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The influence of restricting nitrogen losses of dairy farms on dairy cattle breeding goals

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Abstract

The objective of this paper was to investigate the influence of environmental legislation to restrict nitrogen losses on dairy cattle breeding goals. Linear programming was used to model a dairy farm, including multiple restrictions on product output and production factor input. Management was optimized to maximize labour income. Effects of genetic improvement on labour income (economic values) were derived for dry-matter intake capacity, body weight and milk production (carrier, fat and protein). Also effects of genetic improvement on the farm's nitrogen losses were computed. Basic economic values calculated were 0, –0.05, –0.18, 0.78, and 13.81 for dry matter intake capacity, body weight, carrier, fat and protein, respectively. With more stringent environmental legislation, the economic value of fat increased (1.68) and the economic value of body weight decreased (–0.21), with constant economic values of carrier, protein and dry matter intake capacity. Generally, a higher fat production per cow resulted in a reduction of nitrogen losses, and an increase in body weight increased nitrogen losses.

Keywords: dairy cattle, linear programming, breeding goals, economic value, environmental legislation, nitrogen losses

Introduction

Economic developments of production systems have resulted in dairy farms that utilize 12-16% of total nitrogen (N) input (Aarts et al., 1988). N losses on dairy farms cause environmental problems such as acidification and pollution of ground and surface water. Environmental problems are an important reason for the Dutch and EC governments to develop legislation to reduce such N losses. Introduced legislation consists of quotas (e.g. the amount of phosphate applied per ha) and of prescriptions (e.g. when and how to store or to apply animal manure) (MANF, 1990; MHPE, 1990).

Dairy cattle breeding is aimed at changing genetic merit of cows to improve the efficiency of production systems. Selection emphases on traits are partly determined by the relative weights put on a trait in the breeding goal. These relative weights are quantified as economic values. An economic value of a trait expresses the extent to which economic efficiency of production is improved at the moment of expression of one additional unit of genetic merit for that trait, independent of changes in other traits included in the breeding goal. Economic values used for defining breeding goals depend on expected future production circumstances (Gibson, 1989; Groen, 1989). Changes in production circumstances, e.g. the introduction of environmental legislation, might lead to adjustments of breeding goals, because incorrect economic values will reduce benefits of animal breeding (Smith, 1983; Groen, 1990). A correct definition of the dairy cattle breeding goal with regard to future production circumstances also requires information on the consequences of genetic improvement to reducing N losses of the dairy farm.

The objectives of this study were to determine (1) the effect of different governmental policies to reduce N losses at farm level on the economic values of traits in dairy cattle breeding goals, and (2) to determine the effect of genetic improvement on N losses on dairy farms. The effect of farm intensity on economic values and N losses was considered.

Materials and methods

Economic values need to be derived from an optimized production system (Smith et al., 1986; Dekkers, 1991). Linear programming (LP) allows for optimizing farm plans when multiple restrictions on production factor input(s) and output(s) are applied. In this study, the LP model of a dairy farm (Berentsen et al., 1992) was used to derive economic values and contributions of genetic improvement of individual traits on N losses. Farm plans were optimized with maximum labour income (returns on labour and management) as the objective. The bio-economic model of Groen (1988) was used to determine parameters in the LP model of feed requirements, milk production, body weight and dry matter intake capacity per cow.

The LP model allowed for different options in using cultivated area (sandy soil) with regard to the production of grass (grazing or making silage with N manuring levels of 200, 300, 400 or 500 kg N of manure and fertilizer per ha) and/or maize. Seasonal patterns of grass usage were included. A variety of concentrates (different energy/protein ratios and different N and P_2O_5 concentrations) and fertilizer could be purchased; silage maize could be bought or sold. Different options for storing (open or closed storage) and applying (surface spreading or injecting) manure were created. It was assumed that all cows calved in February and that there was a fixed ratio of young stock per cow. N losses from run-off, leaching, denitrification and volatilization were determined at farm level by subtracting N output through sold milk, meat and roughage, from N input through purchased concentrates, fertilizer and roughage and through deposition. For more about assumptions and options see Berentsen et al. (1992).

In this study the dairy farm was characterized by 24 ha cultivated area and a milk/fat quota of 288000 kg with 4.40% fat (réference content) (12000 kg quota ha^{-1}). Annual production per cow was 6695 kg milk (4.40% fat and 3.38% protein) representing the Dutch Black and White population. Prices represented average levels in the Netherlands for the period 1992/1993. Governmental legislation was translated into direct quotas and prescriptions that restricted the choice of specific options (Table 1). The basic situation represents current (1992) legislation in the Netherlands. Alternative A includes possible legislation as introduced by the Dutch government by the year 2000 (Berentsen et al., 1992). Alternative B is the same as A except for the levy on N losses above 200 kg ha^{-1} (2 Dfl kg^{-1}; Baltussen, 1992).

Legislation on P_2O_5 assumes a normative production of manure (volume and concentration) per animal per year. In the model a fixed volume of manure production per animal was also assumed, but differences in true P_2O_5 concentration could occur as a result of different feed rations. Therefore, true P_2O_5 production at the farm, and thus the available P_2O_5 for manuring land, is to a certain extent variable and influences the production level of grassland. The N limit, however, represented the true manuring level. If true N production or normative P_2O_5 production exceeded the limit, manure had to be removed from the farm at cost Dfl 15 m^{-3}.

To analyse the effect of farm intensity, two additional situations were studied: an extensive farm with 36 ha cultivated area (8000 kg milk quota ha^{-1}), and an intensive farm with 18 ha (16000 kg milk quota ha^{-1}).

Economic values were calculated by changing the level of a particular trait by 2% without changing the level of any other trait. Traits considered were (Groen, 1988): dry matter intake capacity (DMIC, in terms of kg dry matter of a standard reference feed), body weight (BW, mature weight), and milk production (kg of carrier, fat and protein in a 305 d lactation of a heifer).

Table 1. Quotas and prescriptions included[a] in alternatives considered (see text for explanation of alternatives Basic, A, B).

	Basic	A	B
Method of storing manure:			
Open storage	+	–	–
Closed storage	+	+	+
Method of applying manure:			
Surface spreading	Max. 1/3	–	–
Injection	+	+	+
Phosphate limit (kg ha^{-1}):			
P_2O_5 for grassland	200[b]	110[c]	110[c]
P_2O_5 for fodder maize	250[b]	75[c]	75[c]
Nitrogen limit (kg ha^{-1})	No limit	300[c]	300[c]
Levy on N losses >200 kg ha^{-1} (Dfl kg^{-1})	0	0	2

[a] +, Option 'allowed'; —, option 'not allowed'.
[b] P_2O_5 of fertilizer is not included.
[c] P_2O_5 or N of fertilizer is included.

Results

Economic values are in Table 2. The economic value of DMIC was zero in most situations. Increasing DMIC enables a replacement of expensive high-energetic concentrate by cheap, voluminous and low-energetic roughage (Groen & Korver, 1989). However, this principle of maximizing roughage intake only works in practice when DMIC is limiting and when roughage is the cheapest alternative feed available. Only in alternatives A and B for the intensive farm during the grazing period these two conditions were met and, therefore, in these situations the economic value of DMIC was larger than zero (4.81 for A and 5.88 for B).

The economic value of BW ranged from 0.05 to –0.37, indicating that in general, marginal feed costs of maintaining BW exceeded marginal revenues from culled cows. Differences in economic values of BW originated partly from differences in marginal cost per unit feed at different farm intensities: marginal feed costs were lower at a lower intensity of the farm. An increased need for feed at the intensive farm should be matched by purchasing expensive roughage or concentrate, whereas the extensive farm can increase roughage production at a lower cost level. The economic value of carrier was constant over all situations (–0.18 or –0.19) and negative because of the negative base price of carrier in the Dutch payment system.

Increased protein production per cow resulted in higher revenues at farm level, and in an increase of variable costs per cow (with hardly any change in number of cows because of the milk/fat quota). Differences in the economic value of protein within alternatives could partly be explained by higher marginal (feed) costs for more intensive farms. Economic values of protein for the intensive farm in alternatives A and B (and to a lesser extent for the extensive farm in alternative A for protein and also for BW) deviated from others. This was caused by the normative character of the P_2O_5 limit. In these situations, before genetic improvement, the true available P_2O_5 on the farm was limited because of the normative P_2O_5 limit (Table 1).

Table 2. Economic values (Dfl kg^{-1} cow^{-1} yr^{-1}) of DMIC, BW, carrier, protein and fat given different farm intensities and different production circumstances.

Intensity	Alternative	Economic values				
		DMIC	BW	Carrier	Protein	Fat
18 ha	Basic	0	–0.22	–0.18	13.67	1.79
	A	4.81	–0.30	–0.18	17.60	6.10
	B	5.88	–0.37	–0.18	14.96	3.65
24 ha	Basic	0	–0.05	–0.19	13.81	0.78
	A	0	–0.05	–0.19	13.81	0.84
	B	0	–0.21	–0.19	13.84	1.68
36 ha	Basic	0	–0.01	–0.19	13.77	0.65
	A	0	–0.05	–0.19	14.20	0.69
	B	0	–0.10	–0.19	13.75	1.17

Increasing protein production per cow caused an increase of concentrate in the feed ration and thereby increasing P_2O_5 concentration in manure. Thus, the available amount of true P_2O_5 on the farm was increased whereas the normative P_2O_5 production of cows remained the same. The increased true amount of P_2O_5 resulted in increased grass production and hence in a reduction of the average variable feed costs per cow. As a direct consequence of the milk-fat quota, an increase in fat production per cow gives a reduction in the number of cows. This resulted in a reduction of total variable costs at the farm, especially for the more intensive farms. The high economic values for fat for the intensive farm in alternatives A and B resulted from the normative regulation of P_2O_5 usage on the farm. As for protein, increasing fat production per cow resulted in more available P_2O_5 and reduced average variable feed costs per cow. The intensive farm was obliged to remove manure as a consequence of the P_2O_5 limit. The true available P_2O_5 in manure for the intensive farm was increased because the reduction of cows (as a consequence of the milk/fat quota) resulted in a relatively larger reduction of obligatorily removed manure compared with the decrease in the P_2O_5 production. Reduction of the obligatory amount of removed manure resulted also in reduced variable costs.

Total N losses per ha (TNLh) and effects of a 2% increase of genetic merit of each trait on TNLh of the farm are in Table 3. Introduction of environmental legislation (alternatives A and B versus Basic) resulted in a considerable decrease of TNLh, especially for the intensive farm. Effects on TNLh of a 2% increase of a trait ranged between −8.0 and 13.7 kg N ha^{-1}. Introduction of a levy on N losses above 200-kg ha^{-1} (alternative B) resulted in an "economic optimum" level of TNLh for the extensive farm before and after changing levels of the different traits. In all situations, increasing BW resulted in higher TNLh. An increase of fat and carrier and the consequent reduction in the number of cows generally resulted in reduced TNLh.

Table 3. Total N losses per ha[a] and effects of 2% genetic improvement[b] of DMIC, BW, carrier, protein and fat on total N losses per hectare (TNLh) in different situations.

Intensity	Alternative	TNlh	DMIC	BW	Carrier	Protein	Fat
18 ha	Basic	574	0	0.5	−0.3	−0.4	−0.8
	A	344	−0.9	1.3	0.3	10.8	13.1
	B	339	0.1	0.7	−0.0	11.1	13.7
24 ha	Basic	335	0	4.6	−1.5	1.5	−6.9
	A	322	0	1.4	−0.2	−0.0	−3.2
	B	280	0	2.8	−0.4	0.4	−6.1
36 ha	Basic	226	0	1.0	−0.2	−0.1	−2.2
	A	214	0	1.6	−0.2	1.4	−2.1
	B	200	0	0	0	0	0

[a] N input (purchased concentrates, fertilizer, roughage and deposition) minus N output (milk, meat, sold roughage and discharged manure).
[b] 2% Increase was assumed: 96 kg carrier yr^{-1}, 3.5 kg protein yr^{-1}, 4.6 kg fat yr^{-1}, 0.3 kg DM d^{-1} and 12 kg mature BW cow^{-1}, respectively.

Situations in which genetic improvement of a trait caused increased grass production because of limited available P_2O_5 (intensive farm, alternatives A and B for protein and fat and the extensive farm, alternative B for protein and BW) resulted in increased TNLh.

Discussion

Economic values were determined assuming multiple restrictions on various inputs and outputs. In all situations, milk output was restricted as well as the fat content of the milk; depending on the situation, environmental legislation also led to restrictions on the use of N and P_2O_5.

Economic values were derived from changes in labour income after a change in genetic merit of a trait, and resulted from marginal changes in revenues per cow, in number of cows on the farm, in feed costs per cow (Groen, 1989) and also from changes in other variable costs. Optimizing management mainly affected the marginal feed costs per cow by choosing an economic optimum for the feed ration after genetic improvement.

Groen & Korver (1989) derived a method to obtain an economic value for DMIC assuming maximization of roughage input. Optimization of management in the current study did not result in maximization of roughage input, especially in the winter period. Costs of purchasing concentrates seem to be favourable compared to costs of other feed alternatives. Because fresh grass (mainly used in the summer period) and concentrates have low 'fill values' (Jarrige et al., 1986), the DMIC was not limited in the summer and winter period respectively. For the intensive farm in situation A and B, the grass production was limited because of the P_2O_5 limit and silage maize was needed in the feed ration in the summer period. Only in this situation the DMIC became limiting and an increase of the DMIC resulted in an economic value higher than zero. Additional research to analyse the effect of environmental legislation and farm intensity (e.g. considering various production levels) on the DMIC is required.

The results showed some contradictions with regard to the benefits of genetic improvement for either labour income or N losses. This was partly caused by inconsistencies of governmental legislation, especially in this study the normative character of P_2O_5 legislation.

From this study it is concluded that environmental legislation, as introduced in the Netherlands increases the economic values of fat production per cow and reduces the economic value of body weight, maintaining levels of economic values of carrier and protein. Including body weight in the breeding goal of dairy cattle should be considered. Combined selection for milk production and body weight will not lead to smaller cows (Groen & Korver, 1989), but the unfavorable positive correlated genetic response in body weight with single purpose selection for milk production will be reduced.

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