Impacts of more efficient use of manure nutrients at farm and sector level

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1. Introduction

Concentration of production on most competitive farms and regions has been important for agricultural viability and profitability in Finland where farms and regional animal densities have been smaller than in neighbouring countries such as Denmark or southern parts of Sweden. In earlier years land competition was not very intense in Finnish agriculture due to low level of regional concentration of animal farms and animal numbers. In such conditions the main emphasis in farmers' decision making was how to attain economies of scale and other benefits of production specialisation on farms and regions while land was not a significant cost factor (Pietola, 1997). However land competition has intensified in the last 15 years, especially in areas where animal production has significantly increased (Lehtonen&Pyykkönen, 2005, Pyykkönen, 2006).

Changes livestock production, its input and land use intensity, as well as regional concentration of production, are seen as important determinants of farmland values as well as agricultural water pollution. Despite the theoretical fact that decoupling production linked agricultural subsidies should decrease input use intensity and volume of agricultural production, no or little decrease has been observed in agricultural water pollution in Finland during the last 15 years (Ekholm et. al. 2007). This observation, despite the fact that nitrogen surplus has decreased by 42 % and phosphorous surplus by 65 % in Finland 1995-2006, has been a disappointment since ambitious targets have been set for water quality improvements and significant agri-environmental subsidies have been paid for farmers in order to reach the targets (Turtola, 2007). Ekholm et. al. (2007) conclude that simultaneous changes in agricultural production (e.g. regional specialisation) and abnormal weather conditions on several years may also have counteracted the effects of agri-environmental measures. Especially the slowly decreasing phosphorous stock in agricultural soils has been indentified a major problem and hence compelling restrictions have been set to phosphorous fertilisation. This, in turn, restricts economic use of manure nitrogen and requires enlarging livestock farms to rent more land for spreading manure phosphorous.

Aim in this paper is to show how more efficient use of manure nutrients, through separating phosphorous out from slurry, affects regional agricultural production and use of chemical fertilisers in Finland. First, more efficient use of manure nutrients may decrease the use of chemical nutrients in agriculture. This may provide economic value if the costs of nutrient recycling are lower than the costs attributed to chemical fertiliser use. The reduced phosphorous in manure may also imply less land needed for manure spreading due to phosphorous fertilisation limits, as well as significantly decreased costs of manure spreading.

We also take explicitly into account the fact that fractioning out phosphorous from manure has not only immediate production impacts but also structural implications: If phosphorous can be fractioned out from manure (slurry) and shipped out from the region inexpensively, some farms may increase production further. This structural change issue related to the more efficient use of nitrogen, in the context of Finnish dairy farms, however, has been analysed already in Lehtonen (2010). The results of that study, which was a preliminary study to this paper, however showed that structural change implications are likely to be relatively minor in Finland where animal density is most often well below the levels in most intensive production regions in Europe. However, Lehtonen (2010) showed that some increase of dairy production may take place in few individual regions if no land was required for new cattlehouse investments. In this study, however, we aim to realistic descriptions how more efficient use of manure nutrients reduce the need for additional land in livestock investments, and how fractioning out phosphorous is likely to affect agricultural sector, taking into account both variable factors of production (fertilisation) and fixed factors (structural change).

The modelling tool used on this study is dynamic regional sector model of Finnish agriculture (DREMFIA; Lehtonen, 2001), which has been tailored to facilitate consistent integration between physical field scale and catchment scale nutrient leaching models. In addition to analyses of production and income effects of agricultural policies (Lehtonen 2004, 2007), this model has been earlier employed to assess the effects of alternative EU level policy scenarios on the multifunctional role of Finnish agriculture (Lehtonen et.al. 2005, 2006). We use a sector level model because more efficient use of nutrient also affects crop production and may affect relative profitability between production lines in agriculture. Partial analyses focusing on individual production lines, which compete on the same regional land, labour and capital resources, may not always provide a sound basis for policy recommendations. Especially regional changes in agriculture may not be driven by technical change and other (such as managerial abilities of farmers) developments in individual production lines alone, but also by comparative advantage of regions and farms.

The rest of this paper is organised as follows. In the following section we briefly present the overall principles of the agricultural sector model and its tailored components for this study. This is followed by a presentation of a baseline scenario and 3 technology options related to different phosphorous separation efficiency from manure, implying also relaxed land requirements imposed on new cattle house investments. Impacts of these options for agricultural production, overall farm income nutrient use are then reported on whole country and regional levels. Finally, based on the results we discuss and conclude on the potential of phosphorous separation techniques when aiming to decreasing nutrient leaching and reduced use of chemical fertilisers in agriculture, nutrient balances on farmland, and nutrient leaching from agricultural land. We also briefly conclude on the theoretical consistency and empirical feasibility of the presented approach.

2. Method: sector modelling approach

The dynamic regional sector model of Finnish agriculture (DREMFIA) is a dynamic recursive model simulating the development of the agricultural investments and markets from 1995 up to 2020 (Lehtonen 2001, 2004). The underlying hypothesis in the model is profit maximising behaviour of producers and utility maximising behaviour of consumers under competitive markets. According to microeconomic theory, this leads to welfare maximising behaviour of the agricultural sector. Decreasing marginal utility of consumers and increasing marginal cost per unit produced in terms of quantity lead to equilibrium market prices which are equal to marginal cost of production on competitive markets. Each region specialises to products and production lines of most relative profitability, taking into account profitability of production in other regions and consumer demand. This means that total use of different production resources, including farmland, on different regions are utilised optimally in order to maximise sectoral welfare, taking into account differences in resource quality, technology, costs of production inputs and transportation costs (spatial price equilibrium; Takayama and Judge 1971, Hazell & Norton 1986).

The model consists of two main parts: (1) a technology diffusion model which determines sector level investments in different production technologies; and (2) an optimization routine simulates annual price changes (supply and demand reactions) by maximizing producer and consumer surplus subject to regional product balance and resource (land and capital) constraints (Fig. 1). The model for technology diffusion and technical change presented below follows the main lines of Soete & Turner (1984). The choice of this particular diffusion scheme is further motivated in Lehtonen (2001, 2004).

The major driving force in the long-term is the module of technology diffusion. However, if large changes take place in production, price changes, as simulated by the optimization model, are also important to be considered. The investment model and resulting production capacity changes is however closely linked to market model determining production (including land use, fertilisation, feeding of animals, and yield of dairy cows, for example), consumption and domestic prices. Our market model is a typical spatial price equilibrium model (see e.g. Cox and Chavas 2001), except that no explicit supply functions are specified, i.e. supply is a primal specification). The model simulates the development of the agricultural investments and markets in a dynamic recursive way annually from 1995 up to 2020.

The endogenous price of land in the sector model, affected by all production activities regionally, is provided for technology diffusion model as dual values of the explicit regional land resource constraint from the market simulating optimisation model. Hence the regional land prices of the previous year from the market model are taken into account as a cost in the technology diffusion model (since environmental permits and agri-environmental support scheme requires explicitly and implicitly require necessary land availability when investing), which determines profitability and level of investment in different techniques in different animal production lines for the next year. Now the land cost is determined equally for each and every farm type on the basis of land areas needed for manure spreading and roughage production. This means that the livestock investment alternatives (farm size categories) are treated equally in terms of land requirements. The relative profitability of different animal farm types and production lines is not only determined by scale economies and degree of specialisation, or feed availability determined by regional roughage feed balances, but also by the land costs, affected by all agricultural activities in the region, as well as agri-environmental restrictions and policies. Hence the profitability of livestock investments decrease in those regions where land price increase, while livestock investments become more profitable in regions where land price decreases.

Introducing techniques of phosphorous separation from manure, possible for the largest farm size category in the model, implies reduced need for land for manure spreading, due to phosphorous spreading requirements in environmental support system. Having the land requirement per animal in the model, as described above, and introducing phosphorous fractioning techniques in the model, directly implies that (1) some excess phosphorous (P) from livestock intensive regions can be shipped into regions which are in need of P fertilisation, and hence cost savings through the reduced need for chemical P; (2) reduced need for land area per animal required in new livestock facility investments. Hence the model at hand models explicitly the use of manure nutrients and chemical P cost reductions as well as decreased investments costs on large farms which have the opportunity and access on P separation techniques, due to sufficient economies of scale necessary in covering the costs in P separation from manure.

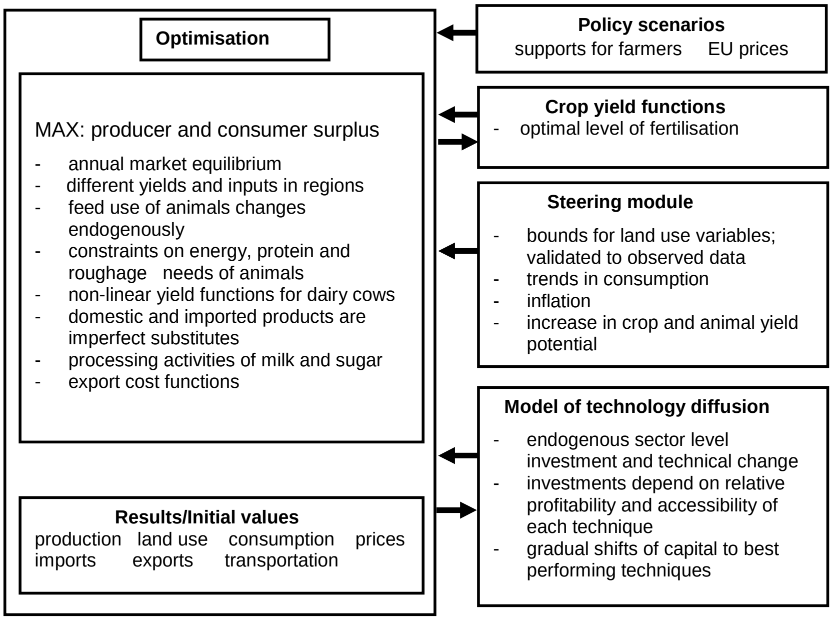

Fig. 1. Basic structure of DREMFIA sector model

The endogenous investments and technical change, as well as the recursive structure of DREMFIA model implies that incentives for changes in production affect production gradually in subsequent years, i.e. all changes do not take place instantaneously. However, the production in DREMFIA model will gradually reach a long-term equilibrium or steady state if no further policy changes take place.

Four main areas are included in the model: Southern Finland, Central Finland, Ostrobothnia (the western part of Finland), and Northern Finland. Production in these is further divided into sub-regions on the basis of the support areas. In total, there are 18 different production regions (Fig. 2). This allows a regionally disaggregated description of policy measures and production technology. The final and intermediate products move between the main areas at certain transportation cost. Hence, the model provides a complete coverage of land use and animal production, which compete on production resources.

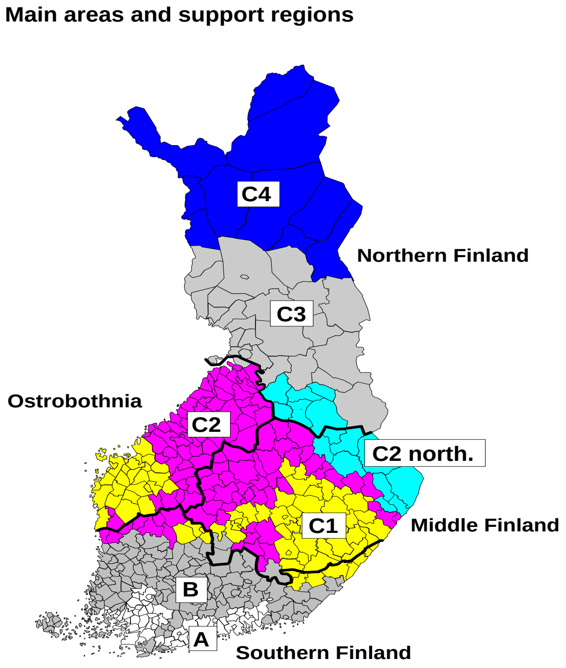

Fig. 2. Regional disaggregation of the DREMFIA sector model. There are 4 main regions split up by subsidy zones (A, B, C2-C4) and 3 small river catchments (not shown here).

Already nitrate directive of the European Union restricts the amount of nitrogen fertilisation to the maximum value of 170 kg N/ha per year. Environmental permits, required for large scale livestock production units, may pose more stringent conditions for a farm, implying more land area for manure spreading. Agri-environmental subsidy scheme in Finland poses significantly stricter requirements for manure spreading since not only nitrogen fertilisation level but also phosphorous fertilisation is given upper limits, as a condition for agri-enviromental subsidies. This phosphorous fertilisation limit is particularly compelling for pig and poultry farms since the phosphorous content of manure of pigs and poultry animals is significantly higher than that of bovine animals.

The price of land, affected by all production activities regionally, is provided as shadow values of the regional land resource constraint. When shadow price of regional land resource constraint is fed as an input price to the technology diffusion model, profitability of livestock investments decrease in those regions where land price (endogenous to the programming model) is high, while livestock investments become relatively more profitable in regions where land prices are low. Implementing a link between land prices between technology diffusion model and programming model however provides one more possibility to validate the simulated development path of regional animal production and land use to the observed ex-post development. Furthermore, regional feed use of animals, also endogenous in the programming model affects the phosphorous content in manure and hence land area required by animal production. Feeding may serve as a substitute, in a limited extend, to land area required for feed and manure spreading.

3. Manure phosphorous separations options and implied land resource requirements to be analysed

The following 3 manure handling scenarios, and implied land resource requirements for livestock production, are imposed for dairy cows, other bovine animals, pigs and poultry animals. The land demand of different agricultural production lines are indirectly taken into account in the sector model through limits imposed for the use of phosphorous from manure and chemical fertilisers, as well as through limits imposed for the total utilisation of nitrogen. These limits are set in the environmental support programme. Land demand due to livestock production and fertilisation limits is initially higher in southern and western (Ostrobothnia) Finland than in central and northern Finland (Fig. 2) with little pig and poultry production or specialised crop production.

In baseline it is simply assumed that *one dairy cow requires one hectare of farmland* because of existing specific regulations of environmental support programme. The specific regulations impose upper limits for nitrogen fertilisation (including both chemical and manure fertilisation) and require the phosphorous stock of soil to be non-increasing, e.g. in practice the annual phosphorous fertilisation is restricted to 20 kg P /ha. These conditions imply that a farmer should have 1 ha per dairycow for manure spreading, which is restricted by the phosphorous content of the manure. This means that a dairy farmer is also obliged to purchase chemical nitrogen fertiliser in order to reach high and of good quality grass silage yields (important for milk quality and farm economy), simultaneously when additional land has to be rented or contracted for manure spreading due to the phosphorous fertilisation limit.

In scenario *"Low efficiency manureseparation technology" (EFF13%)* it is assumed that only 13 % of manure phosphorous can be separated from manure (using screw press) and 0.87 hectare per dairy cow place is required when investing in a new cattle house. This also mean that the nitrogen content of the manure can be utilised more efficiently, i.e. in larger volume per hectare and at fields closer to the farm since phosphorous content is decreased. On pig farms this also means that a part of the purchased nitrogen fertiliser can be avoided, while on a dairy farm phosphorous separation from manure means that a farmer looses a small part of soluble nitrogen when exporting the solid separated manure fraction out of the farm. The resulting changes in available phosphorous and nitrogen due to the manure separation activity are directly fed into the sector model, which adjusts the purchased nitrogen and purchased phosphorous according to the fertilisation limits of the environmental subsidy programme. However we do not go to the details here but merely assume that a low efficiency manure phosphorous separation implies that 0.87 ha of farmland is required per one dairy cow when building new livestock facilities, with no additional building costs in net terms. In other words the phosphorous separation is a cost neutral activity in the sense that the capital costs of the separation machine can be covered mainly by the decreased manure transportation and spreading costs. However it is important to note here that the manure separation becomes a viable option only on large dairy farms (more than 50 cows) whose share of dairycows and production is increasing (endogenous in the model).

In scenario *“Medium efficiency manure separation technology” (EFF40%)* it is assumed that 40 % of manure phosphorous can be separated from manure and 0.87 hectare per dairy cow place is required when investing in a new cattle house.

In scenario *“Highly efficient phosphorous separation technology” (EFF69%)* it is assumed that 69% of manure phosphorous can be separated and only 0.31 hectares of farmland is required per dairy cow when investing in new cattle houses. Also in this scenario the relaxation of the existing rather strict regulations do not affect all existing capacity but applies to all new cattle house investments from 1995, i.e. in the beginning of the simulation period.

4. Results

Equilibrium reasoning strongly prevalent in sector level models in agriculture, i.e. decreasing marginal consumer utility and producer profits with increasing production volume, in other words inelastic domestic demand and relatively high export costs, would suggest that relieved land requirements due to fractioning phosphorous out from manure have relatively little impact on the aggregate milk production in Finland (as already reported by Lehtonen 2010). This is understandable since farm size growth of livestock farms has been rather steady in Finland and land requirements have been relatively minor relative to overall livestock investments.

The results show that a very significant reduction in phosphorous balance on farmland (nutrient input minus nutrient output in harvested crops) as well as in the use of chemical phosphorous fertilisers is possible through gradually enlarging scale of manure phosphorous separations.

Farm income however increases only 1.4 % due to more efficient use of manure phosphorous through manure phosphorous separation (Fig. 3). This is understandable since the structural and production implications of the manure phosphorous separation are likely to be minor, and because manure phosphorous separation implies some other costs for farmers, such as operating, capital, and maintenance costs. Hence the cost savings from reduced need for manure transporting and spreading are largely spent on the costs of manure phosphorous separation.

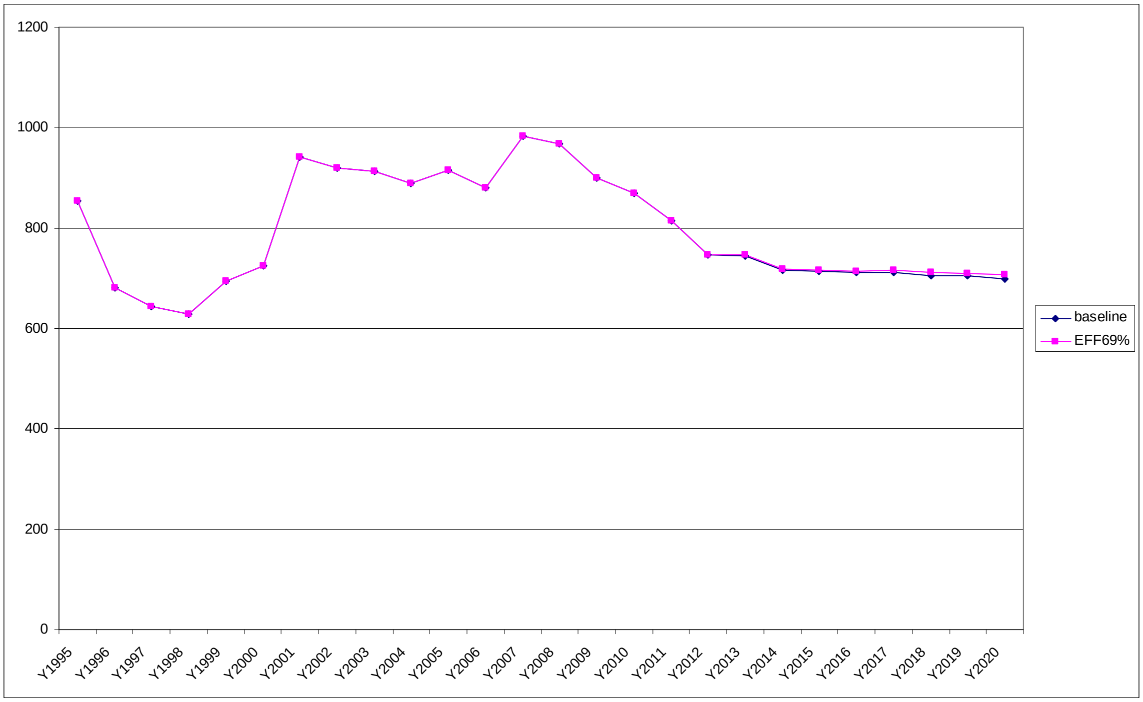

Fig. 3. Change in overall farm income (million euros) due to more efficient manure phosphorous utilisation through mechanical manure phosphorous separation.

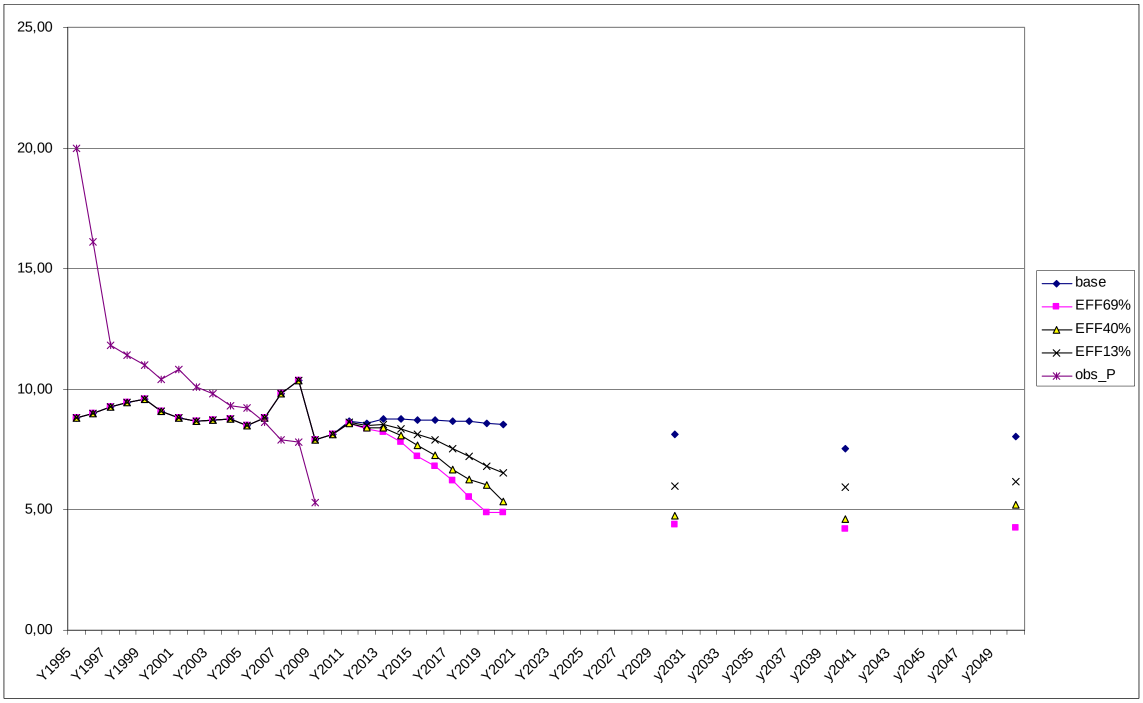

Fig. 4. Change in the use of chemical phosphorous use per ha (kg/ha) due to more efficient manure phosphorous utilisation through mechanical manure phosphorous separation (at different efficiency rates).

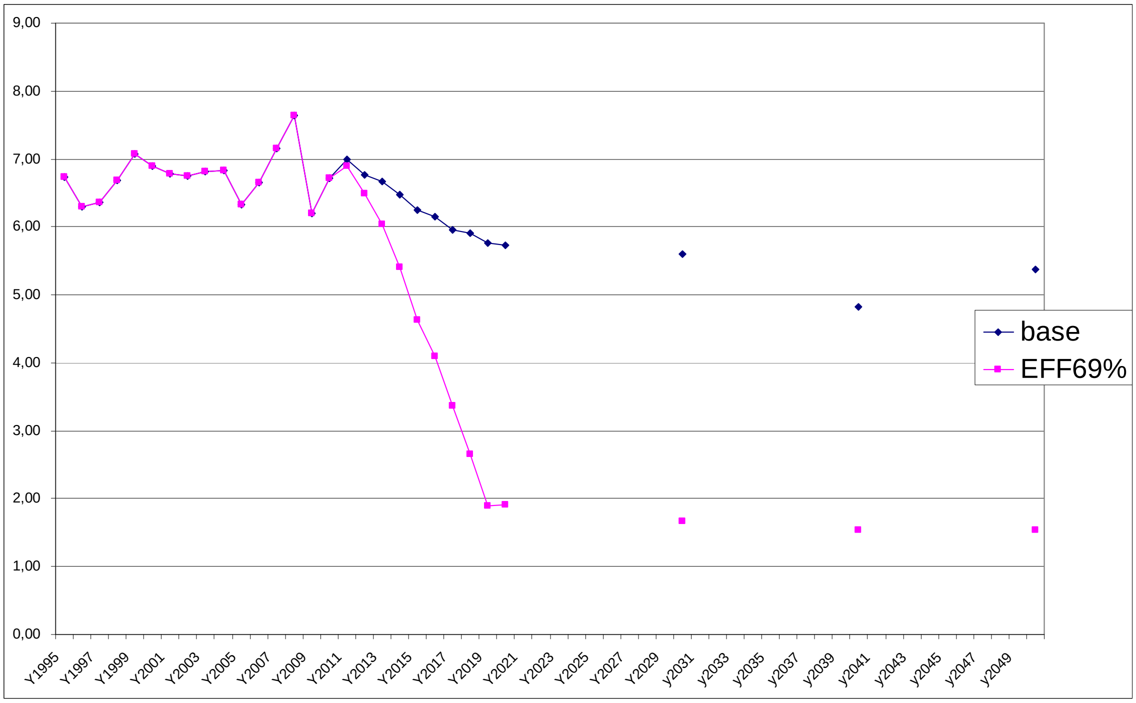

Fig. 5. Change in the nutrient balance of phosphorous per ha (kg/ha) due to more efficient manure phosphorous utilisation through mechanical manure phosphorous separation (at different efficiency rates).

5. Conclusions

The results show that decreasing chemical phosphorous use in agriculture is possible through mechanical phosphorous separation from manure, with little implied changes in agricultural production and farm income. This is encouraging, since the reduction in nutrient balances on farmland as well as in the use of chemical phosphorous fertiliser can be as large as 30-50%. The results also show that also medium or even low efficiency techniques in phosphorous separation may have a significant reduction potential in nutrient balances, if they can be adopted at a reasonable costs. This is because livestock farms also need some phosphorous fertilisation in the long-term, and since excess phosphorous from livestock intensive regions may provide a substantial volume of phosphorous fertiliser supply to crop production regions even at relatively low efficiency rates of manure phosphorous separation.

The optimisation approach employed in the market model facilitate explicit treatment of physical quantities, description of inputs (kg/ha, animal), and their substitution (such as imperfect substitution between chemical fertiliser and manure used as fertiliser; utilisation for plants). This makes the approach suitable for model integrations and interdisciplinary research. The richness of the optimisation approach also lies in duality, i.e the use of dual variables (shadow prices) of explicit resource constraints and balance equations (interpreted as prices). Hence the approach taken can be made efficient in terms of utilisation of different kind of data used in validation. Land price linkage between technology diffusion model and multi-regional market model also provides one more possibility to validate the simulated development path of regional animal production and land use to the observed ex-post development. However, the observed farmland prices are very different from the simulated farmland prices, since unlike real land prices, the model used in the simulations includes only agricultural value for farmland. Our core result here is that relaxed land requirements for new cattlehouse investments may not decrease, but drive up the marginal value of land in the long-term, since more milk is produced, and land is still needed due to feed requirements. Hence relieved land requirements may decrease regional land prices only temporarily.

In technology diffusion model one may also include new technological alternatives and their locally suitable variations which may provide environmental benefits and change the relative profitability of investments in different production lines and techniques. The coupling of the technology and market model components, including land resource constraints, provides a platform for many interesting analysis. For example, one may consistently analyse impact of certain technologies, such as biogas plants and methods for fractioning phosphorous out of manure, making both nitrogen and phosphorous fractions easier to be used as fertilisers in desired quantities on field plots. Such techniques may change the land use intensity, nutrient flows, and relative profitability of investments in different farm types. In practical terms, the model and its components need to be tuned to the data, and there are many options for that in optimisation approach.

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