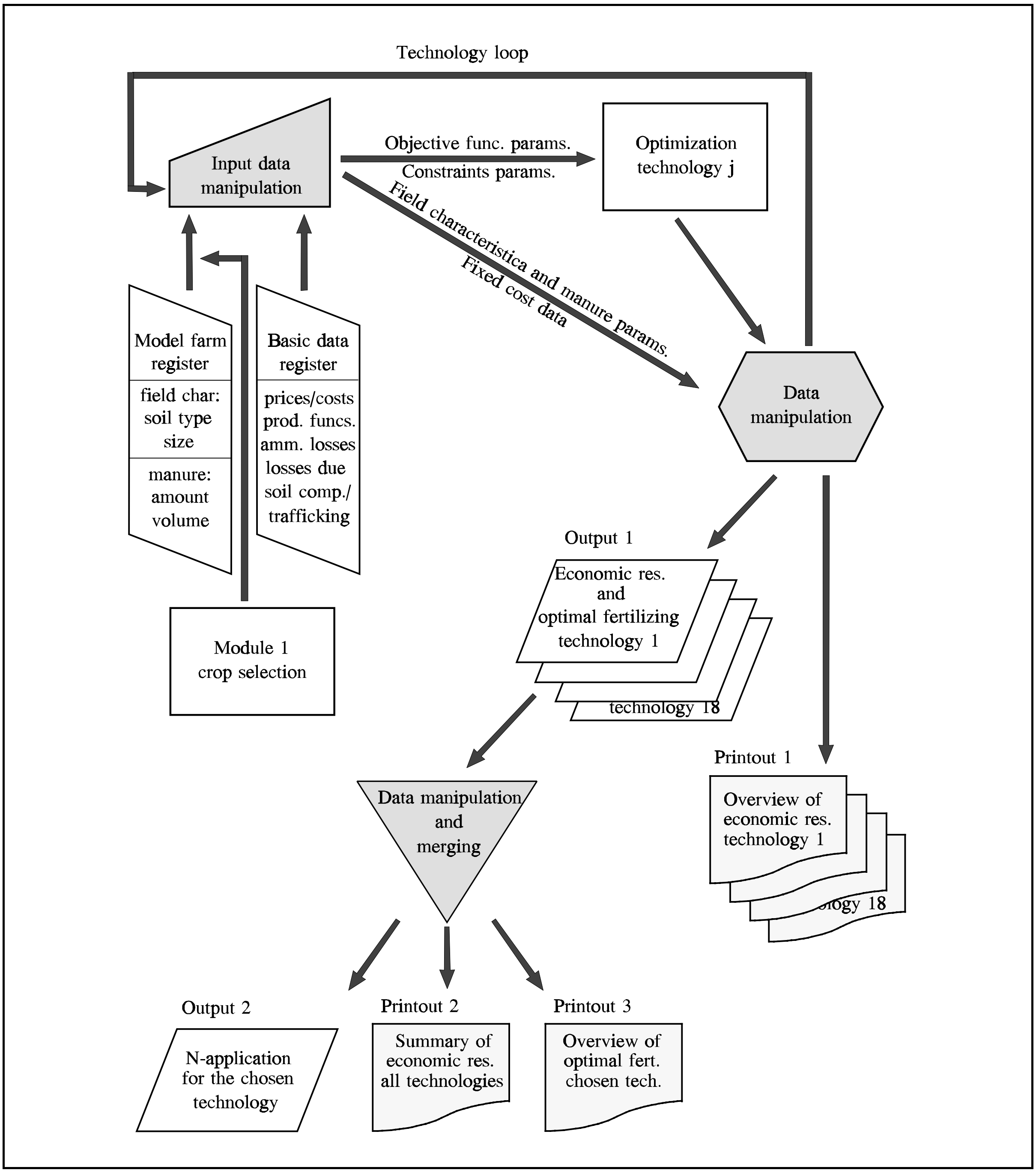

Figure 2 Overview of the data flow in MASH.

3.3 Carry over effects

Carry over effects from manure are of two types. Some of the ammonia spread in fall will still be available the next spring. The other type originates from the pool of organic N in the soil which increases with increased use of manure. From this pool, a certain amount is made available to the plants each year, dependent of the size of the pool. The effect of mineralized organic N is assumed to be a constant fraction of the total amount of organic nitrogen produced/spread annually. The major assumptions behind this is that differences in application from year to year are evened out over time (the percentage added to the pool in the soil is rather small), and that this effect is not soil type dependent.

Since the optimization is static, i.e. each year is treated independently, the ammonia carry over effect is set prior to optimization. Since the value of manure applied in spring is larger than in fall, optimal application of manure in fall is driven by the size of storage, or more precisely how much must be applied in fall in order not to exceed storage capacity during winter. By requiring application of ammonia in fall to be equal for all groups of crops, we insure consistency across years. The carry over effects are estimated using SOILN-NO (Vold et al. 1995; Vold & Søreng 1994).

4 Data and policy measures

4.1 The study area and model farms

Two small watersheds in the south eastern part of Norway were chosen as study areas. Auli in Vestfold county covers 2597 ha of arable land and have 176 farms, while Mørdre in Akershus county covers approximately 446 ha of arable land, having 18 farms. On the basis of information about the actual farms in the areas, 14 model farms (10 in Auli and four in Mørdre) were created. The information on each farm included area with soil type, production type and number of animals. The model farms were created as to maintain the actual variation in production and soil type distribution. Each model farm is characterized by type of production (specialized grain production, milk/beef and pigs/grain), number of fields (with area and soil type), number of different animals (if any) with an associated manure production and a set of baseline technologies (soil preparation system, manure handling, etc). The farms are classified according to size and intensity of production.

Eight of the 14 model farm have livestock production. Table 1 gives an overview of the key characteristics of these model farms.

Table 1. Overview of the livestock farms.

Watershed	Model farm	Production	Classification	Arable land ha	Manure production kg NH_3-N/ha
Auli	1.1	Milk/beef	Small/extensive	13.0	35.2
	1.2	Milk/beef	Large/extensive	31.0	57.6
	1.3	Milk/beef	Intensive	18.0	109.5
	1.4	Pigs/grain	Small/extensive	14.0	52.9
	1.5	Pigs/grain	Large/extensive	28.5	67.4
	1.6	Pigs/grain	Intensive	9.5	241.3
Mørdre	2.1	Milk/beef	Large/extensive	38.5	48.6
	2.2	Pigs/grain	Large/extensive	48.5	31.0

4.2 Policy measurers

A wide range of policy measures are available when trying to reduce non-point source pollution from agriculture. The measures can broadly be divided into two categories: command and control and economic instruments. It is, of course, also possible to use a combination of these two categories.

Since the optimal level of fertilizer is where the value of the marginal product equals the marginal cost with respect to the different inputs, it is possible to induce a reduction in the optimal level by taxing the polluting inputs. In the case of livestock production it is possible to only tax one of the polluting inputs, mineral fertilizer. In general this will have two effects. First it will reduce the use of mineral fertilizer, which will have a positive effect on pollution since the total amount of nitrogen applied will be reduced (manure production and area are constant). Since the marginal cost of the different inputs should equal at optimum, an increase in the price of mineral fertilizer will induce better utilization of manure. We have analyzed three levels of taxes on mineral nitrogen: 50%, 100% and 200% (referred to as resp. Tax 50, Tax 100 and Tax 200).

Leneman et al. (1993) found that for the Netherlands reduced nitrogen content in feed was a cost effective measure in order to reduce nitrate pollution. Veenendaal and Brouwer (1991) also found that this was relatively cheap way to reduce emissions. Reducing the nitrogen content in feed will lead to a reduction in N concentration in the manure, reducing the total amount of manure N spread. We have modelled a situation where the amount of nitrogen in concentrates is reduced (Feed 2), but kept within the limits of existing norms (Bolstad 1994). Policy measures in this case may be directed towards feed producing companies on the basis of mandatory standards. In addition we have also analyzed the combined effect of the new feeding regime and a 100% tax on N (F2+T100).

Another command and control measure that is analyzed is a mandatory full year manure storage capacity (Store 12), making it possible to spread all manure in the growth season. Given reasonable levels of manure on the farm, there will be no fall application of manure, reducing the need for mineral N and losses of nitrogen connected with spring spreading. Also here we have combined the measure with a 100% tax on mineral nitrogen (S12+T100).

All results are compared to a base line scenario where no environmental policy measures are implemented.

5 Results and discussions

In this part of the paper we first present the results for the different measures regarding choice of technology, the effect on pollution and the effect on farm income. In the case of taxes on fertilizer nitrogen we also look at the optimal levels of fertilizer in the light of increased price of nitrogen and the technological changes.

At the end we compare all the measures with respect to cost efficiency (cost to society per reduced unit of leaching) and discuss some policy issues in this respect.

5.1 Tax on fertilizer nitrogen

The choice of technology

An increase in the price of artificial fertilizer will, as mentioned above, increase the value of manure. This will give incentives to the farmer to utilize the manure better, which can be achieved by changing technology. Table 2 shows the technology choice under different tax rates on fertilizer N.

With one exception all model farms undertake some improvement in manure handling. The one exception is model farm 1.6, which sticks to the base line technology. The reason for this is rather simple. This farm has a large amount of manure, and has therefore no incentives to improve the utilization. Since this model farm has a large amount of manure she/he might sell some of it to other farms. With no tax on nitrogen, transportation costs exceeds the price of mineral nitrogen and no trade will take place. At a tax rate somewhere between 50 and 100% it becomes profitable to sell manure, within a certain distance from the farm. Results from this analysis is presented at the end of this section (5.1).

Table 2. Choice of technology under different tax rates. Figures in bold indicate where changes in technology take place. Store is storing capacity in months, spread is spreading technology (t-t = conventional tank trailer, p-h = hose/pipe) and incorp is time lag between spreading and incorporation (s-d = same day, n-d = next day).

Pig/grain farms												
	1.4			1.5			1.6			2.2		
Tax	Store	Spread	Incorp	Store	Spread	Incorp	Store	Spread	Incorp	Store	Spread	Incorp
0	8	t-t	n-d	8	t-t	n-d	8	t-t	n-d	8	t-t	n-d
50	8	t-t	**s-d**	8	t-t	**s-d**	8	t-t	n-d	8	t-t	**s-d**
100	8	t-t	s-d	8	t-t	s-d	8	t-t	n-d	8	t-t	s-d
200	8	t-t	s-d	**12**	t-t	s-d	8	t-t	n-d	**12**	t-t	s-d
Milk/beef farms												
	1.1			1.2			1.3			2.1		
Tax	Store	Spread	Incorp	Store	Spread	Incorp	Store	Spread	Incorp	Store	Spread	Incorp
0	8	t-t	n-d	8	t-t	n-d	8	p-h	n-d	8	t-t	s-d
50	8	t-t	**s-d**	8	t-t	n-d	8	p-h	n-d	8	t-t	s-d
100	**12**	t-t	s-d	8	**p-h**	**s-d**	8	p-h	n-d	8	t-t	s-d
200	12	t-t	s-d	8	p-h	s-d	8	p-h	**s-d**	8	**p-h**	s-d

In general a reduction in the time lag between spreading and incorporation occurs first, indicating that this is the cheapest way to improve the manure utilization.

Our results differ somewhat from Simonsen et al. (1992). The main reason for this is that we have split the effect of changing spreading technology into changes in ammonia losses to air and changes in trafficking damages. We have also differentiated these effects for spreading season and soil type.

The effect on the pollution

As mentioned earlier, there are two main types of nitrogen pollution involved in livestock production: nitrate pollution of water, and ammonia losses to the air. While the first one depends on a lot of different factors like amount of manure applied in fall, the latter one is almost entirely driven by the choice of technology. Figure 3 shows leaching and losses to air under different taxes.

As shown i table 2, model farm 1.6 does not undertake any change in technology. Model farm 1.3 also has much manure, and the only technological change occur under Tax 200, where the time lag between spreading and incorporation on grain is reduced. However, this farm are using the pipe system for applying in the base case, reducing the potential for further improvements. Since 80% of the total area on this model farm is meadow, the reduction in losses to air are only modest (app. 4%). Most of the reduction in pollution for this farm must therefore be attributed to a general reduction in applied nitrogen, which is rather large in gras production mainly due to an increased use of clover.

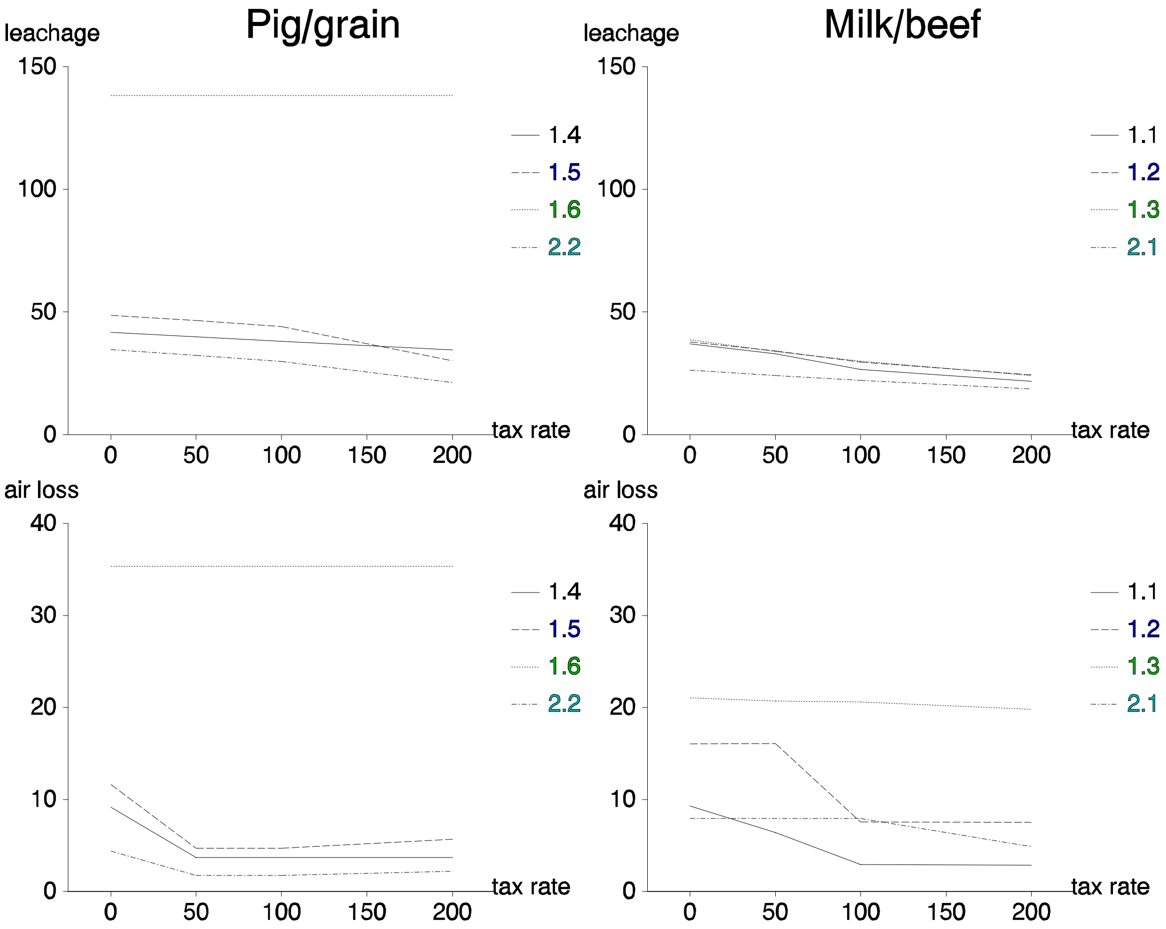

Figure 3. Leaching and losses to air. All figures in kg N per ha.

On farms 1.4 and 2.2 the losses to air increases from Tax 100 to Tax 200. The reason for this is investment in increased storage to a full year capacity, resulting in a larger amount of fertilizer spread in spring when losses to air are larger than in fall. Farm 1.1 also invests in 12 month storage capacity, but here there is no increase in losses to air due to a reduction in manure applied to meadows, counteracting the isolated effect of larger losses in the growth season.

In general the relative reductions in leaching are higher at the milk/beef farms at all levels of the tax. Under Tax 50, if we exclude farm 1.6, the reductions range from 4.6% (farms 1.4 and 1.5) to 12.5% (farm 1.3). Under Tax 100 and Tax 200 the ranges are 8.8% (farm 1.4) to 28.3% (farm 1.1) and 17.6% (farm 1.4) to 41.2% (farm 1.1) respectively.

The effect on farm income

The effects on farm income is important in more ways. From a modelling point of view it is important that income do not drop to much, since type of production is kept fixed. Figure 4 gives an overview of the reduction in income under the different tax regimes. As can be seen the variation is rather large.

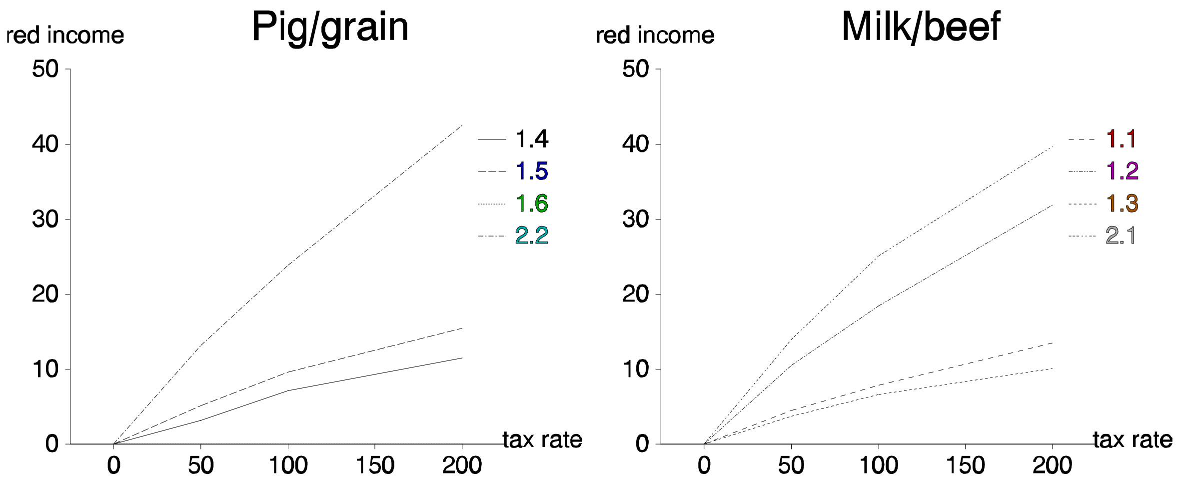

Figure 4. Reduction in farm income (1000 NOK) under different fertilizer N tax rates.

There is a positive correlation between size and reduction in income, as one would expect. Farm 1.6 changes nothing and is using only nitrogen from manure, hence no reduction in income will occur. Farm 1.3 exhibits the second smallest reduction. This farm also have a large per hectare amount of manure, and as shown in table 2 make only small changes in manure handling. The per ha reductions in income show a lower variation.

Fertilizer levels

In figure 5 the total amount of nitrogen applied in the growth season and amount of nitrogen from manure is shown.

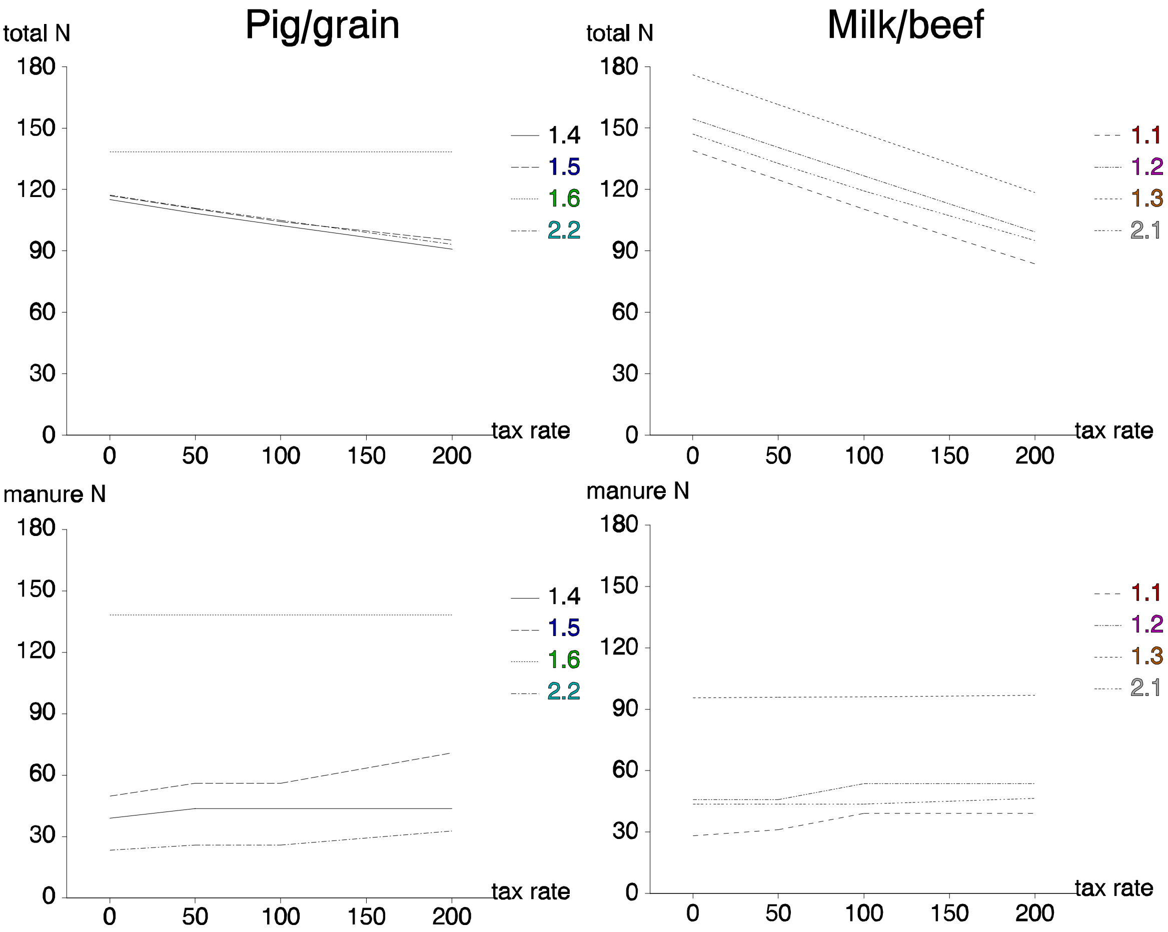

Figure 5. Nitrogen applied in the growth season. All figures in kg N per ha.

As pointed out earlier farm 1.6 is insensitive to a change in mineral N price, since the need of nitrogen is covered by manure. We see that the response to a tax is larger for the milk/beef farms than for the pig/grain farms. The reason for this is a substitution effect on meadow. When increasing the price of fertilizer it becomes profitable to use N fixating crops, in this case clover. This is even more evident if we look at fertilization level for grain and meadow for the milk/beef farms separately. This is shown in figure 6.

Another interesting point is connected to model farms 1.1 and 1.2 under a 100% tax and model farm 2.1 under a 200% tax. They all shift to technologies resulting in less soil compaction and trafficking damages esp. on meadow. This means that for a given level of fertilizer the yield increases, increasing the effectiveness of manure. This has two effects on the optimal fertilization level. Since meadow is used as feed and for dietary reason some meadow is necessary, the marginal value of meadow will decrease. Loosely speaking the farmer is less constrained, resulting in reduction in the optimal level of nitrogen. The other effect is that since marginal productivity increases the optimal N level also increases. It hard to say which of the two effects dominates since also the price of nitrogen changes. What is clear from our simulations (figure 6) is that the use of manure on grain increases more than on meadow.

Regarding utilization of manure, the two types of farms do not show great differences. What is evident, and as expected, is that an increase in storage capacity is the technological change that brings about the largest increase in manure utilization (farms 1.1, 1.5 and 2.2).

The use of purchased nitrogen, which is the difference between total N and manure N in figure 5, varies between farms. Since utilization of manure increases, the reduction in use of artificial nitrogen is larger than the decrease in total N. In relative terms the reduction range from (excluding farm 1.6) 9.4 - 18.9% under Tax 50, 15.7 - 36.1% under Tax 100 and 35.5 - 72.8% under Tax 200. In general the relative reductions are higher for milk/beef farms than pig/grain. This is due to the larger reduction in total N for beef/milk farms, which in turn is due to the substitution effect on meadow and reduced trafficking damages.

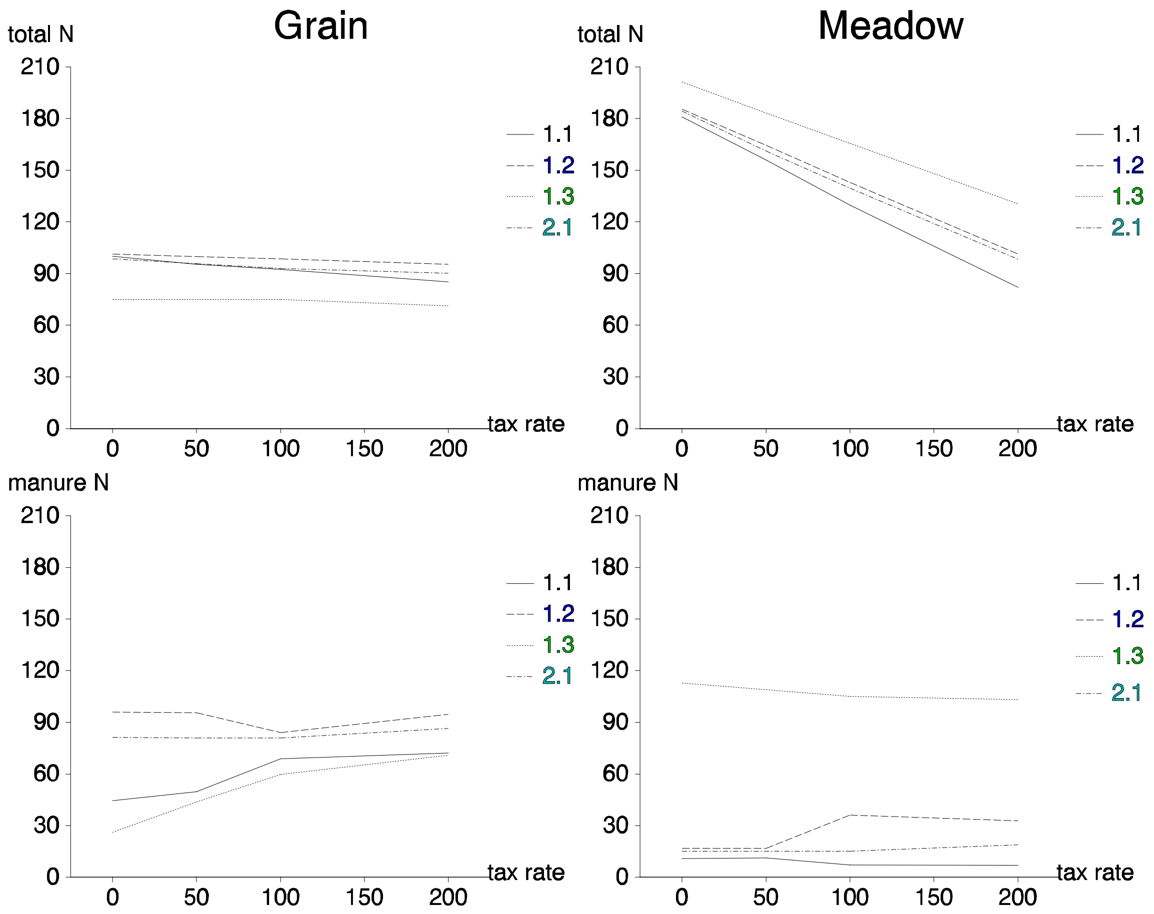

Figure 6. Nitrogen, total and from manure, applied in the growth season on milk/beef farms broken down into use of fertilizer on grain and meadow. All figures in kg N per ha.

Since the use of purchased N is rather linear with respect to nitrogen price (or tax) we can use these numbers to find rough price elasticities. For the pig/grain farms the price elasticity is in the range -0.20 to -0.15, while for milk/beef the range is -0.30 to -0.25. Compared to findings in other countries it seems that the response to a tax is somewhat lower in our analysis. Vermersch et al. (1993) found a price elasticity of -0.31 for intensive livestock production in France, while Fontein et al. (1994) found elasticities to be -1.9 and -0.4 for pig breeding and pig fattening farms respectively.

A market for manure

The idea behind this part of the analysis it that model farm 1.6 sells some of its manure to other farms where it substitutes the mineral fertilizer, yielding the same level of emissions on these farms. We have also assumed that sales will only take place in spring, since a redistribution of manure applied in fall will only redistribute the emissions. The willingness of other farmers to pay for the manure is equal to the opportunity cost, i.e. cost of mineral nitrogen. Due to high transportation cost the net payment to farmer 1.6 does not exceed his reservation price (marginal value of manure used in own production) before the price of mineral N is increased by 50 - 100%. The results presented here is under a 100% on fertilizer N.

At first thought one would expect the farmer to improve manure handling in order to be able to sell more. Regarding increased storage the farmer already has 8 months storage capacity and costs are assumed to be sunk. Even with this capacity it is possible for him to sell some manure. The increased amount for sales when increasing storage must therefore bear all the investment costs. For spreading method and time lag before incorporation there are no sunk cost, but the possible increase in sales from improvements here are rather small. Since both a storage expansion and the use of the pipe system for applying manure are expensive, the optimal choices are 8 months storage and tank trailer. The only change compared to Tax 100 is reduction in time lag between application and incorporation of manure.

Given these choices model farm 1.6 sells about 32% of the total manure, yielding a rather large reduction in nitrogen application on her/his own farm. This in turn leads to a 39% reduction in leaching. There is also a slight increase in income.

5.2 Reduction in nitrogen content in concentrate

Choice of technology

When reducing the content of nitrogen in manure, the costs of utilization per unit will increase since most of the costs are either connected to volume or they are fixed. In the Feed 2 scenario no model farm improve technology. Farm 2.1 does the opposite and chooses to increase the time lag between application of manure and incorporation into the soil. When combining Feed 2 and Tax 100 (F2+T100) the choices of technology are the same as under Tax 100 with two exceptions: farm 1.1 shifts back to 8 month storage capacity and farm 1.2 chooses to apply manure using tank trailer in stead of through pipes. In other words: Tax 100 induces more shifts in technology than the combined measures.

The effect on pollution

Even though reduction in nitrogen content in concentrate does not lead to technological improvements it will still lead to reduction in the pollution levels. The main reason for this is reduction in nitrogen amount applied in fall. Under the new feeding regime all farms choose 8 month storage capacity, and apply the same volume of manure in fall. Since the nitrogen content in manure is reduced the amount of nitrogen applied outside the growth season will decrease, reducing the leaching.

Used alone the reduction in leaching must said to modest, except for farm 1.6. This farm has more nitrogen in manure than is optimal, and a reduction in manure nitrogen will therefore show directly up as reduced leaching. The total amount of nitrogen applied in the growth season do not differ between Base and Feed 2 (or between Tax 100 and F2+T100). The reduction in pollution must therefore be attributed to reduced nitrogen load outside the growth season. The same volume is applied, but with lower nitrogen concentration. For the pig/grain farms a combination of Feed 2 and Tax 100 reduces the leaching more than both measures alone. For the milk/beef farms Tax 100 yields the largest reductions.

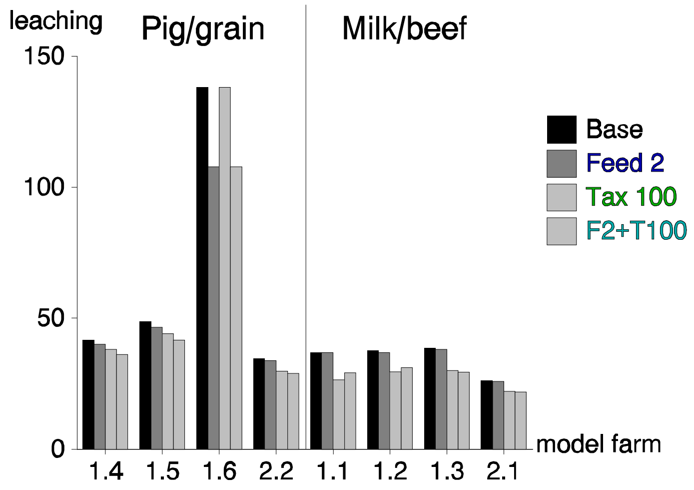

Figure 10. Leaching (kg N/ha) when reducing nitrogen content in feed.

On average the reduction in leaching from Base is 4.8% for Feed 2, 15.0% for Tax 100 and 18.2% for F2+T100.

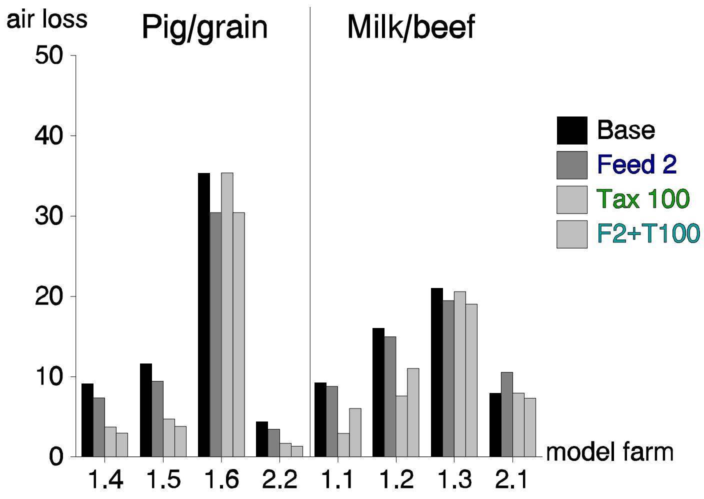

Figure 11. Losses to air (kg N/ha) when reducing nitrogen content in feed.

As mentioned before, losses to air is mainly driven by the choice of technology. In addition we here have another effect. When reducing the nitrogen content in the manure, the losses to air will be reduced since these are technology dependent fixed fraction of applied manure N. This effect is very clear when looking at model farm 1.6 in the figure above. For this farm the same technology is used under all measures, hence the 14%

reduction in losses to air must be attributed to this effect. Model farms 1.1 and 1.2 shifts back to less efficient utilization of manure from Tax 100 to F2+T100, leading to an increase in losses to air. Under Feed 2 farm 2.1 chooses to incorporate manure the next day leading to increased losses, and in this case this effect is larger than the effect of reduced nitrogen content in the manure.

The effect on farm income

The effect on farm income from Feed 2 is modest. The main source of the reduction in income is the need for more purchased fertilizer. On model farm 1.6 the income increases. The reason for this is that under Base the fertilization level is higher than the level yielding maximum production, at least for some crops. As expected the reduction in income increases as more measures are added. It is, however, evident that the largest reduction in income stems from adding the tax.

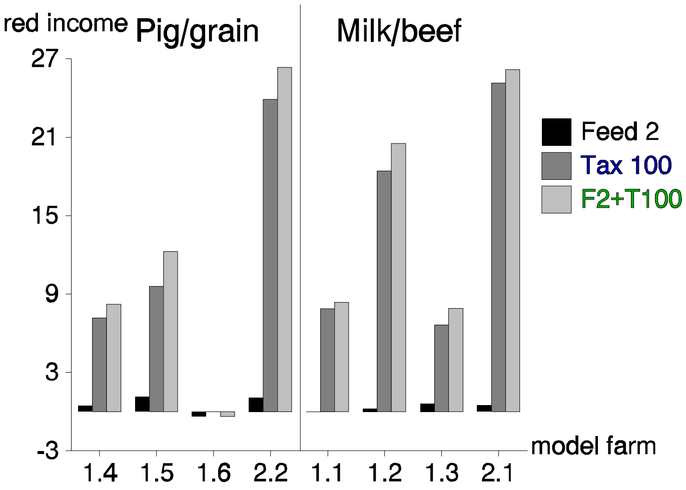

Figure 12. Reduction in farm income (1000 NOK) compared to Base.

5.3 Mandatory full year storage capacity

Choice of technology

As we have shown, a tax on mineral N, even at 200%, is a weak incentive in order to induce investments in storage. However, increased storage capacity will reduce the application of manure outside the growth season, with a positive effect on the environment. It is therefore interesting to look at this option.

It hard to tell a priori if the farmers will also choose other technological improvements when they are required to have 12 months storage capacity. We have seen earlier that reduction in time lag between application and incorporation of manure seems to be a cheap change. Except for model farm 1.6, all the pig/grain farm choose to do change. When applying all manure in spring, which is the effect of 12 months storage capacity, the losses to air increase cet. par. This loss can be reduced by incorporate the manure earlier. In the case of milk/beef production the situation is somewhat different due to a more complex production situation (grain and meadow). Model farm 1.3 shift spreading technology from the pipe system to tank trailer application and at the same time reduces the time to incorporation. At this farm there is a relatively high amount of manure per ha and 80% of the area is meadow. The pipe system has two main effects: reducing ammonia losses and reduce trafficking damages, but it is a costly technology. Also, the trafficking damages are largest on meadow and largest in fall. By shifting to spring application, following from 12 months storage capacity, the difference in trafficking damages between these two technologies is reduced dramatically.

In the combined case (S12+T100) there is an incentive to improve manure utilization further. The difference to Store 12 is that all farms (except 1.6) choose to incorporate the manure the same day.

The effect on pollution

When applying more of the manure in the growth season, the need for mineral fertilizer will be reduced, and the total amount of nitrogen applied will be reduced. Since the situation during the growth season is the same there should be no change in leaching during the growth season when applying more manure in spring. The critical factor is then what happens in fall. If there is a large time lag between application and incorporation the residual amount of should be about the same. The losses to air in fall would of course increase. In our modelling we found it reasonably to assume that the time lag is the same in all manure spreading seasons. Due to this we are not able to test this explicitly.

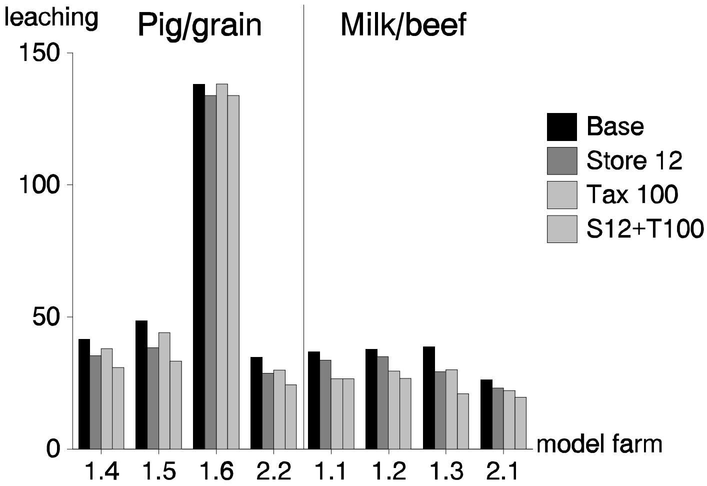

Figure 13. Leaching (kg N/ha) under mandatory storage capacity.

Regarding the discussion above, the results for model farm 1.3 is interesting. With 80% in meadow the choice of time lag between application and incorporation in fall have a small effect on the losses to air. What is clearly evident from our simulations is that leaching is reduced when all the manure is applied in the spring. This is contrary to what was found by Young & Crower (1986) and Leneman et al. (1993).

In general Store 12 induces a higher reduction in leaching than Tax 100. This is also the case for model farm 1.6. Even at this farms high level of nitrogen application there is still a positive marginal plant uptake with respect to nitrogen. However, this does not mean that marginal output is positive. The positive N uptake reduces the residual amount of nitrogen in fall. The combined case (S12+T100) induces a further reduction, which should be attributed to general reduction in optimal N application.

Regarding losses to air these are in most cases reduced under Store 12 due to shorter time lag between application and incorporation, even though the losses are generally higher in the spring. The latter effect shows up on model farm 1.6. Losses to air increases under Store 12, and since this farm does not change technology the reason for this increase must be higher losses in spring. The large increase on farm 1.3 is due to a shift in spreading technology from the pipe system to tank trailer.

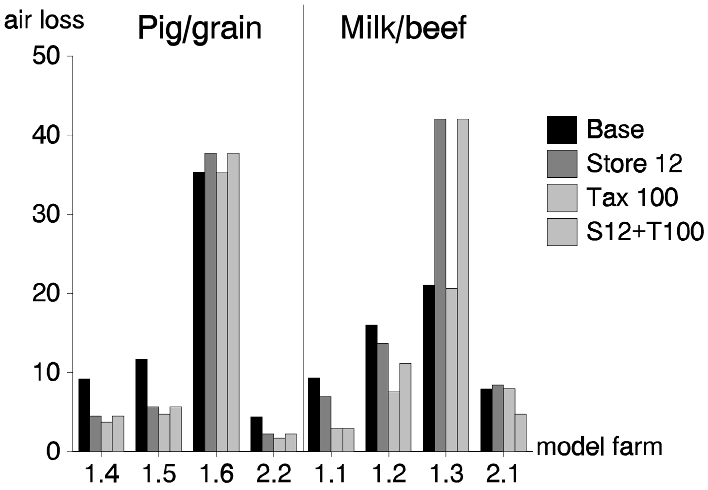

Figure 14. Losses to air (kg N/ha) under mandatory storage capacity.

The effect on farm income

It is costly to invest in increased storage capacity. The cost will vary between farms, due to the variation in manure production. As we have seen, an increase in storage capacity will lead to better utilization of manure and thereby reducing the need for and cost of purchased nitrogen. The value of the gained manure N will vary according to type of production and amount of manure per ha. In other words we would expect to see a large variation.

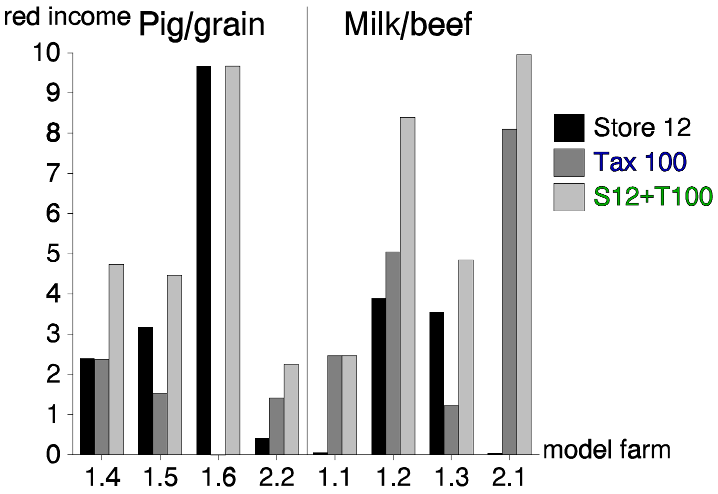

Figure 15. Reduction in farm income (1000 NOK) compared to Base.

Two model farms stand out to be of special interest. Farm 1.6 will not gain anything by expanding storage. Rather the opposite, an increase in fertilization level will at best increase the output slightly, a reduction is more likely. In addition to this, volume of manure is large demanding a large increase in absolute terms. All in all this will make this measure costly for this farm. In the other end of the scale is model farm 2.1. Here the cost of increasing storage is very small. It is almost profitable in the Base case. We also see that there is a large negative effect of a tax (ref. fig. 4) and that this is further increased by combining the two measures.

5.4 Comparing the diffrent measures - cost efficiency

As we have seen above, there is a large variation in effect on pollution and income, both when comparing different measures and comparing different model farms. This is of course what we had anticipated, there is large variation in the real world. However, this makes the comparison of different measures harder. One convenient way to compare different measures is to compare the cost per unit of reduced pollution. From a policy point of view it is most interesting to use social costs as the cost measure. In some cases this differs from the private cost, in other cases they are the same. Regarding taxes on nitrogen, the net tax revenue collected by the regulator can be viewed as a transfer from the farmers to the regulator, i.e. this is not a social cost. Some argue that it is a social benefit from such transfers, the so called double dividend argument. An other possible problem with cost efficiency measures is that it hides information. Total reduction in pollution or total costs does not show up since the cost efficiency is only the ratio between them. A final concern in our case is that we have two sorts of pollution; leaching and losses to air. The question, almost impossible to answer since we do not know the value of the damages of them, is how much of the costs should be attributed to each of them.

In this light is should be clear that the cost efficiency measures should be interpreted with care and in light of the results presented in the previous sections. Table 3 show the cost efficiency of the different measures. Since leaching of nitrogen is considered to be the main problem in Norway all cost is attributed to reduction in leaching.

Without going into details two general comments can be made to the table. First, the variation along both the model farm and measure dimension is large. Model farm 1.6 is at the extreme in both ends of the scale. The second point is that the cost efficiency reduces as the measure get more stringent (either by increasing the tax or combing measures).

Table 3. Cost efficiency of reducing leaching (NOK per kg reduced nitrogen leaching) compared to the base line scenario of the different measures.

Pig/grain farms				
Measure	1.4	1.5	1.6	2.2
Tax 50	21	9	*	8
Tax 100	46	12	*	6
Tax 200	47	14	*	12
Feed 2	22	19	-1	24
F2+T100	38	14	-1	9
Store 12	21	11	236	1
S12+T100	31	10	236	5
Milk/beef farms				
Measure	1.1	1.2	1.3	2.1
Tax 50	16	16	3	46
Tax 100	18	8	8	51
Tax 200	34	21	21	60
Feed 2	-9	60	22	36
F2+T100	22	11	38	50
Store 12	1	21	27	*
S12+T100	18	15	31	39

* = no social cost or no reduction occur, making cost efficiency meaningless.

In addition to these measures we also analyzed the case where model farm 1.6 sold manure under Tax 100. Since leaching was reduced and income increased, cost efficiency is negative (-2).

5.5 Eco-eco modelling at micro level - some remarks

Compared to other more aggregated analysis, our micro based approach yields more information at all levels. Most important in our view, is the information about the interplay between economy and ecology, especially when it comes to technology. One example is that by modelling the effect of ammonia losses to air and trafficking damages separately, more insights are gained. This is most clear when shifting to only application in spring, resulting in higher losses to air but lower trafficking damages. If we had modelled the effect of by assuming an increase in yield when changing from tank trailer to applying manure using pipes, these counter effects would have disappeared.

The large variation in the results is also important information. If the damage function is convex in pollution level, a reduction in variation might be as good as a reduction in the mean. Even though we have not been able to utilize the information about variation, due to the lack of damage functions, we have demonstrated that the variation is large. This might call for special attention when designing policy measures.

In our material we have also seen that the results are sensitive to the assumption we have made about the model farms. In the case of choice of technology this is evident. The differences in expected profit were in many cases very small. One example of this is model farm 2.1. As can be seen in figure 15 the reduction in income under a mandatory 12 months storage capacity is very small. This means that by changing the assumptions about this farm, e.g. by assuming an other resource base, the 12 months storage would have been the choice in the base case. This in turn, would have changed the effects of the different measures. This is also important information, which would have been lost if the aggregation level had been different.

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