Integrated modeling of feeding and breeding strategies to reduce greenhouse gas emissions along the production chain of milk

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ABSTRACT

We evaluated the impact of feeding and breeding strategies to reduce greenhouse gas (GHG) emissions from dairy farming. A whole-farm optimization model was combined with mechanistic modeling of enteric fermentation and LCA to determine the impact on GHG emissions and farm income. Feeding strategies included supplementation of extruded linseed (56% linseed; 1 kg/cow/day in summer, 2 kg/cow/day in winter), supplementation of nitrate (75% nitrate; 1% of dry matter intake), and reducing grass maturity. In case of breeding, the impact of one genetic standard deviation improvement in milk yield (687 kg/cow/year) and longevity (271 days) was assessed. Supplementing linseed reduced emissions by 9 kg CO_2-equivalents (CO_2e)/ton fat-and-protein-corrected milk (FPCM), supplementing nitrate by 32 kg CO_2e/ton FPCM, and reducing grass maturity by 11 kg CO_2e/ton FPCM. All strategies reduced farm income. Increasing milk yield and longevity reduced emissions by 27 and 23 kg CO_2e/ton FPCM, respectively. Both strategies increased farm income.

Keywords: dairy farming, greenhouse gas mitigation, linear programming, economic analysis, life cycle assessment

1. Introduction

Dairy cattle, producing milk, meat, and non-edible products (e.g. manure), are responsible for about 30% of global greenhouse gas (GHG) emissions produced by the livestock sector (Gerber et al., 2013). About half of these GHG emissions is related to enteric fermentation. Other important sources of GHG emissions are feed production and manure management. Two important areas of interest to reduce GHG emissions from dairy farming are feeding strategies to reduce emissions from enteric fermentation, and breeding strategies to improve animal productivity.

Examples of feeding strategies to reduce emissions from enteric fermentation are dietary supplementation of fatty acids, dietary supplementation of nitrate, and reducing the maturity stage of grass herbage and grass silage (Martin et al., 2008; Van Zijderveld et al., 2011; Brask et al., 2013). Examples of breeding strategies to improve animal productivity are increasing milk yield and longevity (Bell et al., 2010). Increasing milk yield per cow reduces GHG emissions per kg milk by diluting emissions from production and fermentation of feed related to maintenance. Increasing longevity reduces GHG emissions per kg milk by reducing the number of female replacements contributing to GHG emissions during maintenance and growth, without producing milk, and by increasing lifetime milk yield per cow, diluting emissions related to rearing.

Most studies that evaluate the potential of feeding and breeding strategies to reduce GHG emissions from dairy farming do not account for emissions other than enteric methane (CH_4), do not account for changes in farm management to adapt the farm optimally to the particular strategy, or do not account for consequential effects in other parts of the milk-production chain. To understand which strategies can contribute to reducing the net contribution of dairy farming to global GHG emissions, an integrated approach is required that accounts for all changes in farm management and includes all changes in GHG emissions along the chain.

The aim of this study was to analyze the impact of several feeding and breeding strategies to reduce GHG emissions from dairy farming on GHG emissions at chain level (i.e. from cradle to farm-gate) and on labor income at farm level using an integrated approach. We combined a whole-farm optimization model with a mechanistic model for enteric methane and life cycle assessment (LCA). Feeding strategies under study included dietary supplementation of extruded linseed, dietary supplementation of nitrate, and reducing the maturity stage of grass herbage and grass silage (for further details, see Van Middelaar et al., 2014a). In case of breeding, we focused on the impact of one genetic standard deviation improvement in milk yield and longevity (for further details, see Van Middelaar et al., 2014b). By evaluating the impact of one unit change in individual traits, the relative value of each trait to reduce GHG emissions along the chain can be determined.

2. Methods

2.1. Dairy farm linear programming model

A dairy farm linear programming (LP) model based on Berentsen and Giesen (1995) was used to simulate a Dutch dairy farm before and after implementing the strategies. The farm production plan was optimized based on the objective to maximize labor income of the farm family. The LP model is a static year model and includes all relevant activities and constraints that are common to Dutch dairy farms, such as on-farm roughage production, purchase of feed, and animal production, including the rearing of young stock. Prices of purchased and sold products were based on KWIN-V (2008).

The central element of the LP model is an average dairy cow from the Holstein Friesian breed, with a given milk production and longevity, calving in February, and conditions representing the dairy cattle of the farm. Feed requirements (energy and protein) and intake capacity of this average cow were determined using the bio-economic model of Groen (1988). The same model was used to determine herd composition and yearly replacement rate, based on the average longevity of the cow. The replacement rate determines the number of young stock that needs to be kept on the farm for yearly replacement of the dairy cows.

The model distinguishes a summer and a winter period regarding feeding. Available land can be used as grassland or as corn land. Dietary options include grass from grazing, grass silage, corn silage, and three types of concentrates that differ in protein levels (i.e. standard, medium and high). All dietary options were available in winter and summer, except for fresh grass (only in summer). Table 1 shows the feed characteristics of the feeds that are standard available in the model. Based on feed restrictions, the LP model matches feed requirements of the cow with on-farm feed production and purchased feed. Constraints of the model include fixed resources of the farm (e.g. land area, family labor), links between activities (e.g. fertilizer requirements of grass- and arable land with available nutrients from manure and purchased fertilizers), and environmental policies (e.g. limits to the application of nitrogen (N) and phosphate (P_2O_5) fertilization). For a more detailed description of the LP model see Van Middelaar et al. (2013).

Table 1. Feed characteristics of feeds standard available in the dairy farm LP model, expressed per kg dry matter (DM).

Feed product	**NE_L [1] (MJ/kg DM)**	**DVE [2] (g/kg DM)**	**OEB [3] (g/kg DM)**	**N [4] (g/kg DM)**	**Fill value [5] (kg/kg DM)**	**NDF [6] (g/kg DM)**	**Crude fat (g/kg DM)**
Concentrates							
- standard protein	7.21	100	6	24.1	0.29-0.72	414	48
- medium protein	7.21	133	28	32.2	0.29-0.72	407	51
- high protein	7.21	200	83	48.3	0.29-0.72	312	46
Dietary urea	0.00	0	2920	467.0	0.00	0	0
Fresh grass normal cut (1700 kg DM/ha)							
- 125 kg N	6.62	94	9	28.0	0.93	457	37
- 175 kg N	6.68	96	16	29.4	0.93	452	38
- 225 kg N	6.73	98	23	30.9	0.93	448	39
- 275 kg N	6.77	99	31	32.4	0.93	445	40
Grass silage normal cut (3500 kg DM/ha)							
- 125 kg N	5.89	70	22	25.6	1.08	506	35
- 175 kg N	5.93	71	31	27.4	1.08	501	36
- 225 kg N	5.97	73	39	29.0	1.08	497	37
- 275 kg N	6.00	74	47	30.6	1.08	493	39
Corn silage	6.56	58	-36	13.4	1.02	373	25

[1] Net energy for lactation. [2] True protein digested in the small intestine according to Dutch standards (Tamminga et al., 1994). [3] Rumen degradable protein balance according to Dutch standards (Tamminga et al., 1994). [4] Nitrogen. [5] Fill value per kg DM feed expressed in kg of a standard reference feed (Jarrige, 1988). The fill value of concentrates increases with an increase in concentrate intake. [6] Neutral detergent fiber.

2.2. Calculating greenhouse gas emissions

We used LCA to calculate emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) from the different stages along the production chain, up to the moment that milk leaves the farm gate. Processes included are the extraction of raw materials to produce farm inputs, the manufacturing and distribution of these inputs, and all processes on the dairy farm. Stages related to transport and processing of milk were assumed to be unaffected by the strategies, and, therefore, not included in the analysis.

Emissions from the production of synthetic fertilizer, pesticides, tap water, and energy sources (gas, diesel, and electricity) were based on Eco-invent (2007), and from the production of concentrates and milk replacer on Vellinga et al. (2013). Emissions from production of concentrates include emissions from the production of inputs (e.g. fertilizers, pesticides, machinery, and energy), direct and indirect N_2O emissions from cultivation, CO_2 emissions from liming and urea fertilization, emissions from drying and processing, and emissions from transport in between stages, up to the farm gate.

Emissions of CH_4 from on-farm processes relate to enteric fermentation and to manure management. Emission of enteric CH_4 from dairy cows was calculated using a mechanistic model originating from Dijkstra et al. (1992). Production of CH_4 is estimated from the hydrogen (H_2) balance. Sources of H_2 include H_2 from production of acetate and butyrate, and from microbial growth with amino acid as N-source. Sinks of H_2 include H_2 used for production of propionate and valerate, for microbial growth with ammonia as N-source, and for biohydrogenation of lipids. The surplus H_2 is assumed to be completely converted into CH_4. To calculate the effect of dietary supplementation of extruded linseed and nitrate on enteric CH_4 production, additional calculations were required (see section 2.3). In case of breeding, results of the mechanistic model were transformed into empirical relations between dry matter (DM) intake of feed ingredients and CH_4 emission factors per ingredient (Vellinga et al., 2013). For young stock, enteric CH_4 emission was based on IPCC Tier 2 methods and default values, i.e. the average gross energy content of feed is assumed to be 18.45 MJ/kg DM, and 6.5% of the gross energy intake is converted to CH_4 (IPCC, 2006). Emissions of CH_4 from manure management were based on national inventory reports, i.e. 0.746 kg CH_4 per ton manure produced in stables, and 0.110 kg CH_4 per ton manure produced during grazing (De Mol and Hilhorst, 2003).

Emissions of CO_2 from on-farm processes related to the combustion of diesel and gas were based on Eco-invent (2007). Emissions of N_2O from on-farm processes include both direct and indirect N_2O from manure management and from N application to the field, including N from manure, synthetic fertilizers, and crop residues. Indirect N_2O emissions result from N that is removed from the farm via leaching of nitrate and volatilization of ammonia and nitrogen oxide (IPCC, 2006). Emissions of N_2O from crop residues were based on IPCC (2006). Other N_2O emissions were based on national inventory reports (see Van Middelaar et al., 2013).

Different GHGs were summed up based on their equivalence factor in terms of CO_2 equivalents (CO_2e) (100-year time horizon): 1 for CO_2, 25 for CH_4, and 298 for N_2O (IPCC, 2007). Emissions were calculated per ton fat-and-protein corrected milk (FPCM), i.e. milk corrected to a fat percentage of 4.0% and a protein content of 3.3%. After summing up emissions, they were allocated to the different outputs of the farm (i.e. milk and meat) based on the relative economic value of these outputs (i.e. economic allocation).

2.3. Feeding strategies

We evaluated the impact of feeding strategies for a current Dutch dairy farm on sandy soil. This farm has 44.9 ha of land, housing facility for 76 dairy cows with young stock, and a milk quota of 603 tons per year. Milk production per cow was assumed to be constant at 7968 kg/year (4.39% fat and 3.52% protein). Data were based on the Farm Accountancy Data Network of the Agricultural Economics Research Institute from the Netherlands (FADN, 2012). The maximum fresh grass intake in summer was assumed to be 12 kg DM/cow per day, because limited grazing was applied. Safety margins for requirements of true protein digested in the small intestine and for rumen degradable protein balance were set at 100 g/cow per day. In addition, the option to feed dietary urea was included. The maximum amount of urea was limited by including a restriction on the amount of non-protein-nitrogen (NPN) equal to the amount of NPN in the diet supplemented with nitrate (see below). The reference situation (REF1), which includes no predefined feeding strategy, was determined by maximizing labor income for this current Dutch dairy farm. Subsequently, one of the three feeding strategies was introduced. Labor income of the farm was maximized again to determine diets and farm plan after implementing each strategy.

Feeding strategy LINS. Extruded linseed was added as a commercially available linseed product described by Dang Van et al. (2008), containing 56.0% crushed linseed, 21.0% wheat, 15.0% sunflower cake, 4.5% field beans, 2.0% butylated hydroxytoluene, 1.0% linseed oil, and 0.5% salt. Table 2 shows feed characteristics of this product. One kg product/cow per day was prescribed in the diet in summer and 2 kg/cow per day in winter (the product contains 0.9 kg DM/kg product). The effect of adding fatty acids in the form of extruded linseed on enteric CH_4 production was based on (Eq. 1) by Grainger and Beauchemin (2011):

$$y = - 0.102 x \qquad \text{Eq. 1}$$

where, y is the reduction in enteric CH_4 (g/kg DM intake); and x is the amount of dietary fat added (g/kg DM).

Feeding strategy NITR. A nitrate source ($5Ca(NO_3)2{\cdot}NH_4NO_3{\cdot}10H_2O$; 75 % NO_3 in DM) was added at 1% of dietary DM. Table 2 shows feed characteristics of this nitrate source. The effect of nitrate on enteric CH_4 production was based on Van Zijderveld (2011). Stoichiometrically, a reduction in CH_4 of 0.258 g/g nitrate is expected. In vivo, efficiency of CH_4 reduction decreases with increased levels of nitrate intake according to Eq. 2.

$$y = - 0.17 x + 1.13 \qquad \text{Eq. 2}$$

where, y is the actual reduction in enteric CH_4 expressed as a fraction of the reduction potential according to stoichiometry; and x is the amount of nitrate expressed in g/kg metabolic weight ($kg^{0.75}$) per day. The metabolic body weight of the cow is assumed to be 129 kg.

Feeding strategy GMS. Reducing the maturity stage of grass herbage and grass silage results in a lower DM yield/ha per year, but increases grass quality in terms of energy and protein content per kg DM. Total yield in MJ net energy for lactation (NE_L)/ha per year was assumed to remain unchanged. In the reference situation, grazing was applied at 1700 kg DM/ha, and harvesting at 3500 kg DM/ha. After implementing the strategy, grazing was applied at 1400 kg DM/ha, and harvesting at 3000 kg DM/ha. Table 2 shows feed characteristics of less mature grass and grass silage (based on CVB, 2011). Costs per grass cut were assumed to be the same as in the reference situation. Due to a lower DM yield per grass cut, the number of cuts per year increased.

Table 2. Feed characteristics of feeds available after implementing the feeding strategies, expressed per kg dry matter (DM).

Feed product	**NE_L [1] (MJ/kg DM)**	**DVE [2] (g/kg DM)**	**OEB [3] (g/kg DM)**	**N [4] (g/kg DM)**	**Fill value [5] (kg/kg DM)**	**NDF [6] (g/kg DM)**	**Crude fat (g/kg DM)**
LINS							
Extruded linseed product	10.51	96	87	36.9	0.29	209	236
NITR							
Nitrate	0.00	0	1170	187.3	0.00	0	0
GMS [5]							
Fresh grass early cut (1400 kg DM/ha)							
- 125 kg N	6.67	96	10	28.9	0.93	442	37
- 175 kg N	6.72	98	18	30.4	0.93	437	39
- 225 kg N	6.77	100	26	31.9	0.93	433	40
- 275 kg N	6.82	102	35	33.5	0.93	430	41
Grass silage early cut (3000 kg DM/ha)							
- 125 kg N	5.96	73	27	27.6	1.08	488	36
- 175 kg N	6.01	74	38	29.5	1.08	484	38
- 225 kg N	6.04	76	48	31.3	1.08	480	39
- 275 kg N	6.08	77	58	33.0	1.08	476	41

[1] Net energy for lactation. [2] True protein digested in the small intestine according to Dutch standards (Tamminga et al., 1994). [3] Rumen degradable protein balance according to Dutch standards (Tamminga et al., 1994). [4] Nitrogen. [5] Fill value per kg DM feed expressed in kg of a standard reference feed (Jarrige, 1988). [6] Neutral detergent fiber.

2.4. Breeding strategies

The LP model was adapted to future production circumstances to allow exploration of economic and environmental consequences of selective breeding. We evaluated the impact of breeding strategies for a representative Dutch dairy farm on sandy soil for the year 2020, and with a cow that has the same characteristics as an average Holstein Friesian cow in 2013 (Table 3). The future farm has 85 ha, which is the estimated size of an average Dutch dairy farm in 2020 (Rabobank, 2009). In 2015, the milk quota system will be abolished in the EU, and, therefore, no milk quota was assumed. The number of cows on the farm is an outcome of the LP model, and restricted by a constraint that prescribes that all manure produced on the farm needs to be applied on the farm. Grass and corn yield per hectare were increased based on historical data analysis (Berentsen et al., 1996; Rijk et al., 2013). For the environmental policies, no changes in limits to the application of N are expected, whereas limits to the application of P_2O_5 are reduced according to the new standards for 2020 (Vierde Nederlands Actieprogramma Nitraatrichtlijn, 2009). Furthermore, prices of milk components and purchased feed products were adapted based on price prediction for 2020 (KWIN-V, 2013). Based on the assumption that farmers become more efficient in the future, safety margins for true protein digested in the small intestine and for rumen degradable protein balance were set to zero. The reference situation for evaluating breeding strategies (REF2) was determined by maximizing labor income for this future Dutch dairy farm.

To determine the impact of one genetic standard deviation improvement in milk yield or longevity, each trait was increased with one genetic standard deviation, while keeping the other traits constant. The genetic standard deviation for milk yield of the Holstein Friesian breed in the Netherlands is 687 kg/cow per year (standard deviation applies to milk yield of a mature cow), and for longevity it is 270 days (CRV, 2012). Using the model of Groen (1988), the effect of this change on average production, feed requirements, herd composition and replacement rate was determined. Increasing milk yield increased feed requirements (Table 3). Increasing longevity changed herd composition (i.e. more cows in later lactations), and decreased replacement rate and number of young stock. Due to an increase in the number of cows in later lactations, milk yield of the average cow increased and fat content of the milk decreased, while feed requirement of dairy cows increased (Table 3). The new data on milk yield, feed requirements, and replacement rate were incorporated in the LP model, and labor income of the farm was maximized again to determine diets and farm plan after implementing each strategy.

Table 3. Production traits and feed requirements per cow, and yearly replacement rate (repl. rate) of the dairy herd for the reference scenario and after increasing milk yield and longevity with one genetic standard deviation.

	Production traits				**Feed requirements**			**Repl. rate**
	Milk yield kg/yr	Fat %	Protein %	Longevity # days	Energy GJ NE_L[1]/yr	Protein kg DVE[2]/yr	Intake capacity kg/yr	%
Reference	8758	4.32	3.51	2150	44,553	545	6009	27.0
Incr. milk yield	9445	4.32	3.51	2150	46,961	583	6137	27.0
Incr. longevity	8795	4.31	3.51	2420	44,712	547	6037	22.5

[1] NE_L: Net energy for lactation. [2] True protein digested in the small intestine according to Dutch standards (Tamminga et al., 1994).

3. Results

3.1. Feeding strategies

Table 4 shows the diets of the dairy cows and farm plan for the reference situation of the current farm (REF1) and the situations after implementing the feeding strategies. In REF1, the maximum amount of fresh grass is fed in summer, because this is the cheapest way of feeding. Corn silage is added up to 6.59 kg DM/cow per day in combination with standard protein concentrates and dietary urea. As a result, minimum requirements for energy and rumen degradable protein are met within the limiting intake capacity. In winter, 2.86 kg DM grass silage/cow per day is fed, which is the amount of grass left for ensiling after grazing, in combination with 10.98 kg DM corn silage/cow per day. High protein concentrates and urea were added to meet requirements for energy, rumen degradable protein, and true protein digested in the small intestine. 70% of the farm land was used as grassland and 30% as corn land. Labor income of the farm family was €42,605 per year. GHG emissions added up to 840 kg CO_2e/t FPCM. The most important contributor was enteric CH_4 (52%), followed by emissions from manure (14%), on-farm feed production (13%), purchased feed products (10%), and fertilizers (8%).

Feeding strategy LINS increased the fat content of the summer diet from 35 g/kg DM (REF1) to 44 g/kg DM. As a result, total DM intake reduced. The amount of corn silage decreased and standard concentrates and urea were removed from the diet. In winter, dietary fat content increased from 32 g/kg DM in REF1 to 56 g/kg DM (LINS). As a result, the amount of corn silage decreased by almost 3 kg DM/cow per day, and urea was removed from the diet. The amount of high protein concentrates remained to fulfill requirements for true protein digested in the small intestine. Labor income reduced to €26,564 per year. This reduction is caused almost completely by the relatively high costs of the extruded linseed product compared to the costs of corn silage and concentrates. In total, GHG emissions decreased by 9 kg CO_2e/t FPCM. Emissions of enteric CH_4 from dairy cows decreased by 42 kg CO_2e/t FPCM. Due to a decrease in the amount of purchased corn silage, concentrates, and urea, emissions related to the production of these products decreased by 29 kg CO_2e/t FPCM in total. Emissions from the production of the extruded linseed product added up to 63 kg CO_2e/t FPCM.

Feeding strategy NITR resulted in a dietary NPN level of 37 g/cow per day in summer, and 31 g/cow per day in winter, being the maximum amount of dietary NPN allowed. As a result, urea was removed from the diet. No other dietary changes occurred. Due to an increase in dietary N content, the amount of N in manure increased.

Table 4. Diets and farm plan for the current dairy farm (REF1) and after implementing one of the three feeding strategies.

		REF1	**LINS**	**NITR**	**GMS**
Diet dairy cows – summer period (kg DM/cow per day)					
Grass herbage		12.00	12.00	12.00	12.00
Corn silage		6.59	6.07	6.59	6.62
Concentrates	standard protein	0.88	-	0.88	0.78
	high protein	-	0.04	-	-
Urea		0.02	-	-	0.01
Extr. linseed product		-	0.90	-	-
Nitrate		-	-	0.20	-
Diet is restricted by [1]		E,I,R	E,T	E,I	E,I,R
Diet dairy cows – winter period (kg DM/cow per day)					
Grass silage		2.86	2.86	2.86	2.75
Corn silage		10.98	8.14	10.98	11.09
Concentrates	high protein	2.40	2.36	2.40	2.37
Urea		0.06	-	-	0.06
Extr. linseed product		-	1.80	-	-
Nitrate		-	-	0.16	-
Diet is restricted by [1]		E,R,T	E,T	E,T	E,R,T
Farm plan					
Dairy cows	n	76	76	76	76
Milk production	ton FPCM/farm/year	603	603	603	603
Young stock	unit [2]	25	25	25	25
Grassland 225 kg N/ha	ha	31.4	31.4	31.4	31.4
Corn land	ha	13.5	13.5	13.5	13.5
Synthetic fertilizer	kg N/ha	117	118	111	116
	kg P_2O_5/ha	8	7	7	10
Purchased corn silage	t DM	96	48	96	98
Purchased concentrates	t DM	55	43	55	53
Urea	t DM	1	-	-	1
Extr. linseed product	t DM	-	38	-	-
Nitrate	t DM	-	-	5	-
Labor income	€	42,605	26,564	37,142	42,142
GHG emissions	kg CO_2e/ton FPCM	840	831	808	829

[1] The diet can be restricted by: E = energy requirements; R = rumen degradable protein balance; T = true protein digested in the small intestine; I = intake capacity. [2] One unit includes 1 animal < 12 months and 0.96 animal > 12 months.

As a result, the amount of synthetic fertilizer decreased. No other changes in farm production plan occurred. Labor income reduced to €37,142 per year. This reduction is caused by the higher costs of dietary nitrate compared with urea. In total, GHG emission decreased by 32 kg CO_2e/t FPCM. Emission of enteric CH_4 from dairy cows decreased by 33 kg CO_2e/t FPCM. Producing nitrate instead of urea increased emissions by 3 kg CO_2e/t FPCM. Changes in other emissions were minor and relate to an increase in the N content of manure.

Feeding strategy GMS did not affect the amount of grass in kg DM/cow per day in the summer diet. Due to a higher energy content and a higher rumen degradable protein content per kg grass, however, the amount of concentrates and urea slightly decreased and that of corn silage slightly increased. Because total DM yield per ha grassland decreased, the amount of grass silage in the winter diet decreased. Corn silage slightly increased, while the amount of concentrates and urea remained unchanged. Due to a higher N and a lower P content in the diet, the amount of N in manure increased, while the amount of P decreased. This is reflected by a change in purchased fertilizers. Labor income reduced to €42,142 per year. This reduction is caused mainly by an increase in costs related to grassland management, resulting from an increase in the number of grass cuts per ha per year. In total, GHG emissions decreased by 11 kg CO_2e/t FPCM. GMS reduced emissions of enteric CH_4 from dairy cows by 10 kg CO_2e/t FPCM. Changes in other emissions were minor and relate to changes in the diet and an increase in the N content of manure.

3.2. Breeding strategies

Table 5 shows the diets of the dairy cows and farm plan for the reference situation of the future farm (REF2) and the situations after increasing milk yield and longevity. For the reference situation the following results apply. In summer the maximum amount of fresh grass is fed. Subsequently, corn silage in combination with a small amount of medium protein concentrates is added to meet requirements for energy and rumen degradable protein balance. In winter, the diet contains 2.7 kg DM grass silage per cow per day, based on the amount of grass remained after grazing. Again, corn silage in combination with medium protein concentrates is added. The reference situation has 168 dairy cows, 59.5 ha of grassland and 25.5 ha of corn land. The number of cows is based on the amount of manure that can be applied on the farm according to environmental legislation. In the reference situation, application standards on the amount of P_2O_5 were restricting. The area of grassland is exactly 70%, which is the minimum requirement for farms to comply with the derogation regulation that allows the application of 250 kg N/ha per year from animal manure, instead of 170 kg N/ha per year. Labor income is €115,050/year. GHG emissions added up to 796 kg CO_2e/t FPCM. The most important contributor was CH_4 from enteric fermentation (50%). Other important contributors were emissions from manure and from production of concentrates (both 13%).

Increasing milk yield by one genetic standard deviation resulted in an increase in the number of cows and an increase in the area of grassland at the expense of corn land. Changes in diets resulted from an increase in requirements for energy and protein, and from an increase in the area of grassland. Grassland increased because of the increase in the number of cows and P_2O_5 application standards being restricting (more P_2O_5 from animal manure can be applied on grassland than on corn land). In the reference situation, the costs of an increase in grassland at the expense of corn land were higher than the revenues of keeping more cows. After increasing milk yield, the revenues per cow increased, and outweighed the costs of an increase in the area of grassland at the expense of corn land. After increasing milk yield, the number of cows and grassland increased until application standards for N from animal manure became restricting. Total milk production at farm level increased to 1691 t FPCM/year, and labor income to €135,477. In total, GHG emissions decreased by 27 kg CO_2e/t FPCM. Increasing milk yield per cow reduced emissions per t FPCM by diluting emissions related to maintenance and young stock. In addition, emissions changed because of changes in diets and farm plan, e.g. emissions from the production of concentrates decreased, because the amount of concentrates in the diets decreased.

Increasing longevity by one genetic standard deviation reduced the replacement rate of the dairy herd (from 27.0% in REF2 to 22.5 % after increasing longevity). Similar to milk yield, this resulted in a situation where corn land was changed into grassland to increase to amount of P_2O_5 that can be applied on the field, and hence the number of dairy cows. Because of the reduced replacement rate, less young stock was kept, reducing manure production of the herd. As a result, the number of dairy cows increased to 182. Again, the application standard for N from animal manure limited a further increase of dairy cows. Total milk production at farm level increased to 1677 t FPCM/year, and labor income to €128,765. In total, GHG emissions decreased by 23 kg CO_2e/t FPCM.

Table 5. Diets and farm plan for the future dairy farm (REF2) and after implementing one of the two breeding strategies.

		REF2	**Milk yield**	**Longevity**
Diet dairy cows – summer period (kg DM/cow per day)				
Grass herbage		12.0	12.0	12.0
Corn silage		8.4	8.9	8.4
Concentrates medium protein		0.7	1.3	0.7
Diet is restricted by [1]		E,R	E,R	E,R
Diet dairy cows – winter period (kg DM/cow per day)				
Grass silage		2.7	5.0	4.2
Corn silage		8.0	8.9	8.4
Concentrates medium protein		6.5	4.6	5.0
Diet is restricted by [1]		E,R	E,R	E,R
Farm plan				
Dairy cows	n	168	171	182
Milk production	ton FPCM/farm/year	1543	1691	1677
Young stock	unit [2]	51	52	46
Grassland 225 kg N/ha	ha	59.5	67.9	67.4
Corn land	ha	25.5	17.1	17.6
Synthetic fertilizer	kg N/ha	107	113	112
	kg P_2O_5/ha	-	-	-
Purchased corn silage	t DM	207	396	381
Purchased concentrates	t DM	247	207	213
Manure application is restricted by [3]		P	aN, P	aN, P
Labor income	€	115,050	135,477	128,765
GHG emissions	kg CO_2e/ton FPCM	796	770	774

[1] The diet can be restricted by: E = energy requirements; R = rumen degradable protein balance; T = true protein digested in the small intestine; I = intake capacity. [2] One unit includes 1 animal < 12 months and 0.96 animal > 12 months. [3] The intensity of the farm is restricted by the possibility to apply manure. Manure application can be restricted by: tN = total mineral N; aN = N from animal manure; P = P_2O_5.

Due to a lower replacement rate, emissions related to young stock (mainly enteric CH_4) decreased by 12 kg CO_2e/t FPCM. Due to a change in the diets of dairy cows towards more roughage and less concentrates, emissions from production of grass and corn silage increased by 10 kg CO_2e/t FPCM (including on- and off farm production), whereas emissions from production of concentrates decreased by 20 kg CO_2e/t FPCM.

4. Discussion

Each feeding strategy reduced GHG emissions along the milk-production chain, but also reduced labor income. A negative impact on labor income reduces the likelihood of adoption by farmers, because profitability is often the main driver in decision making. While supplementing diets with nitrate resulted in the greatest reduction, a reduction in maturity of grass and grass silage resulted in the smallest reduction in labor income. Combining the impact on labor income with the impact on GHG emissions showed that this latter strategy is most cost-effective, and, therefore, offers most potential to be implemented on commercial farms.

Both breeding strategies reduced GHG emissions along the milk production chain while increasing labor income. The reduction in GHG emissions per ton FPCM were greater for milk yield than for longevity. The increase in labor income was also greater for milk yield. In this study, however, correlation between traits were not considered. Including correlations might change the balance between milk yield and longevity in favor of longevity, because production traits such as milk yield are negatively correlated with fertility and health traits, whereas longevity is positively correlated with these traits (Pritchard et al., 2013).

Breeding strategies affect GHG emissions in the long term. To evaluate the impact of an increase in milk yield and longevity, therefore, the model farm was adapted to future production circumstances without a milk quota. Differences in labor income between REF1 (current farm) and REF2 (future farm) are explained mainly by an increase in farm size, greater forage production per ha, and change in prices in case of REF2. Because only prices of important in- and outputs were changed, and because price predictions contain uncertainty, the impact of breeding strategies on labor income should be judged on their relative impact. Opposite to feeding strategies, breeding strategies resulted in an increase in income. Costs related to breeding strategies are covered by breeding organizations resulting in prices farmers have to pay for semen. There is no reason to assume that these prices will change depending on the strategy.

Emissions per ton FPCM in REF1 (current farm) are low compared with results in literature (De Vries and De Boer, 2010). This is mainly caused by the relatively high amounts of maize silage and low amounts of concentrates in the diets of dairy cows, partly because urea was used. In addition, unlike most other studies we used a model farm and calculated feed intake, which may differ from the actual intake and may increase the efficiency of the farm. Differences in emissions between REF1 and REF2 are explained by the higher productivity and efficiency in case of REF2, representing the technical and institutional setting of 2020 in combination with precision feeding (i.e. skipping safety margins for feeding protein). These results imply that future dairy farms can reduce their environmental impact in terms of GHG emission per ton FPCM when aiming for an increase in efficiency.

Results of the breeding strategies represent the impact of one unit change in milk yield and longevity. In practice, genetic selection is based on many traits simultaneously, and realized selection responses depend on the selection intensity for the trait of interest. Determining the impact of a multi-trait selection strategy requires knowledge of genetic parameters (i.e. heritability, genetic correlation) and the values of individual traits in the breeding goal. Results presented in this study, therefore, provide a first step towards a better understanding of the potential of breeding to reduce GHG emissions from dairy production. Due to differences between feeding and breeding strategies under study, results of the strategies cannot be compared directly.

This study focused on the environmental impact of strategies related to GHG emissions. Dairy production, however, has an impact on the environment in other ways, such as eutrophication, acidification, and depletion of fossil energy and phosphorus sources. Including other environmental impact categories might change results.

5. Conclusion

Each feeding strategy evaluated in this study reduced GHG emissions per ton FPCM, but also reduced labor income of the farm family. Supplementation of nitrate resulted in the largest reduction in GHG emissions, but reducing the maturity stage of grass and grass silage resulted in lower costs, and a better cost-effectiveness. One genetic standard deviation improvement of milk yield and longevity resulted in a reduction in GHG emissions, while increasing labor income. The reduction in GHG emissions as well as the increase in labor income were more pronounced for milk yield than for longevity. Identification of strategies to reduce GHG emissions is a first step towards reducing the impact of dairy production in practice. Results indicate that a combination of different strategies is required to substantially reduce GHG emissions from dairy production.

6. References

Bell MJ, Wall E, Russell G, Morgan C, Simm G (2010) Effect of breeding for milk yield, diet and management on enteric methane emissions from dairy cows. Anim. Prod. 50:817-826

Berentsen PBM, Giesen GWJ (1995) An environmental-economic model at farm level to analyse institutional and technical change in dairy farming. Agric. Syst. 49:153-175

Berentsen, P.B.M., G.W.J. Giesen, and J.A. Renkema. 1996. Scenarios of technical and institutional change in Dutch dairy farming. Neth. J. Agric. Sci. 44:193-208

Brask M, Lund P, Hellwing ALF, Poulsen M, Weisbjerg MR (2013) Enteric methane production, digestibility and rumen fermentation in dairy cows fed different forages with and without rapeseed fat supplementation. Anim. Feed Sci. Technol. 184:67-79

CRV, 2012. International Dutch cattle improvement co-operative. Handboek CRV Hoofdstuk E-20 p. 2. www.crv4all.nl/downloads/e-hoofdstukken/e20.pdf

CVB, 2011. CVB Veevoedertabel 2011. Chemische samenstelling en nutritionele waarden van voedermiddelen. Productschap Diervoeder, Den Haag, the Netherlands. (In Dutch).

Dang Van QC, Focant M, Deswysen D, Mignolet E, Turu C, Pottier J, Froidmont E, Larondelle Y (2008) Influence of an increase in diet structure on milk conjugated linoleic acid content of cows fed extruded linseed. Animal 2:1538-1547

De Mol RM, Hilhorst MA (2003) Emissions of methane, nitrous oxide and ammonia from production, storage and transport of manure. Report 2003-03. Institute of Agricultural and Environmental Engineering, Wageningen, the Netherlands. In Dutch, with summary in English.

De Vries M, De Boer IJM (2010) Comparing environmental impacts for livestock products: A review of life cycle assessments. Livest. Sci. 128:1-11

Dijkstra J, Neal HDSC, Beever DE, France J (1992) Simulation of nutrient digestion, absorption and outflow in the rumen: Model description. J. Nutr. 122:2239-2256

FADN, 2012. Farm Accountancy Data Network. Accessed 04/04/2012. www.lei.wur.nl/NL/statistieken/

Eco-invent, 2007. Ecoinvent Data v2.0 Final Reports Ecoinvent 2007. Swiss Centre for Life Cycle Inventories, Dubendorf, Switzerland.

Gerber, P.J., H. Steinfeld, B. Henderson, A. Mottet, C. Opio, J. Dijkman, A. Falcucci, and G. Tempio. 2013. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome.

Grainger C, Beauchemin KA (2011) Can enteric methane emissions from ruminants be lowered without lowering their production? Anim. Feed Sci. Technol. 166-167:308-320

Groen AF (1988) Derivation of economic values in cattle breeding: A model at farm level. Agric. Syst. 27:195-213

IPCC. 2006. Intergovernmental Panel on Climate Change. Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, forestry and other land use. Prepared by the National Greenhouse Gas Inventories Program, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

IPCC. 2007. Intergovernmental Panel on Climate Change. Climate change 2007: Synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change. (Core Writing Team, Pachauri, R.K., Reisinger, A. (eds.) IPCC, Geneva, Switzerland.

Jarrige R (1988) Alimentation des bovins, ovins et caprins. Institut National de la Reserch Agronomique, Paris, France. (In French).

KWIN-V, 2008. Quantitative Livestock Farming Information 2008. ASG, Wageningen UR, the Netherlands.

KWIN-V, 2013. Quantitative Livestock Farming Information 2013. ASG, Wageningen UR, the Netherlands.

Martin C, Rouel J, Jouany JP, Doreau M, Chilliard Y (2008) Methane output and diet digestibility in response to feeding dairy cows crude linseed, extruded linseed, or linseed oil. J. Anim. Sci. 86:2642-2650.

Pritchard T, Coffey M, Mrode R, Wall E (2013) Genetic parameters for production, health, fertility and longevity traits in dairy cows. Animal 7:34-46

Rabobank, 2009. Rapport Anders melken. De toekomst van de Nederlandse melkveehouderij. Report on prospects of the Dutch dairy sector for the year 2020. (in Dutch).

Rijk H, Van Ittersum MK, Withagen J (2013) Genetic progress in Dutch crop yields. Field Crops Res. 149:262-268

Tamminga S, Van Straalen WM, Subnel APJ, Meijer RGM, Steg A, Wever CJG, Blok MC (1994) The Dutch protein evaluation system: the DVE/OEB-system. Livest. Prod. Sci. 40:139-155

Van Middelaar CE, Berentsen PBM, Dijkstra J, De Boer IJM (2013) Evaluation of a feeding strategy to reduce greenhouse emissions from dairy farming: the level of analysis matters. Agric. Syst. 121:9-22

Van Middelaar CE, Dijkstra J, Berentsen PBM, De Boer IJM (2014a). Cost-effectiveness of feeding strategies to reduce greenhouse gas emissions from dairy farming. J. Dairy Sci. 97:2427-2439

Van Middelaar CE, Berentsen PBM, Dijkstra J, Van Arendonk JAM, De Boer IJM (2014b) Methods to determine the relative value of genetic traits in dairy cows to reduce greenhouse gas emissions along the chain. J. Dairy Sci. In press. doi.org/ 10.3168/jds.2013-7413

Van Zijderveld SM (2011) Dietary strategies to reduce methane emissions from ruminants. PhD Thesis, Wageningen University, Wageningen, the Netherlands. General discussion, pp. 101-102

Van Zijderveld SM, Gerrits WJJ, Dijkstra J, Newbold JR, Hulshof RBA, Perdok HB (2011) Persistency of methane mitigation by dietary nitrate supplementation in dairy cows. J. Dairy Sci. 94:4028-4038.

Vellinga TV, Blonk H, Marinussen M, Van Zeist WJ, De Boer IJM (2013) Methodology used in feedprint: a tool quantifying greenhouse gas emissions of feed production and utilization. Wageningen UR Livestock Research, the Netherlands. edepot.wur.nl/254098

Vierde Nederlands Actieprogramma Nitraatrichtlijn, 2009. www.rijksoverheid.nl

Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector

8-10 October 2014 - San Francisco

Rita Schenck and Douglas Huizenga, Editors
American Center for Life Cycle Assessment

The full proceedings document can be found here:
http://lcacenter.org/lcafood2014/proceedings/LCA_Food_2014_Proceedings.pdf

It should be cited as:

Schenck, R., Huizenga, D. (Eds.), 2014. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), 8-10 October 2014, San Francisco, USA. ACLCA, Vashon, WA, USA.

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ISBN: 978-0-9882145-7-6