INTERNATIONAL FARM MANAGEMENT CONGRESS 2003
FARMING AT THE EDGE

AN LP-MODEL TO ANALYSE ECONOMIC AND ECOLOGICAL SUSTAINABILITY IN DUTCH DAIRY FARMING

K.J. van Calker[a,b*], P.B.M. Berentsen[b], I.J.M de Boer[c], G.W.J. Giesen[b] and R.B.M. Huirne[b]

[a] *Research Institute for Animal Husbandry, P.O.Box 2176, 8203 AD Lelystad, The Netherlands*
[b] *Farm Management Group, Wageningen University, P.O. Box 8130, 6700 EW Wageningen, The Netherlands*
[c] *Animal Production Systems Group, Wageningen University, P.O. Box 338, 6700 AH Wageningen, The Netherlands*

KlaasJan.vanCalker@wur.nl

Abstract

Farm level modelling is a way to determine how farm management adjustments and environmental policy affect different sustainability attributes. Attributes can be measured by means of an indicator. The objectives of this paper are to include indicators for economic and ecological sustainability in a dairy farm LP (linear programming)-model and to use the model to analyse experimental dairy farm “De Marke”.

Net farm income is included for measuring economic sustainability. Eutrophication potential, nitrate concentration in groundwater, water use, acidification potential, global warming potential and ecotoxicity are included as ecological indicators. Three optimisations are done with the adapted model: (1) basis situation without environmental legislation, (2) basis situation with Dutch environmental legislation for 2004, and (3) situation with farm management adjustments applied at “De Marke”.
Results of the optimisations show that including environmental legislation leads to a lower net farm income and better performance on all ecological indicators. The farm management measures applied at “De Marke” result in even better performance on ecological sustainability. The model shows to be an effective tool to compare environmental impact of different sets of adaptations in farm management and their financial consequences.

Introduction

Sustainability in agriculture is an issue that has been popular since the report of the Brundtland Commission (1987). Even though many definitions can be found for sustainable agriculture, it remains difficult to link the concept to practical actions and decisions (Hansen and Jones, 1996). Development of sustainability indicators can be an effective tool to make agricultural sustainability operational (Rigby et al., 2001) and to implement sustainability in practical policy decisions (Rennings and Wiggering, 1997).
Modelling at farm level enables simultaneous consideration of production, price and policy information. Modelling at farm level, for that reason, is suitable to evaluate effects of management measures and environmental policy on sustainability indicators in dairy farming (Berentsen and Giesen, 1995).

The objectives of this paper are (1) to include economic and ecological indicators in an existing economic-environmental dairy farm model (Berentsen and Giesen, 1995), and (2) to use the model to analyse experimental farm “De Marke”.

2. Method

2.1. Economic and ecological indicators

Sustainability can be subdivided into four aspects: economic, internal social, external social en ecological sustainability (van Calker et al., 2002). Within these aspects of sustainability, one or more attributes were identified and ranked. Attributes can be measured by means of an indicator. In this paper the focus will be on economic and ecological indicators of sustainability. The selected indicators are included in the Linear Programming (LP) model.

Van Calker et al. (2002) selected profitability as the only attribute for measuring economic sustainability. Net farm income is the used indicator for profitability and shows the remuneration for own labour, own capital and management.

The ecological attributes and indicators that are used in this study are shown in Table 1. These indicators mainly originate from Life Cycle Assessment (LCA) studies (e.g. de Boer, 2003). LCA measures the potential environmental impact of a product or service from "cradle to grave". In the present study, however, the indicators are defined at farm level.

Table 1

The Eutrophication Potential (EP) per ha is used as indicator for eutrophication. In this study EP per ha is expressed in NO_3^- equivalents. Different NO_3^--equivalents factors were used: 1 for nitrate (NO_3^-), 1.35 for nitrogen oxides (NO_x), 3.64 for ammonia (NH_3), and 10.45 for phosphates (PO_4^-) (Weidema et al., 1996).

Nitrate concentration in groundwater is calculated by dividing the amount of NO_3^- leaching to the groundwater by the average precipitation surplus. Dehydration of the soil is included in the LP-model by calculating water use of cattle, water use during milking and water use of crops.
The acidification potential (AP) per ha is used to indicate the emission of acidification gases. Different SO_2-equivalents were used to compute AP per ha of milk production systems: 1 for sulphur dioxide (SO_2), 0.7 for NO_x, and 1.88 for NH_3 (Audsley et al., 1997).
For emission of greenhouse gases different CO_2-equivalent factors were used to compute the global warming potential (GWP) per ton FPCM: 1 for carbon dioxide (CO_2), 21 for methane (CH_4) and 310 for nitrous oxide (N_2O) (Audsley et al., 1997, assuming a 100-years time horizon).

In LCA studies a toxicity assessment focuses on the effect of exposure to pesticides and heavy metals on ecosystems. Data on aquatic and terrestrial ecotoxicity of pesticides and heavy metals used on the farms are taken from Audsley et al. (1997) and Huijbregts et al. (2000); 1,4 dichlorobenzene is used as reference substance.

2.2 Organisation of the analysis

Basis for the calculations is the general farm structure (milk quota, area of land, soil type) of experimental farm "De Marke". On experimental farm "De Marke" the potential for profitable dairy farming on sandy soils while meeting strict environmental standards is investigated. Environmental measures applied on "De Marke" are shown in Table 2 and concern: (1) livestock and crop rotation (2) fertilisation and feeding and (3) layout of the barn.

Table 2

In the analysis optimisations for three situations were done:
(1) situation without environmental legislation and without measures applied at “De Marke”(“Basis”)
(2) situation with environmental legislation and without measures applied at “De Marke” (“Policy 2004”)
(3) situation with environmental legislation and with particular measures applied at “De Marke” (“De Marke 2004”)

Dutch environmental legislation concerns the MINeral Accounting System (MINAS) and Manure Transfer Agreement System (MTAS). In 1998 MINAS was introduced to ensure compliance with the EC Nitrate Directive. If an individual farm exceeds the environmentally safe surplus standard, the farmer will be taxed for every kilogram of N or P2O5 exceeding this standard (Ondersteijn et al., 2002). Starting from 2002, MTAS was added as an additional regulation to avoid leaching of nutrients from animal manure. MTAS is based on standards for N production in manure and for N application from manure (Berentsen and Tiessink, 2003).

By choosing this set-up the effect of environmental policy on economic and ecological indicators can be evaluated. Furthermore the economic and ecological effect of the particular measures applied on “De Marke” can be studied. In Table 3 starting points of the three situations are described. Differences between “Basis”/“Policy 2004” and “De Marke 2004” are a result of the applied environmental measures on “De Marke”.

Table 3

3. Results

3.1 Technical results

Table 4 shows the composition of the rations and resulting land use for the three situations. Triticale is included in the summer ration of the “Basis” situation, despite of the fact that maize production is cheaper per unit of energy than triticale. As triticale is a winter crop two cuts of grass silage can be harvested the same year, so the actual yield is higher. For “Basis” the maximum of 2 kgdm by-products (dried beet pulp, extracted soy meal, undegradable extracted soy meal or extracted rapeseed) is included in the winter ration. By-products are a cheap replacement of concentrates. Rations and numbers of animals determine the area of grassland and the N-level as well as the area of triticale. The remaining land is used for growing maize silage of which 6.9 hectare silage is sold.

Table 4

In the situation with environmental legislation (“Policy 2004”) the acceptable surplus for N restricts N input. Nitrogen input is restricted by decreasing the use of N fertiliser on grassland. The resulting shortage of feed is replaced by growing maize for on farm use instead of selling maize. The lower protein content in the summer ration, as a result of the lower N_{min} use on grassland, is compensated by including more concentrates.

One of the farm management measures applied at "De Marke 2004" is to grow concentrates instead of purchasing concentrates. Ground maize ear silage, therefore, is included in the winter and summer ration. In the summer ration the minimum amount of 6 kgdm additional feeding is included in the ration. Triticale is included as additional feeding instead of maize as a result of the two cuts of grass that can be ensiled after harvesting triticale. These two cuts of grass are relatively cheap and are used in the winter ration. Due to the shorter grazing season for dairy cows and young stock (120 vs. 183 days) and shorter grazing time per day (5 vs. 10 hours) for dairy cows the area of grassland of "De Marke 2004" is considerably lower than in the previous situations.

3.2 Economic results

The economic results follow from the technical results. The gross revenues of the farm consist of revenues from milk, sold animals, sold maize and subsidy on maize and triticale. In the "Basis" situation more maize is sold, consequently gross revenues are higher in this situation in comparison with "Policy 2004". In the "Basis" situation revenues and costs result in a net farm income of 35,777 (Table 5).

Costs that differ between the "Policy 2004" and "Basis" situation are mainly costs of feed, fertilisers and contract work. Costs of feed are higher as soy-products are included in the winter ration and because more concentrates are included in the summer ration. Costs of contract work are lower as a consequence of the lower N level on grassland. This finally results in 2,486 lower net farm income for "Policy 2004" compared to the "Basis" situation.

Gross revenues for "De Marke 2004" are lower because no maize is sold. The feed costs are considerably lower, because concentrates are included in the farm plan (ground maize ear silage). As a result of the changed crop rotation fertiliser costs on "De Marke 2004" are lower. Higher costs are mainly the result of: (1) more maize in the farm plan and changed crop rotation (more contract work costs), and (2) low emission housing (higher costs of buildings). Farm management adjustments applied at "De Marke 2004" lead to a decrease of net farm income of 14,651.

3.3 Ecological results

Table 5 shows the results for ecological indicators. In the "Basis" situation the level of EP per ha is affected mainly by NO_3^- loss (57%), P_2O_5 surplus (21%), and NH_3 emission (18%). Including environmental policy in the LP-model leads to a 17 % lower EP per ha. The decrease in the "Policy 2004" situation mainly is a result of lower NO_3^- loss. Adding farm management measures in the optimisation results in an extra reduction of 41%. This reduction mainly is a result of the lower P_2O_5 surplus.

Table 5

Nitrate concentration of "Policy 2004" is 34 % lower in comparison with NO_3^- concentration of "Basis". The NO_3^- concentration, however, is still higher than the concentration stated in the EC Nitrate Directive (50 mg/l). This is a result of the dry sandy soils where the farm is located. Even after applying additional farm management adjustments for "De Marke 2004" NO_3^- concentrations are higher than the EC Nitrate Directive.

Water use per ha on dairy farms is for more than 90 % a result of the chosen crops. The most effective way to prevent dehydration of the soil is to include drought resistance crops in the farm plan. Water use per ha is lower in "Policy 2004" compared to "Basis" as a consequence of the decreased dry matter yield of grassland. Despite the larger area of maize, the water use per ha for "De Marke 2004" is higher in comparison with "Policy 2004". The higher water use per ha is caused by the water use of the catch crop on maize land.

Acidification Potential per ha is mainly a result of the emission of NH_3 (±85-90 %). Ammonia emissions are lower in the "Policy 2004" situation as a result of the lower protein content in summer ration. Acidification Potential per ha for "De Marke 2004" is 7 % lower compared to "Policy 2004" due to feeding cows according to the standard and due to the lower replacement rate.
Global Warming Potential per ton FCPM is for 63-68 % due to emission of CH_4. Methane emission per cow is dependent on the level of production and digestibility of feed. In the model CH_4 emission, however, depends only on the level of production. Differences in GWP per ton FCPM between "Policy 2004" and "Basis", therefore, mainly are a result of the lower N_2O emission for "Policy 2004". As a consequence of higher milk production and lower replacement rate, CH_4 emissions are lower for "De Marke 2004".

The surplus of heavy metals causes only 4-5 % of the AETP per ha. For TETP per ha 11-13 % is a result of the surplus of heavy metals. The larger share of heavy metals in TETP per ha is a result of the accumulation of heavy metals in the soil. Differences for AETP per ha and TETP per ha between "Policy 2004" and "Basis" are small because the crop plan is almost the same. AETP per ha and TETP per ha is ca. 33 % lower for "De Marke" compared to "Policy 2004". This is due mainly to the lower pesticide use on "De Marke" which is a result of the crop rotation of grassland with maize and triticale. Furthermore less concentrates and by-products are imported on "De Marke". Differences between AETP and TETP are a result of the higher risk of pesticides to pollute the surface water.

4 Discussion and conclusion

In this study the defined indicators were calculated at farm level. Environmental losses during production of farm inputs were not taken into account because the focus in this research is on direct effects of farm management on environmental impact. Besides, environmental impact of producing inputs generally are not quantified so dairy farmers do not have insight in environmental impact of different alternatives. This means that in our study to some extent environmental problems could be shifted to other members of the dairy production chain.

Insight in the effect of farm management on a wide range of ecological indicators of dairy farms is an important addition to the model and to the literature as it allows for the comparison of environmental impact of different sets of adaptations in farm management and their financial consequences. In this way the model offers the opportunity to compare different farming systems on their level of economic and ecological sustainability. Furthermore the model can be helpful in evaluation of effectiveness of environmental policy with respect to different economic and ecological attributes.

Differences between model results for the 3 situations in this study are quite straightforward and can be explained from the assumptions used in the model. Including environmental policy in the LP-model resulted in lower fertiliser use and consequently in a decrease in sales of maize. This led to a decrease in net farm income of ca. 2,500. The Dutch environmental policy was included to comply with the EC Nitrate Directive. This policy improved most used ecological indicators (except AETP per ha and

TETP per ha) and showed to be an effective tool to reduce the environmental impact of dairy farming. Due to the extreme dry sandy soils the EC Nitrate Directive of 50 mg NO_3^- was not met. Adapting the model with farm management measures applied at experimental farm "De Marke" resulted in even better ecological performance compared to the situation with environmental policy alone ("Policy 2004"). Nonetheless this increase in ecological performance led to a considerably lower net farm income.

Author Details
Klaas Jan van Calker is a Researcher at the Research Institute for Animal Husbandry and is doing his Ph.D. research on sustainability of different dairy farming systems in cooperation with the Farm Management Group.
Paul Berentsen is a Lecturer and Researcher at the Farm Management Group, Wageningen University
Imke de Boer is a Lecturer and Researcher at the Animal Production Systems Group, Wageningen University
Gerard Giesen is a Lecturer and Researcher at the Farm Management Group, Wageningen University
Ruud Huirne is Professor in Farm Management and head of the Farm Management Group, Wageningen University

Literature

Audsley, E.., Alber, S., Clift, R., Cowell, S., Crettaz, P., Gaillard, G., Hausheer, J., Jolliet, O., Kleijn, R., Mortensen, B., Pearce, D., Roger, e., Teulon, H., Weidema, B., Van Zeijts, H., 1997. Harmonisation of Environmental Life Cycle Assessment for Agriculture. Final Report, Concerted Action AIR3-CT94-2028, European Commission DG VI, Brussels.
Berentsen, P.B.M., Giesen G.W.J., 1995. An environmental-economic model at farm-level to analyse institutional and technical change in dairy farming. Agricultural Systems 49, 153-175.
Berentsen, P.B.M., Tiessink, M., 2002. Potential effects of accumulating environmental policies on Dutch dairy farms. Journal of Dairy Science 86, 1019-1028.
Berentsen, P.B.M., Giesen G.W.J., 1995. An environmental-economic model at farm-level to analyse institutional and technical change in dairy farming. Agricultural Systems 49, 153-175.
Brundtland, G.H., 1987. Our common future. WCED (World Commission on Environment and Development), Oxford: University Press, Oxford.
de Boer, I.J.M., 2003. Environmental impact assessment of conventional and organic milk production. Livestock Production Science, "in press".
de Haan, M.H.A., 2001. Economics of environmental measures on experimental farm 'De Marke'. Netherlands Journal of Agricultural Science 49, 179-194.
Hansen, J.W., Jones, J.W., 1996. System framework for farm sustainability. Agricultural Systems 51, 185-201.
Huijbregts, M.A.J., Thissen, U., Jager T., van de Meent, D., Ragas, A.M.J., 2000. Priority assessment of toxic substances in life cycle assessment. Part II: assessing parameter uncertainty and human variability in the calculation of toxicity potentials. Chemosphere 41, 575-588.
Ondersteijn, C.J.M., Beldman, A.C.G., Daatselaar, C.H.G., Giesen, G.W.J., Huirne, R.B.M., 2002. The Dutch mineral accounting system and the European Nitrate Directive: implications for N and P management and farm performance. Agriculture, Ecosystems & Environment 92, 283-296.
Rennings, K., Wiggering, H., 1997. Step towards indicators of sustainable development: linking economic and ecological concepts. Ecological Economics 20, 25-36.
Rigby, D., Woodhouse, P., Young, T., Burton, M., 2001. Constructing a farm level indicator of sustainable agricultural practice. Ecological Economics 39, 463-478.

van Calker, K.J., Berentsen, P.B.M., Giesen, G.W.J., Huirne, R.B.M., 2002. Identifying and ranking attributes that determine sustainability in Dutch dairy farming. Submitted to Agriculture and Human Values.
Weidema, B.P., Morteson, B., Nielsen, P., Hauschild, M., 1996. Elements of an impact assessment of wheat production. Institute for Product development, Technical university of Denmark, Denmark.

Table 1 Attributes and indicators for ecological sustainability with respect to Dutch dairy farming

Attributes	Indicator
Eutrophication	Eutrophication Potential per ha
Groundwater pollution	NO_3^- conc. in groundwater (mg NO_3^-/l)
Dehydration of the soil	**Water use (m^3/ha)**
Acidification	Acidification Potential per ha
Global warming	Global Warming Potential per ha
Ecotoxicity	Aquatic and Terrestrial Ecotoxicity Potential per ha

Table 2 Environmental measures applied at "De Marke".

	Adjustment
Livestock and crop rotation	Less young stock
	Growing and feeding ground maize ear silage
	Growing and feeding triticale
	Crop rotation of grassland with maize and triticale
Fertilisation and feeding	Reduced phosphate fertiliser level
	Reduce nitrogen application
	More efficient grazing system
	Catch crop under maize
	Feeding of milking cows according to the standard
	Feeding more maize or triticale in the summer period
	Shortening grazing period of milking cows
Layout of the barn	Low-emission housing

Table 3 Starting points for the calculations

Farm structure	Unit	Basis/ Policy 2004	De Marke 2004
Area	**(ha)**	**55**	**55**

Milk quota	**(* 10^3 kg)**	**658,480**	**658,480**
Milk production	(kg per cow)	8760	9080
Fat	(%)	4.36	4.28
Protein	(%)	3.44	3.48
Replacement rate	(%)	38.0	33.0
Grazing cows	hours/year	2196	600
Grazing young stock	hours/year	5832	2880
Min. additional feeding during summer	kgdm/cow/day	4	6

Table 4 Land use and summer and winter-feed ration for dairy cows for three situations

	Basis	Policy 2004	De Marke 2004
Summer ration (kg dm/day per cow):			
- Grass	13.7	13.0	14.2
- Maize	1.2	2.1	0.0
- Ground maize ear silage	0.0	0.0	1.3
- Triticale	2.8	1.9	6.0
- Concentrates	3.3	4.1	1.8
Winter ration (kg dm/day per cow):			
- Grass silage	5.8	2.8	2.7
- Maize	4.0	6.9	10.0
- Ground maize ear silage	0.0	0.0	2.3
- Triticale	0.0	0.0	0.2
- Byproducts	2.0	2.0	2.0
- Concentrates	9.0	9.0	2.2
Land use:			
- Grassland (ha)	32.7	33.9	22.1
- N level grassland (kg mineral N)	360	199	250
- Maize (ha)	11.5	15.3	20.2
- Maize sold(ha)	6.9	3.1	0.0
- Ground maize ear silage (ha)	0.0	0.0	6.7
- Triticale (ha)	3.9	2.7	5.9
By-products purchased (1000 MJ NEL)	24.8	24.6	36.2
Concentrates purchased (1000 MJ NEL)	144.8	153.4	51.4

Table 5 Economic and ecological indicators of three different situations

Indicator	Unit	Basis	Policy 2004	De Marke
Net farm income	year	35,777	33,291	18,640
Eutrophication potential per ha	(NO_3^- equivalents/ha)	858	711	421
Nitrate concentration in groundwater	(NO_3^- mg/l)	119	79	68
Water use per ha	(m^3/ha)	3614	3318	3488
Acidification potential per ha	(SO_2 equivalents/ha)	92	79	74
Global warming potential per ha	(CO_2 equivalents/100 kg milk)	787	742	684
Aquatic ecotoxicity potential per ha	(1,4 dicholorobenzene equivalents/ha)	3907	3915	2624
Terrestrial ecotoxicity potential per ha	(1,4 dicholorobenzene equivalents/ha)	151	153	103