Manure Market as a Solution for the Nitrates Directive in Italy

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Abstract

This research aims at analysing the economic effects of the European Union's Nitrates Directive implementation on some representative dairy farms in Italy, using a mathematical programming model. The representative farms considered are located in Emilia-Romagna and Lombardia, which are potentially most affected by the Directive given their high livestock density. The study simulates two different farm response scenarios to the Directive. Simulation results show the importance of the creation and use of a manure market to dispose nitrogen from livestock surpluses in order to reduce the negative effects of the Directive on farm income. The herd reduction option is unfavourable, as it causes much larger income drop, which, for some farms, reaches one third of their income.

Keywords. *Nitrates Directive; vulnerable zones; dairy farms; manure market; mathematical programming.*

Résumé

Le but de ce travail est d'analyser les effets économiques de l'application de la directive "nitrates" de l'Union européenne dans des exploitations laitières italiennes, en utilisant des modèles de programmation mathématique. Les exploitations représentatives retenues dans cette étude sont situées dans les régions Emilie Romagne et Lombardie, qui sont potentiellement très touchées par la directive en raison du leur niveau élevé de chargement en bétail. Deux différentes options de réponse par les exploitations à la directive sont simulées. Les résultats de la simulation montrent l'importance de créer et utiliser un marché du fumier pour éliminer l'azote provenant des excédents de lisier afin de limiter les contraintes posées par la directive en termes de revenu des exploitations. La diminution des effectifs animaux n'est pas une option viable étant donné qu'elle entraînerait une réduction beaucoup plus importante du revenu qui, dans certains cas, pourrait atteindre même le tiers.

Mots-clés. Directive nitrate; zones vulnérables; exploitations laitières; marché du fumier; programmation mathématique.

1. Introduction and literature review

The Nitrates Directive (91/676/EEC) is a European Union (EU) directive introduced in 1991 with the aim of protecting ground and surface waters against pollution caused by nitrates from agricultural sources. A high concentration of nitrates in water causes negative effects on human and animal health and on the whole ecosystem. The Member States are required to translate the Directive in national rules (Council Directive, 1991). In order to reach its aim the Directive states five actions that must be applied by each Member State: identification of water nitrates pollution and eutrophic status of water bodies; designation of vulnerable zones; establishment of Codes of Good Agricultural Practices; definition of Action Programs for vulnerable and non-vulnerable zones, and review of Action Programs every four years. In particular, Action Programs define periods when fertiliser and manure application is allowed, minimum distance of application from water bodies, size and characteristics of storage vessels, maximum amount of total nitrogen and livestock nitrogen applicable. The Directive defines the maximum limit of livestock nitrogen applicable as 170 kg N/ha in vulnerable zones and 340 kg N/ha in non-vulnerable zones.

Farmers located in vulnerable and high livestock density areas are potentially most affected by the Directive application. Due to its potential negative consequences on agricultural livestock activities, the Directive was not adequately applied in Italy for many years. As a result, the EU started an infraction procedure against Italy in February 2006. In order to face the infraction, the Italian government revised the Nitrates Directive application by the ministerial decree 7-4-2006. From the end of 2006 the Italian regions started to update their regional regulations in order to comply with the ministerial decree (e.g. Regione Emilia-Romagna, 2007; Regione Lombardia, 2007). This revision led to larger vulnerable zones, more restrictive Action Programs and more realistic and strict parameters of nitrogen excretion by animals. Despite the regional regulations of 2007, most Italian farmers are still not complying adequately with the Nitrates Directive and fear the consequences of its implementation. This is especially true for livestock farms located in Emilia-Romagna and Lombardia, the two highest livestock density regions of Italy, where the main fear is that the number of animals has to be reduced in order to comply with the Directive[1].

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[1] A recent development of the Nitrates Directive application in Italy is contained into law 221/2012, approved by the Parliament at the end of 2012 (Senato della Repubblica, 2012). According to this law the limit of the livestock N applicable by farms located in vulnerable zones can be extended to 340 kg N/ha for one year. This extension has not been considered in our research as one of the two regions under study, Emilia-Romagna, has rejected it and the other region, Lombardia, is still doubtful about its application.

Previous studies, which analysed the technical, economic and ecological effects of the Nitrates Directive, concern countries where the Directive has been in place for many years. From a methodological point of view, most of these studies use mathematical programming farm models (see Buysse *et al*., 2006 for a review). The advantage of mathematical programming in analysing environmental policies is that it makes easy to model technological and institutional constraints, including those related to the Nitrates Directive. However, mathematical programming carries also some disadvantages: for example, the imposition of many constraints can make models rather artificial, such that they become difficult to manage when carrying out simulations. Thus, while constructing mathematical programming models, it is important to keep in mind the trade off between accuracy and rigidity. Moreover, the development of such farm programming models is still incomplete. For example, the inclusion of key elements of the farm business, like risk management and the impact of farmers' risk preferences, is still under development and the empirical applications of the available methodological proposals still need some refinements (see Kaiser & Messer, 2011, for an overview on the integration of risk into programming models).

Among the studies that have addressed the issue of nitrate regulations, Van Calker et al. (2004) analysed the economic and ecological effects of the introduction of a levy on N surplus and of some other environmental measures on a Dutch dairy farm. They showed the trade off between the environmental and the economic performances of the farm: environmental policies and practises which increase the ecological results, decrease farm income. On the other hand, there are other studies that do not show a strong negative impact of environmental legislations on farm's economic performance. Berentsen and Giesen (1994) simulated the introduction of a farm levy on N losses, also implying technical changes in terms of farm management; they concluded that the negative effects of the environmental legislation can be compensated by the positive effects of technical change. Piot-Lepetit and Le Moing (2007) even argued that the application of the Nitrates Directive in the French pig sector may lead to an increase in farm efficiency, which offsets the costs linked to the manure disposal. Belhouchette et al. (2011) analysed the effects of the Nitrates Directive on economic and environmental indicators on three representative arable farm types of the Midi-Pyrénées region; their study shows a reallocation of land among crops and a better management of fertilisation in arable farms as a consequence of the Directive, while farm income is slightly negatively affected. Rigby and Young (1997) modelled the Nitrates Directive in England by the introduction of the limit of 170 kg N/ha; however, these authors only consider the option of a herd reduction as farm response to the Directive, showing that its negative impact on farm income may be rather small. Van der Straeten et al. (2010) developed a spatial mathematical programming multi-agent simulation model applied to the Flanders region of Belgium. With this model they simulated three options from which the farm can choose to comply with the Nitrates Directive (application on its own land, sale on the manure market, processing). They integrated this micro-level model in a multi-agent regional level model, that allowed them to model a manure market and to obtain information on the best location of manure processing. The work of Peerlings and Polman (2008) also considered a manure market, on which farmers with nitrogen surplus dispose their excess supply and pay for that disposal, while farmers with a nitrogen deficit can absorb manure from suppliers and are paid for that. Although their study took into account the disposal costs of nitrogen from livestock, their main focus was on the relationship between the Dutch manure policy and the farm participation in some agri-environmental schemes, while they did not consider the effects of the Nitrates Directive on farm income. Although there are several works studying the consequences of the Nitrates Directive in foreign countries, to the best of our knowledge there are no research works available that analyse the effect of the Directive for Italian dairy farms, taking into account the option of creating a manure market. Given the interest of Italian farmers and policy makers in the consequences of the Nitrates Directive, this research aims at filling this gap by simulating in a farm-level mathematical programming framework a herd size reduction and the creation of a manure market as different farmer's alternatives to comply with the Nitrates Directive. The economic effects of the two alternatives will be analysed for dairy farms in Emilia-Romagna and Lombardia, where livestock density is very high. The potential economic effects consist of changes in the production plan (input and output mix), costs, revenues and profit of representative dairy farms. The research is focused on dairy farms because dairy farming is an important sector in Lombardia and Emilia-Romagna and dairy farms are expected to be seriously affected by the Nitrates Directive, especially those located in the vulnerable zones. In total, eight representative dairy farms from the two regions are considered, differentiated by size, location and the final use of milk. A mathematical programming farm model has been constructed and applied to each representative farm to analyse the impact of the reduction in the herd size and the creation and use of a manure market. A sensitivity analysis is also performed on the price of manure in order to find the price at which one scenario becomes more attractive than the other.

The paper is structured as follows. Section 2 presents the theoretical model and details the empirical model in the baseline situation and after the Nitrates Directive introduction. The data are discussed in section 3. Section 4 describes the simulated scenarios, while section 5 presents the results. Finally, conclusions and policy implications are drawn in section 6.

2. The model

This section presents the structure of the theoretical model and then discusses the empirical model that is presented in detail in Appendix I.

2.1 Theoretical model

Farmers are assumed to maximise profit and their objective function is represented by:

$$\text{Max } \pi = p' y - w' y$$

$$\text{subject to } Ay \leq b$$
$$y \geq 0$$

where π is profit, p is a vector of prices, w is a vector of per unit variable costs of each activity, y is a vector of endogenous output quantities, b is a vector of total available quantities of fixed inputs andis the matrix of technical and institutional coefficients. The elements of the A matrix, α_{ij}, represent the amount of fixed input i required to produce a unit of output j. Profit maximisation implies that the farm chooses the combination of variable inputs and outputs that maximises profit subject to technical and institutional constraints. The technical constraints model the technical input-output relationships, the availability of fixed inputs (land and milk quotas), feed requirements and crop rotation requirements. In the baseline model, that excludes the Nitrates Directive, there is only one institutional constraint for dairy farms, i.e. the milk quota constraint. Once the base model is specified, the Nitrates Directive is introduced in the model by some additional institutional constraints and different scenarios are simulated. The model slightly differs between scenarios in order to represent the possible different farm responses to the Nitrates Directive. We use a linear programming model (Paris, 1991) since the main interest of this research is to predict the consequences of the implementation of the Directive and to carry out some sensitivity analysis (McCarl and Spreen, 2004). Linear programming is the simplest method for this task.

2.2. Empirical model

In the empirical model (see Appendix I) farmers are assumed to maximise family income from farming, *FI*, (see equation (A.1)), which is defined as revenues plus farm payments minus variable costs, depreciation of capital assets and external factor costs (wages, land rent and interest paid). The time horizon is one year, so no dynamic adjustments are considered. In total, nine activities (outputs, y_j) are considered: fodder maize, temporary grass, permanent grass, wheat, barley, grain maize, milk, sale of cull cows, sale of calves and livestock nitrogen production. Only fodder maize and grass production are used on the farm (they are input and output at the same time), while all the other outputs are sold. The variable inputs (x_i) used by the farm are: concentrate, fodder maize, temporary grass, permanent grass, maize meal, nitrogen from manure and chemical nitrogen. We ignore other fertilisers, as nitrogen is supposed to be the most constraining. It has been assumed that there is no market for fodder maize, so the farm uses only on-farm produced fodder maize and the whole amount of fodder maize produced by the farm is used on-farm. This assumption is consistent with the absence of market for maize silage in the two regions considered and it has been confirmed by some local technicians as a common characteristic of most of the farms in Emilia-Romagna and Lombardia. Temporary grass and permanent grass used by the farm derive both from farm production and purchases; however, we assume that the farm cannot sell grass. Besides the nitrogen from manure, the other variable inputs (concentrate, maize meal and chemical nitrogen) are purchased on the market. The concentrate considered in the model is a high protein concentrate, the most common among farms in this area. There are other variable inputs used by the farm and included in the model not under but directly as expenses (c_k): veterinary fees, energy costs, water cost, plant protection expenses and seed costs. For these inputs, given the lack of data, the input-output relationships cannot be modelled. Therefore, a regression analysis of the relationship between expenses and outputs has been carried out[2]; then, the estimated expenses for these purchased inputs are introduced in the model. In the choice of the best combination of inputs and outputs the farm makes a land allocation choice, l_v, among different crops: fodder maize, temporary grass, permanent grass, wheat, barley and grain maize. The revenues consist of the sales of outputs at exogenous market prices (p_j). The variable costs consist of the purchase of variable inputs bought by the farm at exogenous market prices (w_i) and of the costs (c_k) associated to the purchase of other variable inputs not included in x_i (see equation (A.1)). It is assumed that the farmer owns the whole farm land. Taxes are not considered in the model.

In addition to the objective function, we introduced 24 equations for modelling the technical and institutional constraints of a typical dairy farm. Equations (A.2)-(A.6) concern the animal production constraints. Equation (A.2) simply states that the total amount of milk produced per year on a farm equals the exogenous milk yield per cow times the number of cows. Total milk production cannot exceed the available milk quota (equation A.3)[3]. Equation (A.4) expresses the number of heifers as a function of the number of cows. This equation is based on the assumption that the replacement rate of cows is 1/3, that corresponds to the average rate observed in Lombardia and Emilia-Romagna; it has also been assumed, according to the common practices of the areas, that no heifers are bought and that they start

[2] The costs have been regressed against milk production, hectares of arable land and hectares of grassland. The econometric technique used has been OLS or WLS according to the presence of heteroscedasticity tested by a White test. More details on the regressions are available from the authors upon request.

[3] The market for milk quotas is not considered in the model.

delivering milk at the age of two. Besides milk production, there are two other livestock outputs, sale of calves and sale of cull cows (equation (A.5) and (A.6)). Equation (A.5) calculates the number of calves sold in one year as the difference between the total number of calves born on the farm and the calves kept for replacement, considering an average mortality rate. Equation (A.6) shows that one third of dairy cows is replaced every year and sold.

Equations (A.7)-(A.9) concern the nitrogen production on the farm. Equation (A.7) calculates the total nitrogen from livestock as the product of the nitrogen produced per year by each animal, times the number of animals. In the baseline situation, where there is no Nitrates Directive, the whole nitrogen produced by the farm is used on-farm, and therefore, the nitrogen surplus (nsur) is equal to zero (equations (A.8) and (A.9)). So, there is no manure disposal outside the farm and no market is needed. Equations (A.10)-(A.12) express the total nitrogen constraints. These constraints match the need for nitrogen by grassland and arable land with the available nitrogen from manure and purchased chemical nitrogen. Equation (A.10) expresses the total amount of efficient nitrogen that must be provided to crops. The efficient nitrogen is the nitrogen immediately available for the crop. The value of the efficient nitrogen that is recommended per hectare of each crop has been taken from the Decreto Ministeriale 7-4-2006; this value has been corrected for the crop production per hectare of the farm by the use of a correction coefficient extrapolated from the data. The nitrogen demand of the farm is satisfied by the corresponding supply, which consists of nitrogen from manure and chemical nitrogen (A.11). As only efficient nitrogen is considered, there is a workability coefficient, *work*, for nitrogen from livestock, which indicates the portion of the livestock spread nitrogen that is available for the crop immediately after its application. All the chemical nitrogen is immediately available for the crop and so its workability coefficient is 100%. Constraint (A.12) establishes the balance between nitrogen demand and nitrogen supply. The inequality sign gives the farm the possibility to spread the whole nitrogen from manure produced even if it is higher than the total nitrogen demanded. This is the case when the Nitrates Directive is not in place.

Equations (A.13)-(A.15) are the land constraints. The first equation is the total land constraint, while equations (A.14) and (A.15) are about crop rotation. It is stated that the land allocated on fodder maize cannot be larger than one third of the utilised agricultural area. The farm can also not grow cereals on more than one third of the utilised agricultural area. Equation (A.16) imposes that the amount of crop produced on a farm is equal to the exogenous per hectare yield times the land allocated to it. Equation (A.17) states that the fodder maize used by the farm to feed animal, is exactly equal to the amount of fodder maize produced. Equation (A.18) shows that the use of temporary and permanent grass equals the sum of production and purchase.

Equations (A.19)-(A.22) model feed requirements, feed supply, and the feed balance for net energy, protein and dry matter. Demand depends on the number of animals and the feed requirement per animal; supply depends on feed nutritional content and on the amount ingested of each type of feed. The balance equation uses the inequality sign, which means that the demand is assumed to be lower or eventually equal to supply. Constraint (A.22) shows the forage requirement by imposing that at least 35% of the dry matter ingested must come from forage. The model assumes that the quantity of high protein concentrate and the quantity of maize meal, are provided in the same amount (equation (A.23)), that is a practical rule followed in the two regions considered. Finally, a rule of thumb among animal production technicians is that one kilogram of complete concentrate (0.5 kilogram of high protein concentrate plus 0.5 kilogram of maize meal) gives 3 kilograms of milk (equation (A.24)). The last constraint (A.25) is the general form for the regressions of the costs modelled directly as expenses (see above).

2.3. Nitrates Directive

The Nitrates Directive is introduced in the model by the addition of some constraints concerning the limit to the amount of nitrogen from manure applicable per hectare and the limit to the amount of total efficient nitrogen applicable for each crop (see equations (A.26)-(A.28) in Appendix I). As we are interested in the Nitrates Directive application in vulnerable zones, the limit of livestock nitrogen per hectare is fixed at 170 kg/ha, while the limit on the total amount of nitrogen derives from the national implementation of the directive and it is crop specific. It is assumed that the whole farm area is in a vulnerable zone.

3. Data

The empirical model developed in the previous section has been applied to eight representative dairy farms. The farms differ by location (mountain and plain area), farm size (small, medium and large) and for the final use of milk. Milk is either used for Grana Padano cheese production (Lombardia and Piacenza province) or for Parmigiano Reggiano cheese production (some provinces in Emilia-Romagna: Parma, Reggio-Emilia, Modena, Bologna). Representative farms are indicated with roman numbers as shown in table 1. Each farm is assumed to be located in a vulnerable zone. The data used come from the FADN dataset, the local Camere di Commercio, Ismea (the market research institute of the Italian Ministry of Agriculture) and personal communications. The FADN is a EU dataset that contains technical and economic data on farms in each Member State. The data are from the year 2005. 2005 is considered to be a representative year and although the data are not recent, technological and institutional constraints do not change much in the medium term.

Table 1 - *Dairy farm groups*.

Plain area	Small size (<51 cows)	I	V
	Medium size (51-150 cows)	II	VI
	Large size (> 150 cows)	III	VII
Mountain area		IV	VIII

* PC: Piacenza; PR: Parma; RE: Reggio-Emilia; MO: Modena; BO: Bologna.

3.1. Technical coefficients

Crop yields (kg/ha) on a farm are calculated from the FADN data as the average yields of the group it represents for the period 2003-2005. The same procedure is applied for milk production and milk yields. The number of calves born per cow per year (equal to 1) and the mortality rate of newborn calves (equal to 0.05) are taken from personal communications of local experts and represent the averages for the Lombardia and Emilia-Romagna dairy farms. Finally, the amount of nitrogen produced by each animal per year is defined in the Decreto Ministeriale 7-4-2006 and equals 83 kg N/cow/year and 36 kg N/heifer/year. Nitrogen requirements of crops that are not covered by other sources (e.g. atmospheric deposit and mineralization of organic matter in the soil) are taken from the specific legislation (Regione Emilia-Romagna, 2007). As these required nitrogen values refer to a standard yield they have been corrected, using 'correction coefficients', for the real yields of each representative farm. Concerning feed requirements, energy required per animal comes from personal communications of a local animal nutritionist, while values for protein and dry matter demand come from the Emilia-Romagna regional rule (Regione Emilia-Romagna, 2007). The value of net energy is expressed in UFL (Unità Foraggera Latte – the energy unit adopted in Italy). It has been assumed that one cow needs 0.5 UFL/day for moving, 5 UFL/day as subsistence and 0.44 UFL per kg of 4% fat milk produced. As it is assumed that the fat content of milk is 3.64% on average, a conversion coefficient (equals to 0.4+0.15 * %fat) has been used to convert the real milk production in the equivalent milk amount with 4% fat content. The heifers' energy requirements consider only moving and subsistence. Based on these parameters the energy required per year for each farm has been calculated. The protein and dry matter requirements are expressed in kg per animal per year and are based on the average protein content of the diet and on the average dry matter intake. These values are assumed to be the same for each farm. The energy, protein and dry matter content of each feed comes from the personal communications with local animal nutritionists.

3.2. Exogenous variables

Land and milk quota amounts come from the 2005 FADN database as well as capital depreciation and external costs (land rent, wages and interests paid). The price of marketed milk is calculated for each farm by dividing the value of annual milk production by the amount of milk produced. It is assumed that all the milk produced is sold on the market as the milk used to feed calves for a few days after the birth is minimal. The price of calves, as well as the prices of cull cows and feed, come from the Chamber of Commerce of Milan and assume an average weight for calves of 30 kg and an average weight for cows of 600 kg. All prices of crops are taken from Ismea 2005 data (Ismea, 2009). The price of chemical nitrogen is derived from the 2007 urea price (Chamber of Commerce of Mantova, 2009) considering a 45% nitrogen content. The prices used are annual average prices and are considered to be the representative prices for the two regions under study. As in Italy no manure market exists yet, there is no market price of livestock nitrogen. Therefore, in the simulations with a manure market, a sensitivity analysis has been carried out considering a range of possible prices from 3 to 5 euro/kg of livestock nitrogen. This range has been decided based on the Dutch price of manure nitrogen considered by Peerlings and Polman (2008) and by considering transportation costs of manure. According to Ragazzoni and Devenuto (2008) the transport cost of one kilogram of manure varies from 0.20 euro/m^3/km to 0.50 euro/m^3/km. Considering the average content of nitrogen in manure equal to 4 kg N/m^3, the transport cost of one kg of livestock nitrogen could be estimated as equal to 0.0875 euro per km. It has been assumed that the average transport distance between the supplier and demander equals 20 km, which results in transport cost of 1.75 euro/kg N. The transport cost is the difference between the price paid by the manure supplier (market price of livestock nitrogen) and the manure demander. The transport cost is the revenue of the intermediary between supplier and demander and it has been assumed fixed regardless of the market price of manure. Finally, average subsidies for each representative farm have been calculated from the FADN data using 2000-2002 data, since the decoupled farm payments are based on the average of subsidies received in this period.

4. Scenarios

Within the model, two scenarios have been simulated that represent different potential farm responses to the Nitrates Directive: herd reduction and manure trading. There are other alternatives that the farmer could apply to comply with the Nitrates Directive, like diet adjustment or manure processing. However, the first option is not considered as it requires monitoring policies that do not exist in Italy, while manure processing is extremely costly and not economically feasible without government subsidies. Each scenario is applied to each of the eight representative dairy farms. The mathematical representation of each scenario is presented in Appendix II.

Scenario 1: herd reduction

In this scenario the farmer reduces the number of livestock units until the nitrogen production is in compliance with the nitrogen applicable on his farm. There is no possibility of manure disposal.

Scenario 2: manure market

In this scenario a manure market has been simulated. If the livestock nitrogen surplus is positive, the farmer pays to get rid of this surplus on the market and the disposal cost will reduce the income from farming. If the N surplus is negative the farmer has the possibility to absorb a further amount of effluent from the market and is paid for that. In this case the negative surplus will increase the income from farming. The price paid by the farm for manure disposal differs from the price received by the demander by the transportation costs. In this scenario the number of cows on the farm is kept fixed at the level of the baseline situation.

5. Results

In this section the main results of the simulations are presented and discussed. Table 2 shows a summary of the results for revenue, costs and income only, while Appendix III gives a more complete overview.

Our simulations show that the representative Lombard mountain farm (IV) and the representative Emilia small farm (V) are the only farms producing less nitrogen than applicable (Appendix III). Hence, the behaviour of these farms is different from the behaviour of the farms with a positive surplus. The representative Lombardia medium and large farm and the representative Emilia large farm have the highest nitrogen surplus (3,474 kg, 9,262 kg and 11,562 kg respectively) and therefore they are more negatively affected by the Nitrates Directive. The representative Lombardia small farm, Emilia medium farm and Emilia mountain farm are affected only slightly by the Nitrates Directive as in these farms the nitrogen surplus is small.

5.1. Herd reduction scenario

The farms that produce less nitrogen from livestock than they can apply on their land (groups IV and V) are not affected by the Directive in this scenario. Their production plan is unchanged. The farms with a livestock nitrogen surplus are all negatively affected by the Directive. To what extent these farms are affected depends on the amount of surplus produced. Farms I, II, III, VI, VII and VIII reduce their herd size in order to comply with the Directive by 4.1%, 33.8%, 31.2%, 6.1%, 22.8% and 0.4% respectively. It is important to remark that herd reduction lead to a one time revenue when the surplus of cows and heifers is sold, but since this is not a regular revenue we ignore it in our analysis. The herd reduction leads to changes in most of the other variables. First, milk quotas are no longer binding on these farms meaning that the nitrogen limit is more restrictive than the milk quota; in other words, a 'nitrates quota' has been introduced. This implies excess capacity (e.g. for farm buildings and machineries) on the farm. Second, the smaller herd size means a nitrogen production reduction until the surplus equals zero. For some farms (I, II, III) the chemical nitrogen purchase increases as a consequence of the decline in livestock nitrogen applied, while for other farms (VI, VII) there is no increase in chemical nitrogen use as the restricted livestock nitrogen application still satisfies the nitrogen requirements of crops. Then, some representative farms, such as the Lombard farms from the plain area and the Emilia mountain farm, reallocate partially their land from fodder maize to temporary grass. Herd reduction also causes a reduction in concentrate, maize meal and temporary grass purchases. The expenses for veterinary services, energy, water, plant protection and seeds are affected as well; the first three expenses are affected most since their linkage to herd size is stronger. Plant protection and seed costs are affected only by the reallocation of land and these changes are small because of the small reallocation.

Thus, for the farms with a livestock nitrogen surplus revenue falls as a result of the herd reduction. The fall is caused mainly by less milk production as a consequence of the 'nitrates quota' and to a smaller extent by a reduction in sales of animals. The herd cut also leads to a fall in cost on these farms as a consequence of smaller input use. The net effect is a reduction in income from farming. For some farms this reduction reaches approximately one third of the farm income without the Directive. This is the case of the farms with the largest nitrogen surplus (the representative Lombardia medium and large farms and the Emilia large farm), that would experience an income fall of 35.9%, 30.0% and 28.1% respectively (Table 2). The reduction in income of other representative farms is smaller (between 0.4 and 6.4 %), while farms producing less nitrogen than the applicable amount do not have any change in economic results.

5.2. Manure market scenario

Results of scenario 2 shows the advantages of the creation of a manure market: farms with a nitrogen surplus can reduce significantly the negative effects of the Directive, while farms with a negative surplus can take advantages from the market. The manure market scenario keeps the herd size unchanged and the results show that there is no reallocation of land. The only variables affected in this scenario are the amount of livestock nitrogen applied (which decreases for farms with a positive nitrogen surplus and increases for farms with a negative surplus) and, as a consequence, there might be a change in chemical nitrogen use and in total nitrogen application (see Appendix III). The farms with a negative nitrogen surplus (IV and V) attract livestock nitrogen and they are paid for that. In this way, they increase their revenue. In the case of farm V there is also a slight reduction in cost as a result of the partial replacement of chemical nitrogen with manure. Assuming a market price for manure of 3 euros/kg livestock N, income for farm IV and V increases by 35.4% and 5.4% respectively. In the case of a market price of 5 euros/ kg livestock N, these increases are 92.0% and 12.4%. The farms with a livestock nitrogen surplus face an increase in costs (mainly manure disposal costs) but the revenue of these farms remains unchanged because of the unaltered herd size (Table 2). For these farms, income falls much less than in scenario 1. For

Table 2 - *Results of the different scenarios (percentage changes compared to the baseline situation).*

	Revenue			Cost			Income		
	Sc.1	***Sc.2***		***Sc.1***	***Sc.2***		***Sc.1***	***Sc.2***	
euro/kg N **farm groups**		3	5		3	5		3	5
I	-3.5	0	0	-3.3	0.9	1.5	-3.8	-1.3	-2.1
II	-30.2	0	0	-26.0	6.4	10.3	-35.9	-8.6	-13.8
III	-27.9	0	0	-25.7	6.3	10.0	-30.0	-6.1	-9.8
IV	0	6.7	17.3	0	0	0	0	35.4	92.0
V	0	1.5	3.9	0	-0.6	-0.6	0	5.4	12.4
VI	-5.3	0	0	-4.5	0.9	1.6	-6.4	-1.2	-2.1
VII	-20.7	0	0	-15.5	3.2	5.4	-28.1	-4.6	-7.7
VIII	-0.3	0	0	-0.3	0.1	0.1	-0.4	-0.1	-0.2

Source: *Simulations results.*

example, with a manure market price of 3 euros/kg livestock N, none of the farms have an income reduction larger than 10%, with the highest fall in income for farm II (8.6% compared to 35.9% in scenario 1). With a manure market price of 5 euros/kg livestock N only farm II faces an income fall higher than 10% (13.8%). The income fall of farms with a nitrogen surplus in this scenario is partially compensated by the increase in income of farms with a negative manure surplus and of transport intermediaries.

5.3. Sensitivity analyses

Additional simulations have been made to calculate the so-called livestock nitrogen trigger price for each farm and to consider the hypothesis of each farm being located in a non vulnerable zone. The trigger price can be defined as the manure disposal cost of livestock nitrogen at which the farm changes its behaviour in response to the Nitrates Directive. If the manure disposal cost is lower than the trigger price, the farm will prefer the manure market option; if the manure disposal cost is higher than the trigger price, the farm will choose the herd reduction option. Table 3 shows that the trigger prices for livestock nitrogen are very high for all farms. It is hard to imagine that, if a manure market is created, the price would reach such a high level.

When each farm is located in a non vulnerable zone the upper limit for livestock nitrogen application equals 340 kg N/ha. Additional simulations show that in this case none of the farms produce more nitrogen than applicable and so they are not affected by the Nitrates Directive. If a manure market would exist, farms in non vulnerable zones could absorb the manure coming from vulnerable zones.

Table 3 - *Trigger prices of livestock nitrogen for each farm.*

Farm groups	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Euro/kg livestock nitrogen	9.5	13.2	16.6	/	/	15.5	18.4	13.7

Source: *Simulations results.*

6. Conclusions

This study has developed a mathematical programming model to analyse the economic effects of the Nitrates Directive application on Italian dairy farms. In particular, eight representative dairy farms belonging to farm groups from Lombardia and Emilia-Romagna have been modelled. The two regions are in the Pianura Padana area (Po valley), where the Nitrates Directive application especially worries the farmers, due to the high livestock density. The representative farms are assumed to be located in vulnerable zones, where the limit for spreading the nitrogen from livestock equals 170 kg/ha. With the mathematical programming model two different scenarios have been simulated, representing possible farm responses to the Directive.

In terms of methodology, the model represents the production plan of each representative farm quite well, since, in the baseline situation, the model predicts well the revenues from farming. The model is less precise in reproducing costs, but the simulation errors are quite small and comparable among the eight representative farms, such that simulation results are also comparable.

In terms of empirical results, to what extent a farm is affected by the Nitrates Directive depends on the scenario. In the herd reduction scenario, farms with a nitrogen surplus reduce the herd size making the milk quota no longer binding. In this way, the farm has excess capacity and inefficiencies are introduced. In other words, the Nitrates Directive introduces a new kind of quota, the 'nitrates quota'. Under this scenario surplus farms change quite radically their production plan and experience the largest negative income effects. For example, the representative Lombardia medium and large farm and the large Emilia farm have an income fall of approximately one third compared to the baseline situation. The income fall of other farms is smaller, but it is always larger than in the manure market scenario. Farms with negative nitrogen from livestock surplus are not affected in this scenario.

The results of the manure market scenario show that the creation of a manure market may significantly reduce the negative effects of the Nitrates Directive on Italian dairy farms. This scenario affects the production decisions of farms minimally as the herd size and the land allocation do not change. It also avoids the creation of excess capacity on the farms. In addition, the creation of a manure market leads to lower income reduction for farms with positive surplus than in herd reduction case. When the market price of manure is set equal to 3 euros/ kg N, none of the farms with a manure surplus have an income fall larger than 9% and only two farms have an income fall larger than 5%. When the market price increases to 5 euros/ kg N, only one farm has a fall in income larger than 10% (13.8%). Additional simulations show that only with unrealistically high manure disposal cost a manure market is a worse option than herd size reduction. In this scenario farms with negative nitrogen from livestock surplus can increase their income. Finally, the welfare loss is also lower as there is a shift of money from farms with a positive surplus towards farms with a negative surplus and toward transport intermediaries.

In conclusion, the creation of a manure market in Italy is likely to be very important in order to reduce the negative effects of the implementation of the Nitrates Directive on dairy farms with a manure surplus. This confirms the general idea that a market is more efficient than quantity constraints from a welfare theory point of view. Simulations also show that only farms in vulnerable zones are negatively affected by the Nitrates Directive, as they are allowed to spread less manure on land than farms in non-vulnerable zones. This could lead to unfair competition between dairy farms located in vulnerable zones and dairy farms in non-vulnerable zones, an issue that deserves further research.

This issue, together with a refinement of the simulation results, may be addressed through the use of a more sophisticated spatial bio-economic model, that incorporates both a better representation of the manure market and a better representation of the biological constraints characterising dairy farms.

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Appendix I
Model

This appendix presents the empirical model (equations (A.1)- (A.25)).

$$\max_{y_j, x_i} FI = \sum_{j=1}^{9} p_j \times y_j - \sum_{i=1}^{7} w_i \times x_i + subs - \sum_{k=1}^{5} c_k - dep - exc \quad \text{(A.1)}$$

subject to

$$y_7 = m \times cow \quad \text{(A.2)}$$

$$y_7 \leq quota \quad \text{(A.3)}$$

$$hei = 0.66 \times cow \quad \text{(A.4)}$$

$$y_9 = cow \times CB \times (1 - D) - 0.33 \times cow \quad \text{(A.5)}$$

$$y_8 = 0.33 \times cow \quad \text{(A.6)}$$

$$y_{10} = ncow \times cow + nhei \times hei \quad \text{(A.7)}$$

$$nsur = y_{10} - x_6 \quad \text{(A.8)}$$

$$nsur = 0 \quad \text{(A.9)}$$

$$nn = \sum_{v=1}^{6} nnc_v \times \eta_v \times l_v \quad \text{(A.10)}$$

$$ns = x_6 \times work + x_7 \quad \text{(A.11)}$$

$$nn \leq ns \quad \text{(A.12)}$$

$$tl = \sum_{v=1}^{6} l_v \quad \text{(A.13)}$$

$$l_1 \leq \tfrac{1}{3} tl \quad \text{(A.14)}$$

$$\sum_{v=4}^{6} l_v \leq \tfrac{1}{3} tl \quad \text{(A.15)}$$

$$y_v = pc_v \times l_v \quad \text{(A.16)}$$

$$x_2 = y_1 \quad \text{(A.17)}$$

$$x_b = y_b + bx_b \quad \text{(A.18)}$$

$$req_{feed} = reqcow_{feed} \times cow + reqhei_{feed} \times hei \quad \text{(A.19)}$$

$$\sup ply_{feed} = \sum_{i=1}^{5} cr \sup ply_{feed} \times x_i \times dm_i \quad \text{(A.20)}$$

$$req_{feed} \leq \sup ply_{feed} \quad \text{(A.21)}$$

$$\sum_{i=2}^{4} dm_i \times x_i \geq 0.35 \times req_3 \quad \text{(A.22)}$$

$$x_1 = x_5 \quad \text{(A.23)}$$

$$x_1 + x_5 = \tfrac{1}{3} y_7 \quad \text{(A.24)}$$

$$c_k = f(l_v, y_7) \quad \text{(A.25)}$$

where j indexes outputs: fodder maize (j=1), temporary grass (j=2), permanent grass (j=3), wheat (j=4), barley (j=5), grain maize (j=6), milk (j=7), cull cows (j=8), calves (j=9) and livestock nitrogen (j=10); v indexes crops: fodder maize (v=1), temporary grass (v=2), permanent grass (v=3), wheat (v=4), barley (v=5), grain maize (v=6); i indexes inputs: concentrate (i=1), fodder maize (i=2), temporary grass (i=3), permanent grass (i=4), maize meal (i=5), nitrogen from manure (i=6) and chemical nitrogen (i=7); b indexes grass crops: temporary grass (b=1), permanent grass (b=2); k indexes other costs (modelled through regression analysis): veterinary cost (k=1), energy cost (k=2), water cost (k=3), plant protection cost (k=4) and seed cost (k=5);indexes nutritional contents: energy (feed=1), protein (feed=2) and dry matter (feed=3).

FI^f is the income from farming, y_i and x_i are output and input quantities respectively, p_j and w_i are the corresponding exogenous market prices and is the decoupled farm payment; c_k indicates variable costs for the inputs not included in x_i and are estimated by regressions, *dep* is the depreciation of capital assets and the costs of external factors (wages, rent and interests paid). *cow* and *hei* are the number of cows and heifers, *m* is the milk production per cow while *quota* is the milk quota amount. *CB* is the number of calves born per cow per year while *D* indicates the mortality rate of calves. Concerning the nitrogen produced, *ncow* is referred to nitrogen produced per cow, *nhei* to the nitrogen produced per heifer and *ns* is the total efficient nitrogen applied; on the nitrogen demand side, η_v is the correction coefficient for the nitrogen requirement per hectare of crop, nnc_v is the standard requirement of efficient nitrogen per hectare of crop, *work* is the workability coefficient of nitrogen from manure[4] and *nn* is the total efficient[5] nitrogen required; indicates the nitrogen surplus from manure. pc_v represents the production per hectare of crop, while l_v is the land allocated to each crop and *tl* is the total utilised agricultural area on farm f. Concerning the feed constraints, req_{feed} and sup ply_{feed} indicates the total energy, protein and dry matter required and supplied respectively; $reqcow_{feed}$ and $reqhei_{feed}$ are the requirements of energy, protein and dry matter of each cow and heifer, while *cr* indicates ply_{feed} the supply of nutrients per unit of dry matter of each feed. dm_i is the percentage of dry matter in each feed. bx_b is the quantity of grass bought.

Equations (A.26)-(A.28) model the introduction of the Nitrates Directive:

$$x_6 \leq MNap \times tl \qquad (A.26)$$

$$map = \sum_{v=i}^{6} nall_v \times t_v \qquad (A.27)$$

$$ns \leq tnap \qquad (A.28)$$

where *MNap* is the nitrogen from manure applicable per hectare, *tnap* is the total efficient nitrogen applicable and $nall_v$ is the efficient nitrogen applicable per hectare of each crop.

[4] The workability coefficient of chemical nitrogen is assumed equal to 1 and therefore omitted.

[5] Efficient is used to indicate nitrogen immediately available for the crop.

Appendix II
Scenarios

<u>*Herd reduction scenario*</u>

The model is equal to the base model (equations (A.1)-(A.25)) plus constraints (A.26)- (A.28).

<u>*Manure market scenario*</u>

This scenario is represented by equations (A.1)- (A.28), with the exception of equation 9. Some other constraints specific of this scenario are shown below. The values of the variables cow^f and hei^f are fixed and set equal to the outcomes of the base model.

$$\max_{yj,xi} FI = \ldots - DCnsur \ldots$$

$$DCmsur = und \times nsur \qquad \text{if } nsur \geq 0$$

$$DCmsur = (\text{udc} - \text{utr cos}t) \times nsur \qquad \text{if } nsur \leq 0$$

Where *DCnsur* is the total cost of manure disposal, *Udc* is the unitary disposal cost of nitrogen from manure and *untrcost* is the unitary transport cost of nitrogen from manure.

Appendix III
Results

Table V.1 Relevant results of simulations. Percentage changes in decision variables in each scenario compared to the baseline situation

	I		II		III		IV*		V		VI		VII		VIII	
	Sc.1	Sc.2	Sc.1	Sc.2	Sc.1	Sc.2	Sc.1	Sc.2	Sc.1	Sc.2	Sc.1	Sc.2	Sc.1	Sc.2	Sc.1	Sc.2
Milk production	-4.1	0	-33.8	0	-31.2	0	0	0	0	0	-6.1	0	-22.8	0	-0.4	0
Cows	-4.1	0	-33.8	0	-31.2	0	0	0	0	0	-6.1	0	-22.8	0	-0.4	0
Heifers	-4.1	0	-33.8	0	-31.2	0	0	0	0	0	-6.1	0	-22.8	0	-0.4	0
Livestock nitrogen production	-4.1	0	-33.8	0	-31.2	0	0	0	0	0	-6.1	0	-22.8	0	-0.4	0
Livestock nitrogen application	-4.1	-4.1	-33.8	-33.8	-31.2	-31.2	0	67.8	0	36.2	-6.1	-6.1	-22.8	-22.8	-0.4	-0.4
Surplus livestock N (kg) ^	0	132	0	3,474	0	9,262	0	-1,408	0	-1,016	0	554	0	11,562	0	23
Chemical nitrogen application	3.2	7.4	125	161	51	86.5	n.a.**	n.a.	0	-21.8	n.a.	n.a.	n.a.	n.a.	-0.4	0.6
Efficient N requirement	-1.5	0	-6.2	0	-9.4	0	n.a.	n.a.	0	0	0	0	0	0	-0.4	0
Efficient N supply	-1.5	0	-6.2	0	-9.4	0	0	67.8		0	-6.1	-6.1	-22.8	-22.8	-0.4	0
Land fodder maize ***	-4.1	0	-14.2	0	-19.9	0	/	/	/	/	/	/	/	/	/	/
Land temp. grassland	2.6	0	14.2	0	19.9	0	0	0	0	0	0	0	0	0	0.9	0
Land permanent grassland	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0	0	n.a.	n.a.	n.a.	n.a.	-0.4	0
Land wheat	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	/	/	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Land barley	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	/	/	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Land grain maize	0	0	0	0	0	0	/	/	0	0	0	0	0	0	/	/
Temporary grassland hay purchase	-8.6	0	-65.3	0	-74.7	0	0	0	0	0	-11.5	0	-39.0	0	-1.0	0

Continued

Table III.1 Continued

	I		II		III		IV		V		VI		VII		VIII	
	Sc.1	Sc.2	Sc.1	Sc.2	Sc.1	Sc.2	Sc.1	Sc.2	Sc.1	Sc.2	Sc.1	Sc.2	Sc.1	Sc.2	Sc.1	Sc.2
Permanent grassland hay purchase	n.a.	n.a	n.a.	n.a	n.a.	n.a	n.a.	n.a	n.a.	n.a	n.a.	n.a	n.a.	n.a	n.a.	n.a
Concentrate purchase	-4.1	0	-33.8	0	-31.2	0	0	0	0	0	-6.1	0	-22.8	0	-0.4	0
Maize meal purchase	-4.1	0	-33.8	0	-31.2	0	0	0	0	0	-6.1	0	-22.8	0	-0.4	0
Energy demand	-4.1	0	-33.8	0	-31.2	0	0	0	0	0	-6.1	0	-22.8	0	-0.4	0
Energy supply	-4.1	0	-32.8	0	-30.6	0	0	0	0	0	-6.1	0	-22.8	0	-0.4	0
Protein demand	-4.1	0	-33.8	0	-31.2	0	0	0	0	0	-6.1	0	-22.8	0	-0.4	0
Protein supply	-4.1	0	-36.3	0	-33.0	0	0	0	0	0	-6.1	0	-22.8	0	-0.4	0
Dry matter demand	-4.1	0	-33.8	0	-31.2	0	0	0	0	0	-6.1	0	-22.8	0	-0.4	0
Dry matter supply	-4.1	0	-33.8	0	-31.2	0	0	0	0	0	-6.1	0	-22.8	0	-0.4	0
Veterinary cost	-4.9	0	-28.7	0	-43.1	0	0	0	0	0	-6.6	0	-11.2	0	-0.3	0
Energy cost	-3.5	0	-34.5	0	-31.7	0	0	0	0	0	-3.8	0	-16.1	0	-0.2	0
Water cost	-1.5	0	-17.4	0	-18.8	0	0	0	0	0	-2.1	0	-7.8	0	-0.2	0
Plant protection cost	-1.4	0	-4.6	0	-4.3	0	0	0	0	0	0	0	0	0	0	0
Seeds cost	-2.0	0	-5.9	0	-8.3	0	n.a.	n.a.	0	0	0	0	0	0	0	0

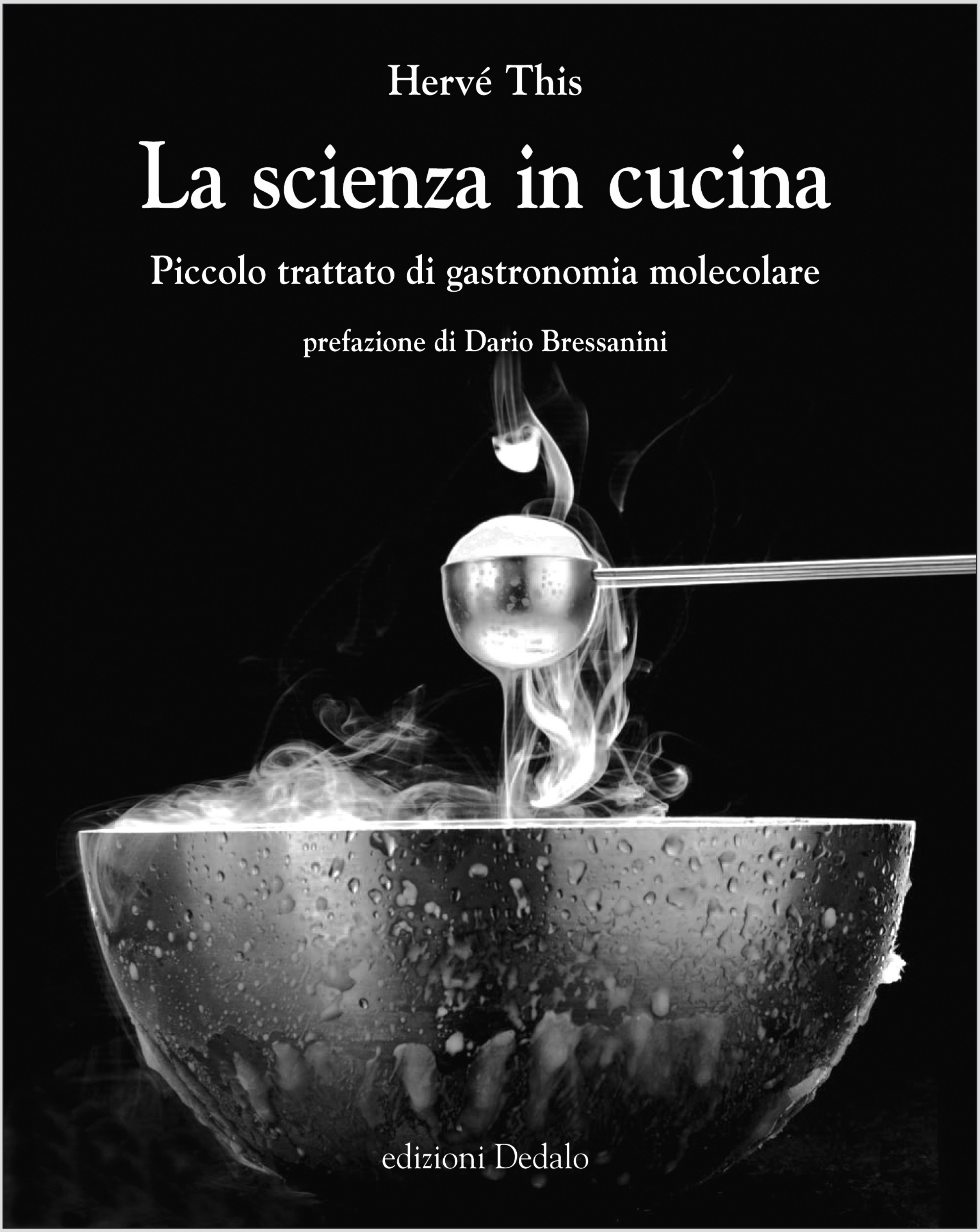
Source: simulation results

^Livestock nitrogen surplus is not expressed in percentage variation but in absolute values.

* As cereal production is not included in the model for Lombardia farms from the mountain area, the percentage change of cereal land does not exist.

** n.a. indicates variables with values in the baseline of zero and therefore no percentage change can be calculated.

** *As fodder maize production is not included in the model of the groups of Emilia farms (V, VI, VII, VIII), the percentage change of fodder maize land does not exist.



Perché l'aragosta bollita è rossa e la meringa è gonfia? Indagine scientifica e abilità culinaria si alleano per comprendere meglio ciò che facciamo ogni giorno in cucina... e per preparare nuove leccornie!