Dutch dairy farms after milk quota abolition: Economic and environmental consequences of a new manure policy

C. W. Klootwijk,^{*1} C. E. Van Middelaar,^{*} P. B. M. Berentsen,[†] and I. J. M. de Boer^{*}

^{*}Animal Production Systems Group, Wageningen University, PO Box 338, 6700 AH Wageningen, the Netherlands

[†]Business Economics Group, Wageningen University, PO Box 8130, 6700 EW Wageningen, the Netherlands

ABSTRACT

The abolition of the Dutch milk quota system has been accompanied by the introduction of a new manure policy to limit phosphate production (i.e., excretion via manure) on expanding dairy farms. The objective of this study was to evaluate the effect of these recent policy changes on the farm structure, management, labor income, nitrogen and phosphate surpluses, and greenhouse gas emissions of an average Dutch dairy farm. The new manure policy requires that any increase in phosphate production be partly processed and partly applied to additional farmland. In addition, phosphate quotas have been introduced. Herein, we used a whole-farm optimization model to simulate an average farm before and after quota abolition and introduction of the new manure policy. The objective function of the model maximized labor income. We combined the model with a farm nutrient balance and life-cycle assessment to determine environmental impact. Based on current prices, increasing the number of cows after quota abolition was profitable until manure processing or additional land was required to comply with the new manure policy. Manure processing involved treatment so that phosphate was removed from the national manure market. Farm intensity in terms of milk per hectare increased by about 4%, from 13,578 kg before quota abolition to 14,130 kg after quota abolition. Labor income increased by €505/yr. When costs of manure processing decreased from €13 to €8/t of manure or land costs decreased from €1,187 to €573/ha, farm intensity could increase up to 20% until the phosphate quota became limiting. Farms that had already increased their barn capacity to prepare for expansion after milk quota abolition could benefit from purchasing extra phosphate quota to use their full barn capacity. If milk prices increased from €355 to €420/t, farms could grow unlimited, provided that the availability of external inputs such as labor, land, barn capacity, feed, and phosphate quota at current prices were also unlimited. The milk quota aboli-

tion, accompanied by a new manure policy, will slightly increase nutrient losses per hectare, due to an increase in farm intensity. Greenhouse gas emissions per unit of milk will hardly change, so at a given milk production per cow, total greenhouse gas emissions will increase linearly with an increase in the number of cows.

Key words: Dairy Act, farm expansion, phosphate quota, manure processing

INTRODUCTION

In 1984, milk quotas were introduced in Europe to address oversupply in the market. The quota policy restricted the amount of milk to be produced by each member state and, consequently, by individual farmers. In April 2015, the European Union (EU) milk quota system was abolished in response to the increasing global demand for milk and to agreements on trade liberalization in global dairy markets (EU, 2015). The abolition of the quota system allows farmers to increase their milk production and is expected, therefore, to increase milk production in most EU countries (Lips and Rieder, 2005).

Livestock density in the Netherlands is the highest in Europe. This is due to the central location of the Netherlands in western Europe, where the demand for livestock products is high, combined with easy import of feed due to close proximity to the harbor of Rotterdam. This high livestock density, however, also results in high production (i.e., excretion via manure) of nitrogen and phosphate per hectare, which causes environmental problems such as eutrophication of ground and surface water (Oenema et al., 2005). Moreover, the livestock sector, including dairy production, is one of the main contributors to greenhouse gas (GHG) emissions (Gerber et al., 2013). The expected increase in milk production per farm due to quota abolition might increase the environmental impact of dairy production.

To limit nitrate leaching from agricultural production to ground and surface water, the European Nitrates Directive was introduced (EU, 1991), imposing a maximum application of 170 kg of N from animal manure per hectare. Within this directive, 7 member states, including the Netherlands, obtained a derogation to go

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¹Corresponding author: Cindy.Klootwijk@wur.nl

beyond the 170-kg limit, under certain country-specific conditions. One such condition for the Netherlands is a phosphate production ceiling of 172.9 million kg/yr for the entire Dutch livestock sector, including a phosphate production ceiling of 84.9 million kg/yr for the dairy sector. To accommodate this phosphate ceiling, the Dutch government introduced a new manure policy. This “Dairy Act” of 2015 is aimed at supporting the growth of the Dutch dairy sector while limiting increases in phosphate production.

Abolition of the milk quota and introduction of the Dairy Act might change the Dutch dairy sector. Changes in farm structure and management can affect a farmer’s income and the environmental impact of dairy production. Several studies have analyzed the effect of quota abolition on the economic and environmental performance of the dairy sector, most using macroeconomic models and analyzed effects at region or country level (Lips and Rieder, 2005; Kempen et al., 2011). Kempen et al. (2011), for example, predicted a loss in overall agricultural income, and an increase in environmental effects (e.g., nitrate leaching and methane emission) related to an expanding dairy herd in large parts of Europe, especially the Netherlands. To our knowledge, however, the effect of the quota abolition in combination with the introduction of the Dairy Act is unknown. Moreover, we found no studies that took a farm-level perspective and considered changes in farm management in response to changes in policy.

The objective of this study, therefore, was to evaluate the effect of quota abolition and introduction of the Dairy Act on the structure, management, and labor income of a Dutch dairy farm. In addition to these effects, we also considered changes in environmental impact (i.e., nitrogen and phosphorus losses, and GHG emissions). To determine the economic and environmental impact, we combined a whole-farm linear programming model with a farm nutrient balance and life-cycle assessment. We have illustrated strategies for an average Dutch dairy farm on sandy soil. To understand the current political context, we first describe milestones in Dutch environmental policy.

MATERIALS AND METHODS

Milestones in Dutch Environmental Policies Before Quota Abolition

Since about 1980, policies have been aimed at regulating the environmental impact of Dutch agricultural production, including dairy production (Oenema and Berentsen, 2005). A first milestone in environmental policy was the introduction of phosphate application standards in 1987. These standards were based on fixed

phosphate excretions per type of animal and set limits on the application of phosphate from animal manure per hectare of grassland or crop land (Berentsen and Tiessink, 2003). Farmers exceeding these standards had to pay a levy. Introduction of phosphate application standards, however, barely reduced nutrient losses from agriculture, because application standards and levies were so generous that dairy farms were essentially unaffected (Berentsen et al., 1992).

A second milestone occurred with the introduction of the European Nitrates Directive (EU, 1991), aimed at reducing the negative effects of nitrogen surpluses on water quality. This directive shifted the focus from phosphate to nitrogen. To ensure compliance with the nitrates directive, the Netherlands introduced the mineral accounting system (MINAS) in 1998; MINAS was based on a farm-gate balance approach, using farm-level inputs and outputs to determine a farm-specific surplus of nitrogen and phosphate (Oenema and Berentsen, 2005). Nutrient surpluses at the farm level that exceeded levy-free surpluses were charged. The MINAS system was considered a step forward in environmental policy, because nutrient surpluses are better indicators of nutrient leaching than manure application standards, and because MINAS gave farmers the autonomy to determine how to reduce their surplus.

A judgment of the European court (EU, 2003) about MINAS’s lack of compliance with the nitrates directive, in combination with other practical reasons such as increasing administrative burdens and possibilities of fraud, led to the abolition of MINAS in 2006 and the introduction of 3 fertilizer application standards—the third milestone. The first standard comprises a maximum application of 170 kg of N from animal manure per hectare of land. Several member states, including the Netherlands, obtained a derogation to go beyond the 170-kg limit, under certain country-specific conditions. Derogation is specific for these member states because they have a high proportion of grassland and a relatively long growing season, justifying a higher nutrient uptake (EU, 2010). Current derogation regulation in the Netherlands prescribes that farms with at least 80% grassland are allowed to apply, depending on soil type and region, 250 kg of N from animal manure per hectare on all of their land. Farmers who receive this derogation are not allowed to use synthetic phosphate fertilizer. To receive derogation for 2014–2017, the Netherlands must comply with a phosphate production ceiling of 172.9 million kg/yr and a nitrogen production ceiling of 504.4 million kg/yr for the entire Dutch livestock sector. The second standard comprises a maximum application of nitrogen fertilizer per hectare of land, including mineral nitrogen from manure, and accounts for nitrogen fixation, deposition, and miner-

alization. The third standard comprises a maximum application of phosphate fertilizer per hectare of land, including phosphate from manure. Although the first and second standards overlap to a degree, all 3 apply to every Dutch dairy farm. The application standards for nitrogen and phosphate fertilization have been decreased several times over the past decade. Farmers exceeding these standards can be brought to court.

Additional Policy After Quota Abolition

To comply with the phosphate production ceiling set by the EU as a condition for derogation, the Dutch government prescribed the dairy sector a phosphate production ceiling of 84.9 million kg/yr based on production levels in 2002. In 2014, however, this limit was exceeded by 0.7 million kg of phosphate (CBS, 2015). To limit further growth as a result of the quota abolition, a new manure policy, referred to as the “Dairy Act,” was adopted in December 2014 as a framework law. The Dairy Act prescribes routes for handling the phosphate surplus at the farm level and limits an increase in phosphate production at the sector level. The concrete content of this law consists of 3 parts that have been developed over time based on progressive insight. Figure 1 shows the implications of these 3 parts for a farm, of which the area remains constant but the number of animals increases.

The starting situation is given by the reference phosphate surplus of a farm in 2013, defined as the production minus the application room (surplus A in Figure 1). Phosphate production is defined here as the

number of livestock × fixed phosphate excretions per type of livestock (Appendix Table A1), and phosphate application room as the number of hectares × the phosphate application standards. Previous legislation stipulated that part of the reference surplus should be processed based on region-specific rules (i.e., 30% in the south, 15% in the east, and 5% in other regions of the Netherlands; Nitraatrichtlijn, 2014); the remaining part can be disposed to other Dutch farms with application room.

The first part of the Dairy Act, developed in 2014 and introduced in 2015, indicated that any increase in phosphate surplus on top of the reference surplus needed to be fully processed. Manure processing involves treating the manure so that phosphate is removed from the national manure market, which can be done by destruction (incineration or gasification to ash), treatment, or export. When the second part of the Dairy Act was developed in 2015, a maximum was set to the volume of the extra phosphate surplus that may be fully processed (surplus B in Figure 1). This maximum was determined by the phosphate production of a farm in 2014.

The second part of the Dairy Act will be introduced in 2016. In an attempt to tie dairy production more closely to the use of land on the same farm, any phosphate surplus on top of surpluses A and B (surplus C in Figure 1) should be partly processed and partly applied to additional land that should be purchased or hired by the farm. Requirements related to the percentage of this surplus C for which extra land should be acquired depend on the level of the total phosphate surplus in

Figure 1. New Dutch manure policy after quota abolition (the “Dairy Act”). The total surplus of 2015 is based on farm-specific excretion factors, whereas calculation of surpluses A, B and the phosphate quota are based on standard excretion factors per type of animal.

the year of analysis (0% if the surplus is $<20 \text{ kg ha}^{-1}$, 25% if the surplus is $20 \text{ to } 50 \text{ kg ha}^{-1}$, and 50% if the surplus is $>50 \text{ kg ha}^{-1}$; Rijksoverheid, 2015).

Because signals indicated that phosphate production in the dairy sector would grow considerably in spite of the new manure policy, the Dutch government announced a third part of the Dairy Act in July 2015. This part consists of a phosphate quota at the farm level to restrict total Dutch phosphate production to comply with the national production ceiling of 172.9 million kg/yr set by the EU. Each farm is assigned a farm-specific phosphate production quota based on the average number of cows on the farm in July 2015 and standard excretion factors (RVO, 2014). The date that this new quota system was announced and the counting date with regard to the number of animals on the farm were aligned to avoid farmers anticipating this new legislation. Quotas can be transferred between dairy farms.

Whereas calculation of surpluses A, B, and the phosphate quota are based on standard excretion factors per type of animal, the actual phosphate surplus in the year of analysis can be based on farm-specific excretion factors.

This overview of milestones in Dutch environmental policies shows that dairy farmers continuously have to anticipate uncertainties and changes in regulations. This study aims to evaluate the effect of the most recent policy changes, including the abolition of the milk quota and introduction of the Dairy Act, on the structure, management, and labor income of a Dutch dairy farm. Changes in environmental impact, including losses of nitrogen and phosphate and emission of GHG emissions are considered as well.

Dairy Farm Model

We used a dairy farm optimization model to simulate a Dutch dairy farm before and after quota abolition and the inclusion of the Dairy Act. The model was originally developed by Berentsen and Giesen (1995), but was recently updated by Van Middelaar et al. (2014). We also updated the prices and included the stipulations of the Dairy Act in the model. The objective function of the model maximized labor income, (i.e., gross returns minus variable and fixed costs). Important activities were on-farm feed production, purchase of feed, animal production, manure application, purchase and application of synthetic fertilizers, and field operations.

We assumed that the average cow in the model belonged to the Holstein Friesian breed and calved on February 1. Female young stock were kept for yearly replacement of the dairy herd, whereas male calves and surplus female calves were sold at an age of 2 wk. The

model distinguished between summer and winter for feeding. Based on feed restrictions, the model matched the feed requirements of the cow with on-farm feed production and purchased feed. Feed requirements concerned energy, RDP balance, true protein digested in the small intestine, and phosphorus. In addition, DMI capacity was limited, based on Jarrige (1988). On-farm feed production included production of maize silage and production of grass for grazing and silage making. One hectare of silage maize yields 15.5 t of DM/yr, which equals 102 GJ of NE_L (CBS, 2013). Grassland yield depends on the level of nitrogen fertilization, which can vary from $100 \text{ to } 500 \text{ kg/ha}$ per year. Based on 225 kg of N/ha per year, 1 ha of grassland yields 66 GJ of NE_L /yr. Purchased feeds included maize silage (to be ensiled by the farmer; KWIN-V, 2014) and 3 types of concentrates that differed in protein levels (i.e., standard, medium, and high). We updated the costs of farm inputs according to long-term expected market prices (KWIN-V, 2014). All dietary options were available in winter and summer, except for fresh grass (only available in summer). Table 1 shows the feed characteristics and prices of the available feed products. We determined farm-specific excretion based on inputs and outputs at herd level, represented by the average cow with young stock.

Constraints of the model included links between activities (e.g., between feeding requirements and produced and purchased feed, and between manure production/application and environmental policies). Environmental policies, for example, include limits to the application of nitrogen and phosphate on the farm as explained before. According to the application standards for 2015–2017 (Nitratrichtlijn, 2014), the maximum annual amount for mineral nitrogen on sandy soil is 250 kg/ha for grassland and 140 kg/ha for maize land, and the maximum annual amount for nitrogen from animal manure is 230 kg/ha with derogation and 170 kg/ha without derogation. For phosphate, the maximum annual amount is 90 kg/ha for grasslands and 60 kg/ha for maize land. The environmental impact calculations formed an integral part of the model and are explained in the next section.

Environmental Impact

A common method of quantifying losses of nutrients is the nutrient balance approach (Oenema et al., 2003). A nutrient balance computes the difference in nutrients entering and leaving a system, and can be used to quantify environmental indicators such as the nutrient surplus expressed per hectare of land or per unit of valuable output. This study used a farm-level nutrient balance to quantify nitrogen and phosphate surpluses

Table 1. Feed characteristics and prices of available feed products

Feedstuff	NE _L (MJ/kg of DM)	DVE ¹ (g/kg of DM)	OEB ² (g/kg of DM)	Fill value ³ (kg/kg of DM)	Nitrogen (g/kg of DM)	Phosphorus (g/kg of DM)	Market price ⁴ (€/t of DM)
Concentrate							
Standard protein	7.21	100	6	0.29–0.72	24.1	4.5	215
Medium protein	7.21	133	28	0.29–0.72	32.2	5.0	250
High protein	7.21	200	83	0.29–0.72	48.3	8.0	315
Grazed grass							
125 kg of N	6.62	94	9	0.90	28.0	4.1	—
175 kg of N	6.68	96	16	0.90	29.4	4.1	—
225 kg of N	6.73	98	23	0.90	30.9	4.1	—
275 kg of N	6.77	99	31	0.90	32.4	4.1	—
Grass silage							
125 kg of N	5.89	70	22	1.10	25.6	4.1	—
175 kg of N	5.93	71	31	1.10	27.4	4.1	—
225 kg of N	5.97	73	39	1.10	29.0	4.1	—
275 kg of N	6.00	74	47	1.10	30.6	4.1	—
Maize silage	6.56	58	–36	0.91	10.9	1.9	60

¹True protein digested in the small intestine according to Dutch standards (Tamminga et al., 1994).

²Rumen-degradable protein balance according to Dutch standards (Tamminga et al., 1994).

³Fill value per kilogram of DM feed expressed in kilogram of a standard reference feed (Jarrige, 1988). The fill value of concentrates increases with an increase in concentrate intake.

⁴Applies only to purchased feed products (KWIN-V, 2014).

per hectare of on-farm agricultural area, as an indicator for the local environmental pressure related to nitrogen and phosphate losses. Inputs of nitrogen and phosphorus are in the form of concentrates, maize silage, fertilizer, and atmospheric deposition, whereas outputs are in the form of milk, culled animals, and, potentially, manure. A positive nitrogen balance implies that nitrogen is potentially lost to the environment through volatilization of ammonia or nitrous oxide, or through runoff and leaching of dissolved nitrate, for example. A positive phosphate balance implies that phosphate can accumulate in the soil and is potentially lost to the environment through leaching and runoff, contributing to eutrophication of ground and surface waters (Sharpley, 1995).

In contrast to site-specific effects such as eutrophication, climate change is a global problem. To analyze the effect on climate change, therefore, changes in GHG emissions should be evaluated at the chain level, taking into account not only on-farm processes, but also other stages along the production chain (Van Middelaar et al., 2013). We used life-cycle assessment to evaluate emissions of the 3 major GHG related to agricultural production: carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), from cradle to farm gate. Processes included were the extraction of raw materials to produce farm inputs, the manufacturing and distribution of these inputs, and all processes on the dairy farm.

Emission calculations have been described in detail by Van Middelaar et al. (2014). Emissions from the production and combustion of energy sources, and from production of synthetic fertilizer, pesticides, and tap water were based on Weidema et al. (2013). Emissions

from the production of concentrates were updated (Appendix Table A2). We calculated enteric methane from dairy cows based on empirical relations between DMI of feed ingredients and methane emission factors per ingredient (FeedPrint, 2015). For young stock, we based enteric methane emission on Intergovernmental Panel on Climate Change (IPCC) tier 2 methods and default values (IPCC, 2006). Methods to calculate emissions from manure management, and from fertilizer application to the field, were derived from national reports (e.g., De Mol and Hilhorst, 2003).

Greenhouse gases were summed up based on their equivalence factor in terms of CO₂: 1 for CO₂, 28 for biogenic CH₄, 30 for fossil CH₄, and 265 for N₂O (IPCC, 2013). Emission of GHG were expressed per tonne of fat- and protein-corrected milk (FPCM). To express emissions per tonne of FPCM, we used economic allocation to allocate emissions between milk and meat.

Setup of the Analysis

The starting point for model was an average dairy farm in 2014 (i.e., before quota abolition), applying day grazing. Input data, including milk quota, farmland, barn capacity, labor availability, and dairy cow production traits, were based on national statistics (CBS, 2015; LEI, 2015) and are included in Table 2. Milk price was based on expectations for 2014–2024 according to KWIN-V (2014) and is included in Table 2. Maximum grass intake during grazing was assumed 10 kg of DM/cow per day (Taweel et al., 2004; Abrahamse et al., 2009; Kennedy et al., 2009). We used the linear

Table 2. Model input data to simulate an average Dutch dairy farm before quota abolition (situation 2014) and after quota abolition and introduction of the Dairy Act (situation 2016)

Item	Unit	Situation 2014	Situation 2016
Milk quota ¹	t yr ⁻¹	679	No
Farmland ¹	ha	50	50
Barn capacity ¹	No. of cows	83	83
Labor availability ¹	h	4,000	4,000
Milk production ²	kg cow ⁻¹ yr ⁻¹	8,160	8,160
Fat content ¹	%	4.40	4.40
Protein content ¹	%	3.50	3.50
Milk price ³	€ t ⁻¹	355	355
Replacement rate ¹	%	26.4	26.4
Dairy Act ¹		No	Yes
Reference surplus 2013	kg of phosphate yr ⁻¹	—	800
Reference surplus 2014	kg of phosphate yr ⁻¹	—	1,142
Phosphate quota	kg of phosphate yr ⁻¹	—	4,841
Manure disposal ³	€ t ⁻¹ yr ⁻¹	9	9
Manure processing ³	€ t ⁻¹ yr ⁻¹	13	13
Extra labor ³	€ h ⁻¹	17	17
Extra barn capacity ³	€ cow ⁻¹ yr ⁻¹	—	558
Extra farmland ³	€ ha ⁻¹ yr ⁻¹	—	1,187
Extra phosphate quota ³	€ kg of phosphate ⁻¹ yr ⁻¹	—	2.10

¹CBS (2015).²LEI (2015).³KWIN-V (2014).

programming model for economic optimization of this farm before quota abolition (i.e., situation 2014).

Then, we removed the milk quota from the model and included the Dairy Act. We used economic optimization again to determine the new optimal farm plan (i.e., situation 2016) and evaluate changes in farm structure, management, labor income, nitrogen and phosphate surpluses, and GHG emissions resulting from the policy changes. Input data to optimize the situation after quota abolition (situation 2016) are included in Table 2. The reference phosphate surplus in 2013 and the phosphate surplus in 2014 were based on the average number of cows on a Dutch dairy farm in the corresponding years according to national statistics (CBS, 2015). The phosphate quota was based on the average number of cows on a Dutch dairy farm in 2014, as the average number of cows in 2015 was not available yet (CBS, 2015). We allowed 70% of the reference phosphate surplus in 2013 to be disposed to another farm without processing. The price of liquid manure (slurry) disposal without processing was assumed to be €9/t, and the additional price of processing was assumed to be €4/t (KWIN-V, 2014). Purchase of farmland, barn capacity, and phosphate quota was optional (Table 2). Costs of additional land that can be either used for grass or maize were assumed to be €1,187/ha per yr, based on the current average Dutch land price of €46,000/ha (KWIN-V, 2014), an interest rate of 4.5% (KWIN-V, 2014), and an inflation rate of 1.92% over the past 5 yr (CBS, 2015). The price of additional labor was assumed to be €17/h, and the price of additional barn capacity was assumed to be €558/cow place, including

young stock. Costs of phosphate quota were assumed to be €2.10/kg of phosphate, based on current prices for quota in the pig sector (i.e., €70/pig, producing 7.4 kg of phosphate), a depreciation period of 5 yr, and an interest rate of 4.5% (KWIN-V, 2014).

Sensitivity Analyses

Assumptions on production parameters and market factors can influence results. We performed a sensitivity analysis to explore 5 alternative situations for 2016, based on existing ranges of 2 production parameters and 3 market factors. Situation 2016A simulated a farm with a larger barn capacity before quota abolition. We set barn capacity at 120 dairy cows before optimization, based on an increase in barn capacity on Dutch dairy farms toward quota abolition in practice (PBL, 2013). Situation 2016B simulated a highly productive dairy farm; milk yield per cow and grass and maize yield per hectare were increased by 10% compared with situation 2016. National statistics show a range in average milk production on Dutch dairy farms in 2014 from about 6,697 kg cow⁻¹ yr⁻¹ (25% lowest) to 9,616 kg cow⁻¹ yr⁻¹ (25% highest) (CRV, 2014). Situation 2016C simulated the effect of lower prices for manure disposal and processing. The price for manure disposal was set at €5/t, and the additional price for manure processing at €3/t, based on price ranges according to KWIN-V (2014). Situation 2016D simulated the effect of a lower land price. The price of additional land was set at €573/ha per year, based on long-term rental contracts (KWIN-V, 2014). Situation 2016E simulated the effect

of a higher milk price. The price per tonne of milk was set at €420, based on the maximum milk price during the last 10 yr (KWIN-V, 2014).

RESULTS AND DISCUSSION

Farm Structure, Management, and Labor Income Before Quota Abolition

Farm structure and management of the farm before quota abolition (situation 2014) are shown in Table 3. Farm size was restricted by milk quota. Based on an average milk production of 8,160 kg/cow per yr and a replacement rate of 26.4%, 83 dairy cows and 49 young stock were kept (Table 3). Farmland was divided in 80% grassland and 20% maize land, which allowed an application of 230 kg of N/ha per year from animal manure. In summer, the diet of the dairy cows consisted of 10.0 kg (DM) of fresh grass, 1.1 kg (DM) of grass silage, 3.1 kg (DM) of maize silage, and 5.7 kg (DM) of concentrates/cow per day. The maximum amount of fresh grass was fed because this was the cheapest feed resource. The amount of grass silage was based on the amount of grass left for ensiling, minus the amount of grass silage fed in winter. Maize silage and concentrates were added to meet the requirements for energy and RDP balance, because these 2 feed restrictions appeared to be binding. In winter, the diet consisted of 7.3 kg (DM) of grass silage, 3.3 kg (DM) of maize silage, and 6.2 kg (DM) of concentrates/cow per day. Requirements for energy, RDP balance, and true protein digested in the small intestine were met. Purchased feed consisted of 193 t of DM concentrates, and external labor requirement was 42 h/yr. There was no manure surplus, which meant that all the manure was applied on the farmland. The total phosphate excretion of 3,990 kg was lower than the quota of 4,841 kg. This was explained by the fact that the phosphate quota was based on standard excretion factors, whereas phosphate excretion in the model was based on farm-specific excretion. In addition, the phosphate quota was based on 89 dairy cows (CBS, 2015), whereas only 83 cows were needed to fulfill the milk quota. The difference in the number of cows between an average farm in practice and our model farm is explained by the fact that in 2014, many farmers produced above their milk quota in anticipation of the quota abolition.

Labor income on the farm before quota abolition was €10,343/yr (Table 4). Revenues could be attributed primarily to milk sales, and costs to feed purchases and fixed costs for buildings and machinery. The net farm income for this type of farm would generally be €20,000/yr higher than the labor income because of owner equity.

Farm Structure, Management, and Labor Income After Quota Abolition

Farm structure and management of the farm after quota abolition and introduction of the Dairy Act (situation 2016) are shown in Table 3. Farm size was no longer restricted by milk quota but by phosphate application room. On the farm, 87 dairy cows and 51 young stock were kept, and total milk production was 707 t of milk/yr. Due to the limitations of the Dairy Act, increasing the number of cows was only possible when manure was processed or extra land was obtained. However, the revenues of an extra cow did not outweigh the extra costs of manure processing and extra land, in combination with the costs of extra barn capacity, hired labor, and feed. Farm intensity increased from 13,578 kg of milk/ha before quota abolition to 14,130 kg of milk/ha after quota abolition. The winter diet was the same as before quota abolition, but the summer diet contained less grass and maize silage per cow per day, as well as more concentrates. With an increase in the number of cows per hectare, less grass silage per cow per day was available in summer. This resulted in a lower RDP balance, compensated for by an increase in concentrates per cow per day. The external labor requirement increased to 127 h/yr. With a total phosphate excretion of 4,200 kg/yr, phosphate quota was still not restricting. The labor income of this farm was €10,848 (Table 4), only slightly higher than before quota abolition.

Sensitivity Analyses

Table 5 shows the results of the sensitivity analyses. Situation 2016A represented a farm that increased its barn capacity before quota abolition to 120 dairy cows plus young stock. Results showed that the available barn capacity was fully used (Table 5). Increasing the number of cows beyond the available barn capacity was not economically attractive under current prices. Six additional hectares of farmland were obtained to increase the phosphate application room compared with situation 2016. The percentage of grassland remained 80%, which allowed for derogation. The number of cows per hectare was restricted by both the nitrogen and phosphate application room, resulting in an intensity of 17,440 kg of milk/ha. To meet the feeding requirements of the dairy herd, 94 t (DM) of maize silage and 316 t (DM) of concentrates were purchased. Total phosphate excretion was 5,884 kg/yr. As a result, 1,043 kg of extra phosphate quota was purchased. The possibility of disposing 70% of the phosphate surplus from 2013 was maximally used. In addition, 608 kg of phosphate was processed. Due to higher fixed costs related to increased barn capacity, labor income was only €2,005/yr.

Table 3. Farm structure and management of an average Dutch dairy farm before quota abolition (situation 2014) and after quota abolition and introduction of the Dairy Act (situation 2016)

Item	Unit	Situation 2014	Situation 2016
Farm structure			
Dairy cows	No.	83	87
Young stock	No.	49	51
Total milk production	t yr ⁻¹	679	707
Total farmland	ha	50	50
Grassland	%	80	80
N _{min} application on grassland ¹	kg of N ha ⁻¹ yr ⁻¹	225	225
Maize land	%	20	20
Farm intensity	kg of milk ha ⁻¹	13,578	14,130
Diet dairy cows: summer	kg of DM/cow per day		
Grass		10.0	10.0
Grass silage		1.1	0.3
Maize silage		3.1	2.7
Concentrates		5.7	6.7
Diet restricted by ²		E, R, G	E, R, G
Diet dairy cows: winter	kg of DM/cow per day		
Grass silage		7.3	7.3
Maize silage		3.3	3.3
Concentrates		6.2	6.2
Diet restricted by ²		E, R, T	E, R, T
External inputs			
Purchased maize silage	t of DM yr ⁻¹	0	0
Purchased concentrates	t of DM yr ⁻¹	193	218
Hired labor	h	42	127
Manure management			
Manure application restricted by		—	Phosphate
Total excretion	kg of phosphate yr ⁻¹	3,990	4,200
Extra phosphate quota	kg of phosphate yr ⁻¹	—	0

¹N_{min} = N mineral.²E = energy requirements, R = rumen-degradable protein balance, G = maximum fresh grass intake, T = true protein digested in the small intestine.

Situation 2016B represented a highly productive farm. Results showed a farm size of 107 dairy cows, and no additional land was obtained. Based on the Dairy Act, a further increase in the number of cows would require additional land. Similar to situation 2016A, the number of dairy cows per hectare was restricted by the total nitrogen and phosphate application room. Due to higher productivity, however, farm intensity was 19,191 kg of milk/ha. Labor income was €32,093/yr. Results

showed that farm productivity could considerably increase labor income.

In situation 2016C, the costs of manure processing were decreased to €8/t of manure. Results showed a farm size of 100 dairy cows, and no additional land was obtained. The number of dairy cows was restricted by the phosphate quota. Again, the number of cows was higher than the number of cows used to calculate the phosphate quota, due to lower farm-specific excretion

Table 4. Labor income (€/yr) for an average Dutch dairy farm before quota abolition (situation 2014) and after quota abolition and introduction of the Dairy Act (situation 2016)

Item	Situation 2014	Situation 2016
Revenues		
Milk	241,037	250,843
Livestock sales/purchases	27,430	28,546
Government payments	13,500	13,500
Variable costs		
Concentrate purchases	47,877	54,210
Roughage purchases	0	0
On-farm roughage production	52,983	52,182
Manure disposal and processing	0	0
Hired labor	714	2,145
Other	36,378	37,858
Fixed costs	133,672	135,646
Labor income	10,343	10,848

Table 5. Farm structure and management for an average Dutch dairy farm with grazing in sensitivity analyses A to E for situation 2016

Item	Unit	Situation 2016 A: Increased barn capacity	Situation 2016 B: Higher field and cow productivity	Situation 2016 C: Lower manure disposal and processing prices	Situation 2016 D: Lower land price	Situation 2016 E: Higher milk price
Farm structure						
Dairy cows	No.	120	107	100	100	180
Young stock	No.	71	63	59	59	106
Total milk production	t yr ⁻¹	979	961	817	814	1,469
Total farmland	ha	56	50	50	58	84
Grassland	%	80	80	80	80	80
Maize land	%	20	20	20	20	20
Farm intensity	kg of milk ha ⁻¹	17,440	19,191	16,331	14,130	17,440
External inputs						
Purchased maize silage	t of DM yr ⁻¹	94	80	48	0	141
Purchased concentrates	t of DM yr ⁻¹	316	290	263	251	474
Hired labor	h yr ⁻¹	1,064	694	480	556	2,937
Nitrogen application on grassland	kg of N ha ⁻¹ yr ⁻¹	250	250	250	225	250
Manure management						
Manure application restricted by ¹		tN, P	tN, P	tN	P	tN, P
Total phosphate excretion	kg of phosphate yr ⁻¹	5,884	5,376	4,841	4,841	8,826
Applied on own land	kg of phosphate yr ⁻¹	4,717	4,208	3,857	4,841	7,075
Manure disposal	kg of phosphate yr ⁻¹	560	560	560	0	560
Manure processing	kg of phosphate yr ⁻¹	608	608	424	0	1,191
Purchased phosphate quota	kg of phosphate yr ⁻¹	1,043	534	0	0	3,985
Labor income	€ yr ⁻¹	2,005	32,093	11,162	14,240	80,489

¹tN = total mineral nitrogen, P = phosphate.

values compared with standard values. Labor income was €11,162/yr.

In situation 2016D, land costs were decreased to €573/ha. Results showed a farm size of 100 dairy cows. Similar to situation 2016C, the number of dairy cows was restricted by the phosphate quota. In this situation, however, 8 additional hectares of land were obtained to apply all manure on farmland. The number of cows per hectare was restricted by the phosphate application room.

In situation 2016E, the milk price was increased to €420/t. Results showed a farm size of 180 dairy cows and 84 ha of land. The number of cows was restricted by machinery capacity, which could be solved quite easily in practice. Reaching this artificial maximum implied that the farm could experience unlimited growth when external inputs such as labor, land, barn capacity, and feed were available without limits at current prices. The number of cows per hectare was restricted by the nitrogen and phosphate application room, resulting in a farm intensity of 17,440 kg of milk/ha. The external labor requirement was 2,937 h/yr. Total phosphate excretion was 8,826 kg/yr, which means that 3,985 kg of phosphate was purchased. Labor income was €80,489/yr.

Environmental Impact

Figure 2 shows the nitrogen and phosphate surpluses per hectare of the farm before (situation 2014) and after (situation 2016–2016E) quota abolition. The nitrogen surpluses per hectare after quota abolition (192 to 213 kg/ha) were higher than before quota abolition (186 kg/ha). The level of nitrogen surplus was highly related to farm intensity, except for situation 2016B. Situation 2016B had the highest intensity but a relatively low nitrogen surplus, related to higher farm productivity, meaning more efficient use of inputs.

The phosphate surpluses after quota abolition varied from 3 to 11 kg/ha, whereas the phosphate surplus before quota abolition was 7 kg/ha. The lower phosphate surpluses after quota abolition in situation 2016B were explained by higher farm productivity and, in situation 2016C, by the relatively large amount of phosphate disposal and processing.

Figure 3 shows the results for GHG emissions per tonne of FPCM for the farm before (situation 2014) and after (situation 2016–2016E) quota abolition. The GHG emissions per tonne of FPCM after quota abolition (range from 938 to 1,001 kg of CO₂eq/t of FPCM) were in the same range as before quota abolition (985 kg of CO₂eq/t of FPCM). Per tonne of FPCM produced, the increase in off-farm emissions from concentrate production was offset by the decrease in on-farm

emissions related to enteric fermentation and roughage production. Situation 2016B resulted in the lowest GHG emissions. This can be explained by an increase in farm productivity, resulting in, for example, dilution of GHG emissions related to maintenance.

Taking into account the increase in total milk production, total GHG emissions (i.e., from cradle to farm gate) at the farm level increased from 707,385 kg of CO₂eq/yr before quota abolition to 738,706 kg of CO₂eq/yr after quota abolition. This increase of 4.4% implied an almost linear increase of GHG emission with the number of cows.

General Discussion

Milk production in the Netherlands has increased in recent years because farmers have anticipated the end of the milk quota system, but it is unlikely that the volume of milk production in the Netherlands will undergo further substantial increases under the new manure policy. Due to additional costs related to manure processing, additional farmland, and the phosphate quota, the costs of production will probably increase rather than decrease. In addition, the possibility of obtaining additional land varies across the Netherlands, limiting the expansion of dairy farms in areas where farmland is scarce. Most importantly, the phosphate quota will restrict the growth of the national dairy herd. It is unlikely that the Netherlands will become more competitive or supply more milk to the world milk market.

Our review of developments in manure legislation shows continuous changes and uncertainties in the transitions from old to new regulations. This creates risks for dairy farmers in anticipating developments in the dairy sector. In addition to policy risks, dairy farm-

Figure 2. Nitrogen (N) and phosphate (P₂O₅) farm surpluses per hectare for an average Dutch dairy farm before quota abolition (2014) and after quota abolition (2016). Results A to E are variants of 2016 scenario: A = increased barn capacity, B = higher field and cow productivity, C = low manure disposal and processing prices, D = low land price, and E = higher milk price.

Figure 3. Greenhouse gas emissions [kg of CO₂ equivalents (CO₂-eq) per tonne of fat- and protein-corrected milk (FPCM)] for an average Dutch dairy farm before quota abolition (2014) and after quota abolition (2016). Results A to E are variants of scenario: A = increased barn capacity, B = higher field and cow productivity, C = low manure disposal and processing prices, D = low land price, and E = higher milk price.

ers face market risks. The alternative situation, with a high milk price, showed a large effect of milk price on income. In addition, the volatility of the milk price in the EU is increasing due to decreasing governmental intervention (Holmer, 2015).

Increasing phosphate efficiency at the farm level offers the potential to increase milk production within the limits of the phosphate quota. Balancing phosphorus levels in the diet with the phosphorus requirements of the cow, for example, offers the potential to decrease phosphate excretion. Based on the current analysis, cows were found to be fed 37% above phosphorus requirements in winter and 42% in summer, indicating potential for improvement.

So far, the costs for extra phosphate quota are unclear. Based on current prices for quota in the pig sector, we assumed yearly costs of €2.10/kg of phosphate. This followed from a total investment of €413/dairy cow, a depreciation period of 5 yr, and an interest rate of 4.5% (KWIN-V, 2014). Further analysis of the results showed that for the situations with the increased barn capacity and with the high milk price, phosphate quota would be purchased until yearly costs reach a level of about €11/kg of phosphate, which equaled an investment in phosphate quota of around €2,000/dairy cow.

In agreement with Daatselaar et al. (2015), nitrogen surplus per hectare increased with an increase in farm intensity. Nutrient surpluses in this study were at the lower range of nutrient surpluses found on an average Dutch dairy farm in practice (LEI, 2015). Differences can be explained by the use of an optimization model, which may increase farm efficiency, and by the fact that most recent data on nutrient surpluses of actual

farms (LEI, 2015) are from 2011. Our results showed higher GHG emissions per tonne of FPCM than Van Middelaar et al. (2014), which can be explained by the update of emission factors for concentrate production (FeedPrint, 2015) and an update of the global warming potentials of CH₄ and N₂O (IPCC, 2013).

CONCLUSIONS

Several factors have limited the growth of Dutch dairy farms after quota abolition. Based on current prices, increasing the number of cows is profitable up to the level that requires manure processing or additional land to comply with the new manure policy. This results in an increase in the number of cows and in farm intensity of about 4% compared to before quota abolition. When costs of manure processing or of land decrease, phosphate quota becomes a limiting factor. Within the phosphate quota, however, farm intensity can increase about 20% by increasing the efficiency of phosphate use. If milk prices increased to the high level of 2013–2014, farms could grow unlimited, provided that the availability of external inputs such as labor, land, barn capacity, feed, and phosphate quota at current prices were also unlimited. Results showed that the milk quota abolition, accompanied by the Dairy Act, will slightly increase nutrient losses per hectare, due to an increase in farm intensity. Greenhouse gas emissions per unit of milk will barely change, so at a given milk production per cow, total GHG emissions will increase linearly with an increase in the number of cows.

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APPENDIX

Table A1. Dutch phosphate excretion values for 2015 to 2017 (RVO, 2014)

Item	Milk yield (kg of milk yr ⁻¹)	Phosphate excretion (kg of phosphate animal ⁻¹ yr ⁻¹)
Dairy cow	8,125–8,374	41.3
	8,375–8,624	42.0
	8,625–8,874	42.7
Young stock <1		9.6
Young stock >1		21.9

Table A2. Composition of concentrates with 3 protein levels (standard, medium, and high) and corresponding greenhouse gas (GHG) emissions for production of ingredients

Ingredient	Concentrate composition (%)			GHG ¹ (total CO ₂ equivalents in kg t ⁻¹)
	Standard ²	Medium ²	High ³	
Peas	0.00	1.20	0.00	752
Barley	0.35	0.15	0.95	388
Soybean meal CF 45–70 CP <450 ⁴	0.14	2.95	0.00	615
Soybean meal CF 45–70 CP >450 ⁴	0.09	0.48	0.00	636
Soybean meal Mervobest	0.00	0.15	28.45	632
Soybean hulls CF 320–360 ⁴	14.52	19.47	0.00	391
Sugarcane molasses SUG <475 ⁴	3.01	3.17	2.10	302
Rape seed, expeller	0.17	0.99	0.03	528
Rye	5.15	1.10	1.84	449
Wheat	2.05	2.17	0.15	390
Palm kernel expeller CF <180 ⁴	11.80	15.95	19.33	547
Sugarbeet pulp SUG >200 ⁴	3.80	4.70	6.33	366
Maize	15.87	6.57	1.48	595
Wheat middlings	11.32	2.07	2.62	249
Soy oil (palm kernel oil)	0.01	0.00	0.00	3,902
Maize gluten feed CP 200–230 ⁴	8.60	1.65	17.32	1,815
Sunflower seed meal CF >240 ⁴	0.67	1.00	0.22	487
Salt	0.46	0.56	0.00	180
Chalk (finely milled)	0.99	1.28	0.00	19
Triticale	5.45	6.03	1.32	587
Palm kernel oil	0.20	0.40	0.00	3,902
Rape seed, extruded CP >380 ⁴	0.18	0.47	0.00	481
Rape seed, extruded CP 0–380 ⁴	1.78	5.38	0.00	477
Rape seed meal	0.00	0.15	0.00	484
Premix	1.00	1.00	1.00	4,999
Vinasses sugarbeet CP <250 ⁴	2.99	3.00	0.00	394
Magnesium oxide	0.04	0.01	0.00	1,060
Distillers grains and solubles	9.36	17.93	7.47	296
Citruspulp dehydrated	0.00	0.00	7.64	747
Fat animal origin	0.00	0.00	0.04	7,726
Ureum	0.00	0.00	1.70	1,650

¹Greenhouse gas emissions for production of ingredients were updated based on FeedPrint (2015).

²Concentrate composition of standard and medium protein level were updated based on Nevedi (2012, 2013, 2014, 2015).

³Concentrate composition of high protein level was based on Van Middelaar et al. (2014).

⁴CF = crude fiber, SUG = sugar (in g/kg).