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Analysis of the economic impact of different strategies after the introduction of the new manure policy

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Abstract

Dutch farmers are looking for more environmental-friendly and economic strategies to deal with the phosphate excretion on their dairy farms after the introduction of new manure policy. The objective of this paper is to evaluate the economic performances of four potential strategies to improve phosphorous use efficiency at the dairy farm after new manure policy. Strategies here are (1) reducing the phosphate content of the concentrates, (2) increasing the ration of maize silage in the daily diet, (3) outsourcing all young stocks, (4) increasing the barn capacity of the farm. The average Dutch dairy farm with the new manure policy was defined as reference situation, and the labor income in the reference situation was calculated. Based on the reference situation, each strategy was implemented in an optimization model to maximize the labor income. The final result under the optimization model was used to compare the economic performance between the reference situation and the situations with four strategies. Then the nutrient balance assessment was used to determine the phosphorus use efficiency on farm level. The reference phosphorous use efficiency of average Dutch dairy farm was 68.4%. All the first three strategies improved phosphorous use efficiency, which were 73.1%, 69.1% and 71.0% respectively. The last strategy was not ideal, as the phosphorous use efficiency was 58.4%. From the economic perspective, strategy 1, strategy2 and strategy 4 performed better compared to the reference situation, but strategy 3 resulted in lower labor income compared to the reference situation. The balance between environmental impact and the economic result of strategies to improve phosphorous use efficiency needs to be investigated in more studies.

Key words: phosphorus use efficiency; new manure policy; Dutch dairy farm; economic effect

1. Introduction

With the growth of population and the improvement of living standards, the global demand for food is also increasing. Meeting this increased demand is a challenge for agricultural production (Schröder, et al., 2011; Edgerton., 2009). The high demand for food and the limited land capacity on Earth stimulate maximizing yields of feed and food crops, among others by increasing the application of inputs like nitrogen (N) and phosphorus (P) (Marcha, et al., 2016). Meanwhile, the efficient use of nutrients is an important issue in agricultural sustainability (Johnston, et al., 2008). There are mainly two reasons. First, inefficient use of N and P can result in potentially harmful losses to the environment, and N and P losses also can imply an economic loss. Environmental consequences, such as eutrophication of ground and surface water and acidification, will reduce when nutrient use efficiency increases (Oenema et al., 2005). Second, mineral P is derived from P rock, which is a limited and non-replaceable resource. This makes an efficient use of P even more important (Dawson, et al., 2011).

Dairy products form an important part of the diet, due to the biologically active compounds which are difficult to obtain from in low dairy or dairy-free diets (Park, et al., 2013; Rozenberg, et al., 2016). Like other agricultural systems, the dairy production system requires the input of P as an important nutrient for the crop, grass, and animal production. As said, inefficient use of P can contribute to environmental pollution. There are many potential processes on the dairy farm that contribute to P losses to the environment， such as the use of fertilizer during the cultivation of on-farm feed, the excretion of P by animals, and P loss during manure storage. Improving P use efficiency related to the dairy farming activities can reduce P losses and contribute to better environmental and economic performance of a dairy farm (Arriaga, et al., 2009).

Livestock density in the Netherlands is the highest in Europe (European Commission, 2017). The study of Gerber, et al. (2009) shows that in regions with a high livestock density, the P surplus per ha is high. It says there are already around 270,000 ha in the sandy areas of Netherlands which are phosphorus-saturated due to the high livestock density. To limit the amount of nitrate leaching, the Dutch agricultural sector faces a regulation that limits the amount of manure that can be applied per ha of land (EU, 1991). Within this directive, seven countries are allowed to use more than 190 kg of N per ha of land, including the Netherlands, an exception known as derogation. To comply with this derogation rule, the Dutch dairy sector should not exceed the P production ceiling based on the level in 2002, which was set at 84.9 million kg/year. Due to these reasons, Dutch government paid more attention on P loss at dairy farms, and promulgated the new manure policy (so-called "Dairy act") after the abolition of the milk quota system in 2015, to limit further growth on P production on the national level (Klootwijk, et al., 2016; Flach, 2017).

The study of Klootwijk et al. (2016) described the concepts of new manure policy and its developments overtime. The new manure policy was established in 2015 which consists of an P quota at farm level. From July 2015 onwards, there is a P quota at the farm level to control the P excretion of the Netherland. Each farm has its own exact P excretion which is determined by the number of animals and the excretion factor per specific animal (Klootwijk, et al., 2016) (Table 1). The farmer needs to pay penalty if the P excretion is exceeding the P quota. It is useful to restrict the increase of animals in the dairy farm after the abolition of milk quota system (Klootwijk, et al., 2016).

Table 1: Dutch phosphate excretion values for 2015 to 2017 (RVO, 2014)

Item	Milk yield (kg of milk animal^{-1} yr^{-1})	P excretion (kg of P 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

The implementation of the new manure policy scheme is as follows. First, the farmer needs to check if the owned farm exceeds the P quota. The farmer should pay for additional value if the execution was indeed exceeded. In the dairy farm, there is a limited amount of application room of P at the farm, which depends on the number of hectares of the farmland and the P application standards. Within the application room, the farm can fertilize its own cropland or grassland. However, if the P production of the farm is higher than the application room, manure needs to be disposed or processed based on the quantity of surplus. The first part of new manure policy was introduced in 2013 and it quantifies the first part of surplus, based on the reference surplus of that year. The maximum surplus is about 800 kg of P per year, and around 15%-30% of this surplus needs to be processed depending on the exact regional rules of the country. The Second part of new manure policy is the part which exceeds the range of first part (>800 kg). It was established in 2015 and it indicates that all the increases above first part needs to be fully processed. The maximum surplus of the second part is decided by the P production of the farm. The third part of the new manure policy was introduced in 2016, and it indicates that the surplus of second part should be partly processed and partly applied on additional land of their own farm. The additional land which needs to be purchased by the farmer is decided by the percentage of total surplus level on total P production. The whole procedure was shown in Figure 1.

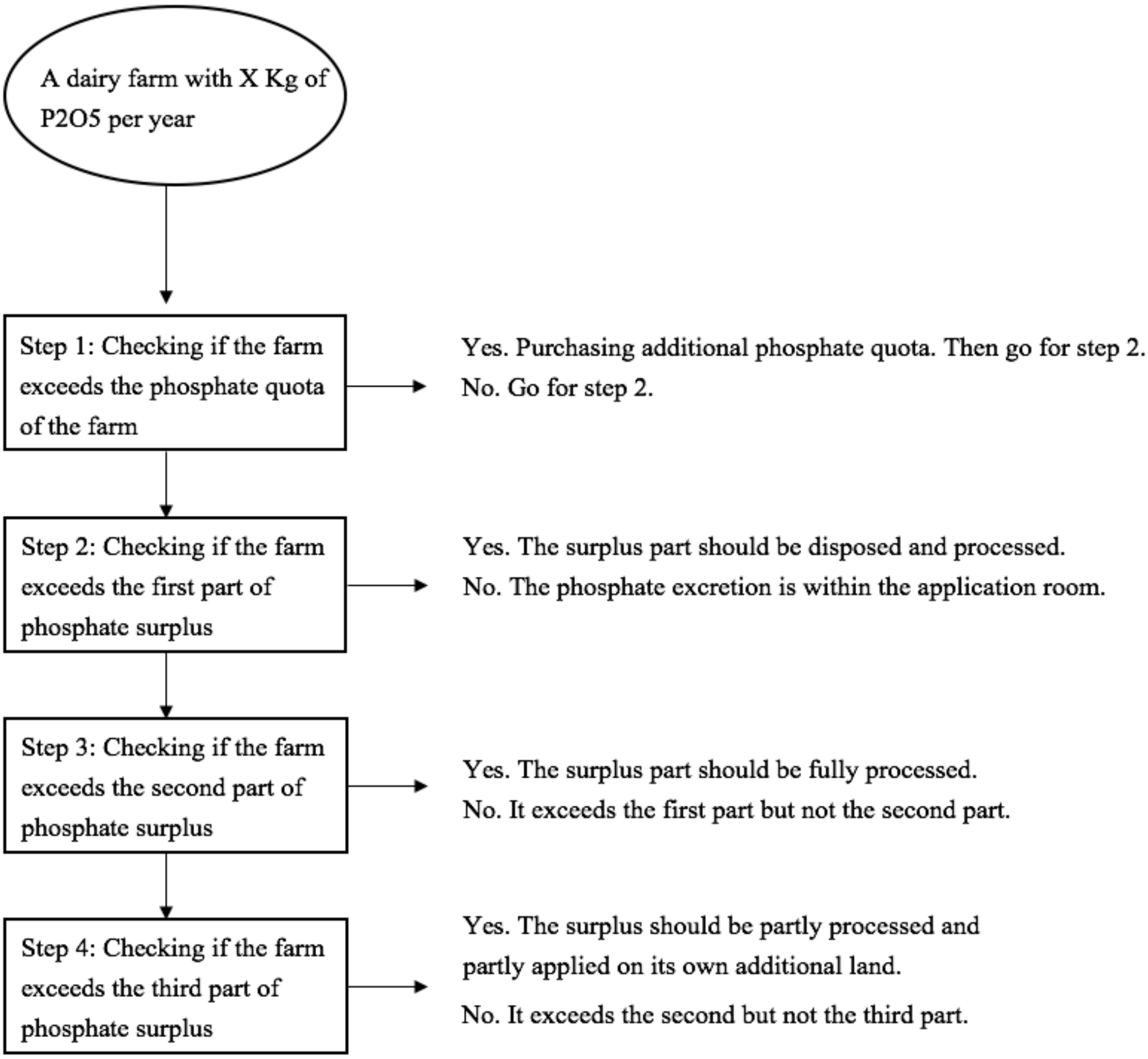

Figure 1: The procedure of P application on Dairy Act. Step 1 is based on new manure policy; Step 2 is based on the reference 2013; Step 3 is based on reference 2014; Step 4 is based on reference 2015

As mentioned above, there is a penalty for farms which exceed the P quota. Under the new policy, therefore, it is essential for farmers to obtain the optimum strategies to increase the P use efficiency of dairy farms. There are many studies that have analysed the impact of strategies to improve the P use efficiency on dairy farms (Neeteson, 2000; Arriaga, et al., 2009; Ferris, 2014;). Better farm management, dietary changes and improvements in crop production are both possible options. Some possible strategies are discussed in more detail below.

1.Decreasing the P content of concentrates. There are many types of studies which indicate that the P content in concentrates is the main contributor to the dietary P in the animal feeds. Many dairy farms are feeding too much P to the dairy cows (Knowlton et al., 2004; Nennich and Harrison, 2008). The study of Knowlton (2004) shows that P is often fed 20 to 40% in excess of published requirements. So it is possible to reduce the content of P in feed and this will not have any adverse impacts on cows' health (VandeHaar, et al., 2006; Nordqvist, et al., 2014; Ferris, 2014). Ferris (2014) shows P content level of about 3.6-3.8 g/kg DM in the feed is needed to support the health of the cow. Similarly, the report of Dou et al. (2003) indicates that a dietary P concentration of about 3.2 to 3.8 g/kg DM is sufficient to keep cows healthy that produce about 25-55 kg/day of milk. Some researchers use the percentage of P content in the diet to indicate the requirement of P. The report from National Study Council of United States (2001) suggests, a P concentration of 0.32% to 0.42% is sufficient. To improve the P use efficiency, it is essential to balance the P requirement of the animal and the P content of the diet.

2.Increasing the ration of maize silage in the daily diet. Data from Schothorst Feed Research (2017) shows that fresh grass and grass silage has a relatively higher P content compared to maize silage (4.09 g P/kg DM and 1.89 g P/kg DM respectively). Therefore, it is possible to reduce the total amount of P content in the daily diet by substituting maize silage for grass silage (Petrovska et al., 2015). Increasing the proportion of maize silage in the daily ration does not have a negative impact on the performance and health status of the dairy cows (Hart et al., 2015).

3.Outsourcing all the young stock to another farm. Many farmers choose to do off-farm rearing of young stock, so they can specialize in milking cows and increase milk production per cow (Oenema et al., 2011). The higher milk production may contribute to better P use efficiency. Furthermore, there is more space available on the farm to keep more dairy cows when outsourcing young stock to another farm. For young stock specialized farms, Rotz et al. (2002) showed that young stock consumes more roughages but less concentrates compared to dairy cows. It means the need for supplemental P in heifer diets is lower compared to dairy cow's feed; it may also improve the P use efficiency. Hence, specialized young stock farms and dairy farms will increase P use efficiency at the regional level.

4.Increasing the barn capacity of the farm. The barn capacity represents the number of dairy cows on the farm. After the abolition of milk quota in the Netherlands, there is a tendency for farmers to raise more dairy cows (Klootwijk et al., 2016). With more dairy cows on the farm, more farmlands need to be acquired. The study of Rotz et al. (2002) showed that the expansion of animal numbers led to less accumulation P on the farm, which results in better P use efficiency. More animals on the farm also results in more cost for manure processing and disposing. It is doubtful if the higher production with more animals would compensate for the higher costs for additional land and other expenses and if it would bring higher P use efficiency with corresponding higher inputs on the farm.

5.Increasing the replacement rate of the farm. More dairy cows are sold from the farm with higher replacement rate. The number of young stocks would rise. Young stock consumes relative more roughages compared to concentrates, which include a lower amount of P (Rotz et al., 2002). This might contribute to better P use efficiency due to lower P input. Lopez-Villalobos et al. (2010) indicated that, with a smaller replacement rate of the farm, it could achieve a better economic result and bring better farm profit. Therefore, increasing the replacement rate may negatively affect farm income.

6. Changing into heifer farm. The study of Rotz et al. (2002) demonstrated that, if merely take better P use efficiency into account, changing the dairy farm to a heifer-specialized farm could be possible for a long-term P balance. The reason for this strategy is fewer feeds (maize silage and concentrates) purchased during the rearing. However, it reduces the P output as well. Therefore, it is unsure if this strategy is promising to the Dutch situation. The labor requirements for the heifer-specialized farm are less compared to the normal farm, the profitability of the heifer-specialized farm might be considerable.

Currently it is unknown how these P use efficiency strategies affect the economic performance of Dutch dairy farms and which strategy is most promising from economic aspect under the constraint of the new manure policy. Therefore, the objective of this study is to evaluate the economic performances of strategies to improve the P use efficiency at dairy farms in the Netherlands within limits of the new manure policy. To achieve this objective, the following sub-questions are formulated:

1. What is the P use efficiency and labor income of average Dutch dairy farms after introduction of the new policy?

2. What are possible strategies to increase the P use efficiency of dairy farms?

3. What is the impact of these strategies on average Dutch dairy farms from environmental aspect?

4. What is the impact of these strategies on average Dutch dairy farms from economic aspect?

2. Materials and Methods

The first method used in this study is a linear optimization model. It is economic-oriented and aimed at simulating better labor income under certain restricts. In this study, the reference situation is the average Dutch dairy farms after the introduction of new manure policy. The optimization model is used to simulate a new farming plan including the relative P use efficiency strategies. The model is built in Excel. Using the tool “solver” in Excel, the goal to be optimized, the parameters that can be changed, as well as the constraints are entered into the model. Then the Excel perform the calculation to find the optimal solution. Based on the feasibility of the model and literature study, the first four strategies mentioned above were chosen for this study.

The second method nutrient balance assessment(NBA) is used to calculate the P use efficiency of the farm. Comparisons between reference situation and situation including the different strategies will be made.

2.1 Model description

The original optimization model was built by Berentsen and Giesen (1995) and updated by Van Middelaar et al. (2014). This model includes all relevant activities and constraints that are common to Dutch dairy farms. The objective function maximizes labor income, i.e. gross returns minus variable and fixed costs. The solution procedure optimizes feeding, manure application, and land use, given the activities and constraints of the model. Important activities are (1) on-farm feed production, including production of maize land and production of grassland (2) purchase of feed, including maize silage and a variety of concentrates with regard to protein content, (3) animal production, including dairy cows for sale, (4) manure application, (5) purchase and application of synthetic fertilizers, and (6) labor employment. Constraints of the model include some resources of the farm (e.g. land area, milk quota, and barn capacity), links between activities, and environmental policies. Examples of links between activities are the feed restrictions, which match on-farm feed production and purchased feed with animal requirements for energy and protein (DR Loket, 2012).

In this study, the model was simplified due to the limited time. Activities like the purchase and and application of synthetic fertilizers were excluded as they are considered not the most important parameters. The original dietary options include grass, grass silage, maize silage, and three types of concentrates with different protein levels: standard, medium and high. In this study, “high protein” concentrates are excluded because of the high price and “medium protein” concentrates are named as “high protein” concentrates. Then the milk quota was removed from the model and the new manure policy was included.

The general mathematical formulation for the model is:
$MAX\{Z = c'x\}$
Subject to $Ax \leq b$ or $Ax \geq b$
and $x \geq 0$

$x = vector\ of\ activities$
$c = vector\ of\ gross\ margin\ or\ costs\ per\ unit\ of\ activity$
$A = matrix\ of\ technical\ coefficients$
$b = vector\ of\ right-hand-side\ values$

The 7 major activities in the simplified model are distinguished:

(1) Milk production for sale. This is the major revenue for the dairy farm.

(2) Livestock sale, some of the dairy cows are sold based on the replacement rate.

(3) Government payments. This depend on the size of the farm.

(4) Purchase of feed with a variety of concentrates and roughage that can be bought.

(5) On-farm feed production, with grass production available for grazing and silage making and maize silage production.

(6) Labor costs. These depend on the hired labor hours and labor price per hour.

(7) Fixed costs. These include land rent, government land taxes, loan repayments, living expense and other finance costs.

Optional activities include purchase of additional barn, purchase of additional land and costs of manure disposal and processing. As the original barn capacity on the farm was limited, the purchase of additional barn allows farmers to raise more cows. If more cows cause P excretion to exceed the P application room of the farm, farmers have to spend money on manure disposal and processing. If the P excretion exceed the P quota, farmers have to purchase additional land. These optional activities were also included in the simplified model.

Each activity has its own specific vector of input and output coefficients. All vectors together form the matrix *A.* The first three activities together form the total revenues, and the fourth to seventh activities together form the variable costs. The final outcome is the labor income of the farm and is determined by subtracting the fixed costs and variable costs from the farm revenues. It is the remuneration for labor and management that is left over after all other costs have been paid. The formula for calculating the labor income is:

$$Labor\ income = Total\ revunues - variabe\ costs - fixed\ costs$$

2.2 Reference situation

This situation is the average Dutch dairy farm after milk quota abolition and introduction of the new manure policy. The basic data of this situation is copied from Klootwijk et al. (2016) and shown in Table 2. In their study, an optimization model was used to evaluate the effect of quota abolition and introduction of the new manure policy on the average Dutch dairy farm. It was assumed that the average cow belonged to the Holstein Friesian breed. Total farmland was 50 hectares and it was divided in 80% grassland and 20% maize land. One hectare of maize land yields 15.5 t of DM/yr, which equals 102 GJ of NEL (CBS, 2013). One hectare of grassland yields 66 GJ of NEL/yr. Purchased feeds included maize silage and concentrates. On the farm, 87 dairy cows and 51 young stock were kept, the milk production per cow was 8126 kg cow^{-1} yr^{-1} and total milk production was 707 ton of milk/yr. The milk price was 355€/ton. The barn capacity was 90 cow places and the replacement rate was 26.4%. The external labor requirement was 127 h/yr. For P, the maximum annual amount applied is 90 kg/ha for grasslands and 60 kg/ha for maize land (Nitraatrichtlijn, 2015). The price for the surplus above application room as manure disposal without processing was €9/ton, and the additional price of processing was assumed to be €4/ton (KWIN-V, 2014). Costs of additional land that can be either used for grass or maize were assumed to be €1,187/ha per year, based on the average Dutch land price of €46,000/ha, an interest rate of 4.5% (KWIN-V, 2014), and an inflation rate of 1.92% over the past 5 years (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 P quota were assumed to be €2.10/kg of P, based on current prices for quota in the dairy sector (KWIN-V, 2016).

Table 2：Basic data of reference situation which represent the average Dutch dairy farm after milk quota abolition and introduction of the new manure policy (Klootwijk, et al., 2016).

Item	Unit	Average Dutch dairy farm
Farmland	ha	50
Maize land percentage	%	20
Grassland percentage	%	80
Barn capacity for cows	No. of cows	90
Number of cows	No.	87
Number of young stock	No.	51
Milk production	kg cow^{-1} yr^{-1}	8126
Milk price	€ t^{-1}	355
Replacement rate	%	26.4
Purchased maize silage	t of DM yr−1	83
Purchased standard concentrates	t of DM yr−1	0
Purchased high protein concentrates	t of DM yr−1	149
P quota	kg of P yr^{-1}	4841
Application room	kg of P yr^{-1}	4200

Total excretion	kg of P yr^{-1}	4032.7
Manure disposal price	€ $t^{-1}yr^{-1}$	9
Manure processing price	€ $t^{-1}yr^{-1}$	13
Extra labor	h	127
Extra labor price	€ h^{-1}	17
Extra barn capacity price	€ $cow^{-1}yr^{-1}$	558
Extra farmland price	€ $ha^{-1}yr^{-1}$	1187
Extra P quota price	€ kg of $P^{-1}yr^{-1}$	2.10

In this study, the sold price for each dairy cow was updated to 1250€ (CBS, 2017). The production price for maize land and for grassland was updated to 2883€/ha and 570€/ha respectively (Jacob et al., 2013). This thesis also updated the current price of concentrates and some nutrient contents (energy content, rumen degradable protein balance, and P content) of the concentrates (Table 3) based on the current market price (October 2017) offered by Schothorst Feed Research (2017).

Table 3: Nutrient content (Energy, rumen degradable protein and P content) and market price of different feeds for the dairy cows (Schothorst Feed Research, 2017).

Feedstuff	NE_L (MJ/kg of DM)	DVE (g/kg DM)	OEB (g/kg DM)	Phosphorus (g/kg DM)	Market price (€/t of DM)
Concentrate					
- Standard protein	7.21	95.74	1.16	4.30	234.4
- High Protein	7.21	120.00	20.00	4.60	251.9
Grazed grass					
125 kg of N	6.62	93.92	9.31	4.09	-
175 kg of N	6.68	95.85	16.14	4.09	-
225 kg of N	6.72	97.68	23.45	4.09	-
275 kg of N	6.73	99.39	31.23	4.09	-
Grass silage					
125 kg of N	5.89	69.86	22.22	4.09	-
175 kg of N	5.93	71.46	30.62	4.09	-
225 kg of N	5.97	72.91	38.97	4.09	-
275 kg of N	6.00	74.21	47.27	4.09	-
Maize silage	6.56	58.00	-36.00	1.89	176

Based on the data above, the labor income of the reference situation could be calculated：

$$Milk\ sale = Number\ of\ cows * milk\ production\ per\ cow * milk\ price$$

$$Livestock\ sale = Number\ of\ cows * replacement\ rate * sold\ price\ per\ cow$$

$$Government\ payment = Farmland * 270€\ per\ ha$$

$$Concentrates\ purchase = Purchased\ concentrates * concentrates\ price$$

$$Roughage\ purchase = Roughage\ silage * maize\ silage\ price$$

$$\begin{aligned} On-farm\ roughage\ production \\ &= Farmland * maize\ land\ percentage * maize\ production\ price\ per\ ha \\ &+ Farmland * grassland\ percentage * grass\ production\ price\ per\ ha \end{aligned}$$

$$Hired\ labor\ costs = Hired\ labor * labor\ price$$

The total excretion on the farm in the reference situation was 4032.7 kg of P yr-1 and did not exceed the farm application room which is 4200 kg of P yr-1. This means that the costs for manure disposal and processing was €0.

2.3 Implementation of P use efficiency strategies

The primary input for the model was an average Dutch dairy farm after the introduction of manure policy which is also the reference situation. On the basis of the reference situation, each strategy will bring some changes to the input of the model (detailed changes of strategies in the model ***are*** in appendix ***1***). ***For instance, strategy 2 is increasing the ration of maize silage in the daily diet, so the input of maize silage is increased in the model during the implementation of this strategy.*** All strategies have the same target cell which is the maximum labor income, and ***the*** changing cells ***include the number of dairy cows, amount of concentrates and maize silage and purchased land***. There are the common constraints for all strategies:

(1) $Energy\ in\ the\ feed \geq Energy\ requirement\ of\ animals$

The energy required for dairy cows is 47GJ per year per animal (Moran, 2005), the energy required for young stock is 20GJ per year per animal (Holmes, et al., 2007).

(2) $Protein\ in\ the\ feed \geq Protein\ requirement\ of\ animals$

The crude protein required for dairy cows is 0.91Kg per day per animal (MSD Manual, 2018), the crude protein required for young stock is 0.19Kg per day per animal (Dairy NZ, 2018).

(3) $Dry\ matter\ intake \geq Dry\ matter\ requirement\ of\ animals$

The dry matter intake required for dairy cows is 11Kg per day per animal (Siobhan, 2015), the dry matter intake required for young stock is 2.8Kg per day per animal (Heinrichs, et al., 2007).

(4) $P\ in\ the\ feed \geq P\ requirement\ of\ animals$

The P required for dairy cows is 27g per day per animal (Burton, 2015), the P required for young stock is 7g per day per animal (NRC, 2011).

(5) $Concentrates\ intake \geq Concentrates\ requirement\ of\ animals$
The concentrates required for dairy cows is 4.85Kg per day per animal (Siobhan, 2015), the concentrates required for young stock is 1.2Kg per day per animal (Handcock, 2016).

(6) $Number\ of\ cows \leq Barn\ capacity$

(7) $P\ excretion \leq P\ quota$

2.3.1 Strategy1: Reducing the P content of the concentrates

There are two types of concentrates on the market. One with standard protein content and another one with high protein content. In this strategy, the P content of concentrates with standard protein was reduced to 3.5 g P/kg dry matter from 4.3 g P/kg dry matter. The concentrates with high protein was reduced to 3.8 g P/kg dry matter from 4.6 g P/kg dry matter respectively. Lower P content in the concentrates results in higher purchasing price(Table 4). In the input of the model, the price for concentrates with standard protein raised from 234.4 euros per ton to 240.8 euros per ton, and the price for concentrates with high protein increased from 251.9 euros per ton to 266.7 euros per ton. The changing cells include purchased maize silage, purchased standard protein concentrates, purchased high protein concentrates and dairy cow numbers. All the constraints of this strategy are the common constraints mentioned in last section.

Table 4: Changes on P content and selling price for two kinds of concentrates

Item	P content changes (g P/kg dry matter)	Price changes (€/ton)
Standard protein concentrates	4.3 →3.5	234.4→240.8
High protein concentrates	4.6 →3.8	251.9→266.7

2.3.2 Strategy2: Increasing the ration of maize silage in the daily diet

Maize silage was required to be fed 1 kg DM/cow/day more than the amount of maize silage in the reference situation. So in the input of the model, the maize silage intake per cow per day increased from 6.2 kg to 7.2 kg. This would not affect the production of dairy cows (Eastridge, et al., 1998), so the milk production per cow was kept as 8126 kg per year. The changing cells include purchased standard protein concentrates, purchased high protein concentrates and dairy cow numbers. All the constraints were kept the same with strategy 1.

2.3.3 Strategy3: Outsourcing young stock

All the external inputs for young stock such as additional feeds vanished. The forages harvested on the farm were used only for dairy cows. The labor for young stock was no longer needed and this was a reduced cost. The outsourcing costs for the young stock-rearing farm was based on the price of Dutch market from KWIN in 2016. The value was assumed to be 2.5 euros per animal per day. The estimated time for outsourcing in this study was 12 months. The changing cells in the model include purchased maize silage, purchased standard protein concentrates, purchased high protein concentrates and dairy cow numbers. All the constraints were still kept the same, but the barn capacity increased because outsourcing youngstock provided more places for dairy cows. It was assumed that the places for the original 51 young stock can be used for 25 dairy cows, so the barn capacity increased to 115 from 90. One more constraint in this strategy which limited the cow number is the total excretion should not exceed the farm appplication room.

2.3.4 Strategy4: Increasing the barn capacity

The barn capacity was set at 120 dairy cows before optimization, based on an increase in barn capacity on Dutch dairy farms (PBL, 2013). This is a practical situation after the abolition of milk quota (Klootwijk et al., 2016). In the input of the model, the costs for purchasing additional barn capacity was counted. The number of dairy cow number increased to 120, and the number of young stock increased to 70 with a constant replacement rate of 26.4%. The increase in the number of cows and young stocks led to an increase in total farm excretion, exceeding the farm application room and even exceeding the P quota. As a consequence, the costs for manure disposal and processing, the costs for the purchase of additional land and costs for the purchase of extra P quota were also taken in to account. It was assumed that the purchased farmland was divided in 80% grassland and 20% maize land. The changing cells include purchased maize silage, purchased standard protein concentrates, purchased high protein concentrates, dairy cow numbers and purchased farmland.

2.4 Environmental impact

Nutrient Balance Assessment (NBA) is a sufficient tool for long-term documentation of ecological impact (Paramasivam et al., 2017). Additionally, it gives a general overview of evaluation of environmental measures (Taube et al., 2001). It can be used to calculate the nutrient use efficiency on different levels. In this study, the focus will be on the P use efficiency on the farm level. It quantifies P use efficiency by computing the inputs and outputs (Figure 2). General inputs of P are in concentrates, imported maize silage, and atmospheric deposition. In strategy 3 (outsourcing the young stock), P content of heifers returned from the outsourced farm is also the input in the calculation. The outputs of P are in milk, sold animals. If the result is close to 1, it implies that the potential losses to the environment are low. The general structure of the formula is:

$$Efficiency\ of\ the\ P\ use = P\ output/P\ input$$

*P output= P values of sold milk + P values of sold animals

*P input= P values of purchased feeds (concentrates and maize silage) + P values of atmospheric deposition + heifers regained (applied for strategy 3)

Based on the literature, the P content of raw milk was set at 0.7g/ kg of milk (Zamberlin, et al., 2012), the P content in the sold livestock was set at 5 kg per animal (IFP, 2018). The atmospheric deposition was assumed to be 1 kg P/ha in the Netherlands (Neeteson, 2000).

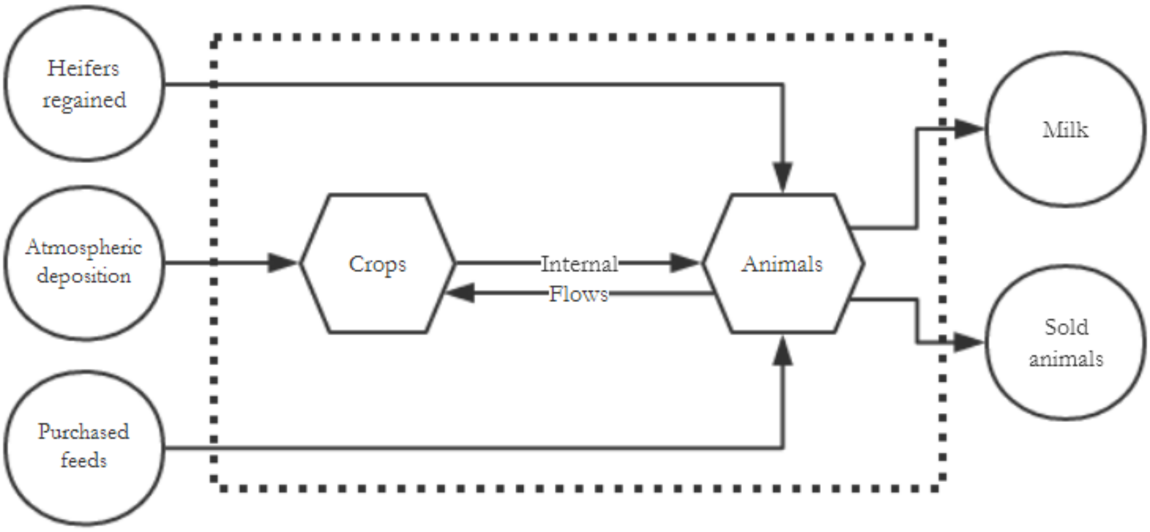

Figure 2: P flow on dairy farm level

2.5 Sensitivity Analysis

Variations in the production parameters and market factors can influence results. A sensitivity analysis was performed to evaluate the effect of varying parameters on the optimal solution.

In this study, there were four P use efficiency strategies implemented to optimize the labor income. As milk price and P quota were sensitive parameters for all these strategies. We optimized the labor income of the farm with 15% lower P quota, with 15% higher P quota, with 15% lower milk price and with 15% higher milk price based on all four strategies. In addition, each situation has specific sensitive parameters. So we also optimized the labor income of the farm with 15% lower and 15% higher purchased concentrates price based on strategy 1, the labor income of the farm with 15% lower and 15% higher purchased maize silage price based on strategy 2, the labor income of the farm with 15% lower and 15% higher outsourcing price based on strategy 3, and the labor income of the farm with 15% lower and 15% higher purchased land price based on strategy 4.

3.Results

This study optimized the labor imcome based on four P use efficiency strategies. Table 5 shows the optimized farm structure in these four situations, and Table 6 shows the optimized revenues, costs and final labor income in these four situations. Information of the reference situation was also included in Table 5 and Table 6. The P use efficiency in four optimized situations and reference situation was calculated respectively. The inputs of P and outputs of P are shown in Table 7. For each optimized situation, we performed sensitivity analysis based on three different parameters. The sensitivity analysis results of strategy 1, 2, 3 and 4 are shown in Table 8, 9, 10 and 11 respectively.

3.1 Farm structure and labor income

3.1.1 Strategy 1

Reducing the P content of the concentrates resulted in more dairy cows on the farm compared to reference situation. The number of dairy cows increased from 87 to 90 dairy cows, the number of young stock did not change. Hired labor increased to 211 hours per year because more labor was needed for raising the increased dairy cows. The farmland was fixed at 50 ha and a proportion of the grassland at 80% of the total farmland. To satisfy the energy and nutrients requirements of the animals, the model chose to feed more concentrates compared to reference situation. The amount of purchased high protein concentrates increased from 149 to 196 ton per year, and the amount of purchased maize silage decreased from 83 to 36.5 ton per year. The total P excretion was more than in the reference situation, increasing from 4032 to 4156 kg of P per year. All the manure from the farm could be applied on the land because the production of P did not exceed the application room of the farm. The lower P content of concentrates resulted in higher costs for concentrates, which were compensated by a higher revenue of milk sale. In this strategy, the labor income was €12,707 euros per year, which is a little bit more than the labor income in the reference situation.

3.1.2 Strategy 2

Strategy 2 represented the situation where maize silage use was increased. Results showed a farm with 90 dairy cows and 51 young stocks, which means that the barn capacity was fully used. The diet structure of dairy cows changed a lot. The amount of purchased maize silage increased from 83 to 122.5 ton per year, the amount of standard protein concentrates increased from 0 to 37 ton per year, and the amount of high protein concentrates decreased from 149 to 45 ton per year. Also, due to the more animals on the farm, the time for hired labor increased to 211 hours per year. The total P excretion was more than the reference situation, increasing from 4032kg to 4156 kg of P per year. All the manure from the farm could be applied on its land because the production of P did not exceed the application room of the farm. Although the revenue from milk sale increased because of the increased number of dairy cows, it could not compensate for the increased costs of purchasing more feed due to the new diet. In this situation, the labor income was €6,366 per year, which was about €4,000 less than the labor income in the reference situation.

3.1.3 Strategy 3

In strategy 3, all the young stock was outsourced. With more space on the farm, the number of dairy cows was considerably higher compared to reference situation. The number of dairy cows kept on the farm increased to 101 and all 51 young stock were outsourced. No additional land was purchased. Without young stock in the farm, the internal produced maize silage was sufficient for dairy cows, so no more maize silage was purchased. The amount of purchased standard protein concentrates increased from 0 to 181 ton per year, and the amount of purchased high protein concentrates decreased from 149 to 102 ton per year. Labor for dairy cow increased to 411 hours per year, but the saved labor for young stock was 765 hours per year, so the costs for hired labor decreased. The total excretion increased to 4200 kg of P per year which was the maximum application room of the farm, and therefore all the manure produced could be applied on own land. The revenue of milk sale increased from €25,0971 to €29,3348 per year compared to the reference situation, and it was enough to compensate the high fixed costs for outsourcing young stock (€2.5/animal/day). In this situation, the final labor income was the highest compared to other situations, which was €24,293 per year.

3.1.4 Strategy 4

In strategy 4, the barn capacity of the dairy cows was increased to 120. From the result, it showed that all the stalls were entirely used, which means that 120 dairy cows were kept. The number of young stock increased to 70 young stocks, because the replacement rate was still set at 26.4%. The labor request was much higher compared to the reference situation, hired labor increased from 127 to 1341 hours per year. Total excretion increased to 5561 kg of P per year which exceeded the application room of the farm and also exceeded the P quota. So thirteen additional hectares of farmland were purchased, and 720 kg additional P quota was purchased. The amount of manure disposal was 161 kg of P, and the amount of manure processing was 69 kg of P. The total farmland increased to 63ha, so the government payment increased from €13,500 to €17,134 per year. To meet the requirement of these animals, the farmer needed to buy a large amount of concentrates. Purchase of high protein concentrates increased to 271 ton per year. However, the amount of purchased maize silage decreased from 83 to 68 ton per year, because additional internal maize silage could be produced on the new farmland. Although the costs of land purchase, P quota purchase, and manure disposal and processing was large, the increased revenue from milk sale milk was greater. So the labor income in this situation was still significantly higher than the labor income in reference situation, which was increased to €21,485 per year.

Table 5: Optimized farm structure and management for an average Dutch dairy farm with new manure policy (reference situation) and simulated farms with P use efficiency strategies.

Items	Unit	Reference situation	Strategy 1: Reducing P content of concentrates	Strategy 2: Increasing the ration of maize silage	Strategy 3: Outsourcing the young stock	Strategy 4: Increasing barn capacity
Dairy cows	No.	87	90	90	101	120
Young stock	No.	51	51	51	51	70
Total milk production	$t\ yr^{-1}$	707	731	731	826	975
Total farmland	ha	50	50	50	50	63
Grassland percentage	%	80	80	80	80	80
Maize land percentage	%	20	20	20	20	20
External inputs						
Purchased maize silage	t of DM yr^{-1}	83	36.5	122.5	0	68
Purchased standard protein concentrates	t of DM yr^{-1}	0	0	137	0	0
Purchased high protein concentrates	t of DM yr^{-1}	149	196	45	181	271
Hired labor	h	127	211	211	538	1341
Manure management						
Total excretion	kg of P yr^{-1}	4031	4156	4156	4200	5561
Extra P quota	kg of P yr^{-1}	0	0	0	0	720
Applied on own land	kg of P yr^{-1}	4031	4156	4156	4200	5331
Manure disposal	kg of P yr^{-1}	0	0	0	0	161
Manure processing	kg of P yr^{-1}	0	0	0	0	69

Table 6: Optimized economic results for an average Dutch dairy farm with new manure policy (reference situation) and simulated farms with P use efficiency strategies.

Items (€/yr)	Reference situation	Strategy 1: Reducing P content of concentrates	Strategy 2: Increasing the use of maize silage	Strategy 3: Outsourcing the young stock	Strategy 4: Increasing barn capacity
Revenues					
Milk sale	250971	259625	259625	293348	347680
Livestock sale	28710	29700	29700	33557	39600
Government payments	13500	13500	13500	13500	16042
Variable costs					
Standard protein concentrates purchase	0	0	32113	0	0
High protein concentrates purchase	37533	52220	11335	45342	68265
Roughage Purchase	14608	6424	21560	0	11968
On-farm roughage production	51630	51630	51630	51630	59402
Manure disposal	0	0	0	0	1448
Manure processing	0	0	0	0	897
Hired labor	2159	3587	3587		17867
Additional barn purchase	0	0	0	0	16740
Additional farmland purchase	0	0	0	0	15983
Additional P quota purchase	0	0	0	0	1512
Outsourcing costs	-	-	-	46537	-
Other	39026	39026	39026	39026	39026
Fixed cost	137203	137203	137203	137203	137203
Labor income	11022	12707	6366	24293	21485

3.2 P use efficiency

The P use efficiency in the reference situation was 68.4%. In Strategy 1, reducing P content of the concentrates gives a better P use efficiency on the farm. The efficiency improved from 68.4% to 73.1%, which was the highest in all situations. In Strategy 2, the P use efficiency was 69.1%, and a little higher than in the reference situation. In Strategy 3, the P use efficiency increased to 71.0%. In Strategy 4, however, the P use efficiency was lower compared to the reference situation, decreasing from 68.4% to 58.4%. Table 7 gives an overview of the P inputs and P outputs in four optimized situations and in reference situation.

Table 7: The P in input and output of the farm and P use efficiency under reference situation and situations with different P use efficiency strategies.

Items	Reference situation	Strategy 1: Reducing P content of concentrates	Strategy 2: Increasing the use of maize silage	Strategy 3: Outsourcing the young stock	Strategy 4: Increasing barn capacity
Input (kg of P)					
Purchased concentrates	685.4	744.0	650.5	784	11246.6
Purchased maize silage	156.8	68.9	211.2	0	128.5
Atmospheric deposition	50.0	50.0	50.0	50.0	63.0
Heifer regained	0	0	0	219	0
Sum (kg of P)	892.2	862.9	911.6	997	1221.3
Output (kg of P)					
Milk	494.9	511.9	511.9	574.6	682.5
Livestock sale	114.8	118.8	118.8	133.3	158.4
Sum (kg of P)	609.7	630.7	630.7	707.9	840.9
P use efficiency	68.4%	73.1%	69.1%	71.0%	58.4%

3.3 Sensitivity analysis

3.3.1 Sensitivity analysis of Strategy 1

Based on Strategy 1, six alternative situations were simulated. Situation 1A represented a farm with 15% lower P quota which was 4100 Kg of P per year. Results showed that the number of dairy cows decreased from 90 to 88, and the labor income decreased from €12,707 to €6,305 per year. Situation 1B represented a farm with 15% higher P quota which was 5560 Kg of P per year. The number of cows did not change, and the labor income increased to €14,405 per year. Situation 1C represented a farm with 15% lower milk price which was €300 per ton. The number of dairy cows were kept the same, and the labor income decreased from €12,707 to €-25,818 per year. Situation 1D represented a farm with 15% higher milk price which was €408 per ton. The number of dairy cows were kept the same, and the labor income increased to €53,166 per year. Situation 1E represented a farm with 15% lower concentrates price which was €204.6 and €226.7 per ton for standard protein concentrates and high protein concentrates respectively. The number of dairy cows were kept the same, more standard protein concentrates were purchased instead of high protein concentrates and the labor income increased to €21,613 per year. Situation 1F represented a farm with 15% higher concentrates price which was €276.9 and €306.7 per ton for standard protein concentrates and high protein concentrates respectively. The number of dairy cows were kept the same, and the labor income decreased to €7,520 per year. The economic results of all six situations are in Table 8.

Table 8: Economic results for an average Dutch dairy farm in sensitivity analysis 1A to 1F based on Strategy 1.

Items (€/yr)	Situation 1A: 15% lower P quota	Situation 1B: 15% higher P quota	Situation 1C: 15% lower milk price	Situation 1D: 15% higher milk price	Situation 1E: 15% lower concentrates price	Situation 1F: 15% higher concentrates price
Revenues						
Milk sale	253,856	259,625	219,402	298386	259,625	259,625
Livestock sale	29,040	29,700	29,700	29,700	29,700	29,700
Government payments	13,500	13,500	13,500	13,500	13,500	13,500
Variable costs						
Standard protein concentrates purchase	0	23,357	23,357	23,357	48,203	26,859
High protein concentrates purchase	53,873	22,402	22,402	22,402	0	25,732
Roughage Purchase	7,392	11,053	11,055	11,055	1,548	10,912
On-farm roughage production	51,630	51,630	51,630	51,630	51,630	51,630
Manure disposal	0	0	0	0	0	0
Manure processing	0	0	0	0	0	0
Hired labor	2,946	3,587	3,587	3,587	3,587	3,587
Other	39,026	39,026	39,026	39,026	39,026	39,026
Fixed cost	137,203	137,203	137,203	137,203	137,203	137,203
Labor income	6,305	14,405	-25,818	53,166	21,613	7,520

3.3.2 Sensitivity analysis of Strategy 2

Based on Strategy 2, six alternative situations were simulated. Situation 2A represented a farm with 15% lower P quota which was 4100 Kg of P per year. The number of dairy cows decreased from 90 to 88, and the labor income decreased from €6,366 to €1,450 per year. Situation 2B represented a farm with 15% higher P quota which was 5560 Kg of P per year. The number of cows did not change, and the labor income increased to €7,243 per year. Situation 2C represented a farm with 15% lower milk price which was €300 per ton. The number of dairy cows were kept the same, and the labor income decreased to €-32,980 per year. Situation 2D represented a farm with 15% higher milk price which was €408 per ton. The number of dairy cows were kept the same, and the labor income increased to €46,004 per year. Situation 2E represented a farm with 15% lower maize silage price which was €149 per ton. The number of dairy cows were kept the same, more maize silage was purchased and the labor income increased to €10,550 per year. Situation 2F represented a farm with 15% higher maize silage price which was €202.4 per ton. The number of dairy cows were kept the same, and the labor income decreased to €4,009 per year. The economic results of all six situations are in Table 9.

Table 9: Economic results for an average Dutch dairy farm in sensitivity analysis 2A to 2F based on Strategy 2.

Items (€/yr)	Situation 2A: 15% lower P quota	Situation 2B: 15% higher P quota	Situation 2C: 15% lower milk price	Situation 2D: 15% higher milk price	Situation 2E: 15% lower maize silage price	Situation 2F: 15% higher maize silage price
Revenues						
Milk sale	253,856	259,625	219,402	298386	259,625	259,625
Livestock sale	29,040	29,700	29,700	29,700	29,700	29,700
Government payments	13,500	13,500	13,500	13,500	13,500	13,500
Variable costs						
Standard protein concentrates purchase	25,784	32,112	42,426	42,426	42,426	42,426
High protein concentrates purchase	19,396	11,335	0	0	0	0
Roughage Purchase	20,768	11,053	21,472	21,472	21,472	21,472
On-farm roughage production	51,630	51,630	51,630	51,630	51,630	51,630
Manure disposal	0	0	0	0	0	0
Manure processing	0	0	0	0	0	0
Hired labor	2,946	3,587	3,587	3,587	3,587	3,587
Other	39,026	39,026	39,026	39,026	39,026	39,026
Fixed cost	137,203	137,203	137,203	137,203	137,203	137,203
Labor income	6,366	7,243	-32,980	46,004	10,550	4,009

3.3.3 Sensitivity analysis of Strategy 3

Based on Strategy 3, six alternative situations were simulated. Situation 3A represented a farm with 15% lower P quota which was 4100 Kg of P per year. The number of dairy cows decreased from 101 to 99, and the labor income decreased from €24,293 to €9,971 per year. Situation 3B represented a farm with 15% higher P quota which was 5560 Kg of P per year. Both the number of cows and the labor income did not change. Situation 3C represented a farm with 15% lower milk price which was €300 per ton. The number of dairy cows were kept the same, and the labor income decreased to €-28,847 per year. Situation 3D represented a farm with 15% higher milk price which was €408 per ton. The number of dairy cows were kept the same, and the labor income increased to €60,400 per year. Situation 3E represented a farm with 15% lower outsourcing price which was €2.12 per animal per day. The number of dairy cows were kept the same, and the labor income increased to €31,366 per year. Situation 3F represented a farm with 15% higher outsourcing price which was €2.87 per animal per day. The number of dairy cows were kept the same, and the labor income decreased to €9,715 per year. The economic results of all six situations are in Table 10.

Table 10: Economic results for an average Dutch dairy farm in sensitivity analysis 3A to 3F based on Strategy 3.

Items (€/yr)	Situation 3A: 15% lower P quota	Situation 3B: 15% higher P quota	Situation 3C: 15% lower milk price	Situation 3D: 15% higher milk price	Situation 3E: 15% lower outsourcing price	Situation 3F: 15% higher outsourcing price
Revenues						
Milk sale	285,588	291,358	246,217	334,856	291,358	291,358
Livestock sale	32,670	33,330	33,330	33,330	33,330	33,330
Government payments	13,500	13,500	13,500	13,500	13,500	13,500
Variable costs						
Standard protein concentrates purchase	33,519	0	33,519	33,519	0	33,519
High protein concentrates purchase	9,244	45,342	9,068	9,068	45,342	9,244
Roughage Purchase	10,384	0	10,384	10,384	0	10,384
On-farm roughage production	51,630	51,630	51,630	51,630	51,630	51,630
Manure disposal	0	0	0	0	0	0
Manure processing	0	0	0	0	0	0
Hired labor	7,990	9,146	9,146	9,146	9,146	9,146
Other	39,026	39,026	39,026	39,026	39,026	39,026
Fixed cost	137,203	137,203	137,203	137,203	137,203	137,203
Labor income	9,971	24,292	-28,847	60,400	31,366	9,715

3.3.4 Sensitivity analysis of Strategy 4

Based on Strategy 4, six alternative situations were simulated. Situation 4A represented a farm with 15% lower P quota which was 4100 Kg of P per year. The number of dairy cows did not change, and the labor income decreased from €21,485 to €19,929 per year. Situation 4B represented a farm with 15% higher P quota which was 5560 Kg of P per year. The number of cows did not change, and the labor income increased to €22,995. Situation 4C represented a farm with 15% lower milk price which was €300 per ton. The number of dairy cows were kept the same, and the labor income decreased to €-32,146 per year. Situation 4D represented a farm with 15% higher milk price which was €408 per ton. The number of dairy cows were kept the same, and the labor income increased to €73,166 per year. Situation 4E represented a farm with 15% lower land price which was €10082 per ha. The number of dairy cows were kept the same, and the labor income increased to €23,895 per year. Situation 4F represented a farm with 15% higher land price which was €1365 per ha. The number of dairy cows were kept the same, and the labor income decreased to €19,088 per year. The economic results of all six situations are in Table 11.

Table 11: Economic results for an average Dutch dairy farm in sensitivity analysis 4A to 4F based on Strategy 4.

Items (€/yr)	Situation 4A: 15% lower P quota	Situation 4B: 15% higher P quota	Situation 4C: 15% lower milk price	Situation 4D: 15% higher milk price	Situation 4E: 15% lower land price	Situation 4F: 15% higher land price
Revenues						
Milk sale	346,167	346,167	292,536	397,848	346,167	291,358
Livestock sale	39,600	39,600	39,600	39,600	39,600	39,600
Government payments	16,042	16,042	16,042	16,042	16,042	13,500
Variable costs						
Standard protein concentrates purchase	0	0	0	0	0	33,519
High protein concentrates purchase	68,264	68,264	68,264	68,264	68,264	9,244
Roughage Purchase	10,560	10,560	10,560	10,560	10,560	10,560
On-farm roughage production	59,402	59,402	59,402	59,402	59,402	59,402
Additional barn capacity purchase	16,740	16,740	16,740	16,740	16,740	16,740
Additional farmland purchase	15,983	15,983	15,983	15,983	13,585	18,380
Manure disposal	1,442	1,442	1,442	1,442	1,442	1,442
Manure processing	893	893	893	893	893	893
Extra P quota purchase	3,068	2	1511	1511	1511	1511
Hired labor	17,867	17,867	17,867	17,867	9,146	9,146
Other	39,026	39,026	39,026	39,026	39,026	39,026
Fixed cost	137,203	137,203	137,203	137,203	137,203	137,203
Labor income	19,929	22,995	-32,146	73,166	23,895	19,088

4. Discussion

This study gives an overview of the possible strategies of improving P use efficiency from dairy nutritional management (strategy 1 and 2) and farm management (strategy 3 and 4). The optimization model is used to simulate and evaluate each strategy. However, there are some restricts in this study. The first restrict is that the optimization model structure. We used a simplified model because the original model includes too many activities and it is difficult to complete in a limited time. Although the simplified model takes into account the most important on-farm activities, it still can not provide the most accurate optimization solution. Some activities that were excluded from the model, such as the purchase of fertilizer, is not only a part of the costs of the farm, but also a constraint in the model. The second restrict is that the not all the data in the model was up to date due to the data availability. For instance, the production of maize land and grassland per hectare was based on the data for 2013. The results under the model would not be representative without enough current data because any changes of the input data in the model could affect the final optimization.

In this study, we focused on the conditions of the average Dutch dairy farms, and have not risen to a higher level. Middelaar et al. (2013) indicated that the analysis at different levels matters in system thinking. In their study of evaluating a feeding strategy to reduce greenhouse gas emissions from dairy farming, the results showed that this strategy is promising at animal level, but not feasible at farm and chain level (Middelaar et al., 2013). So it is essential to think from other analysis levels such as regional level, or even higher. For instance, outsourcing all the young stocks to another farm gave a better P use efficiency on this dairy-specialized farm, but the P use efficiency on the young stock-specialized farms need to be investigated in further studies. The study of Rotz, et al. (2002) showed young stock-specialized farm indeed provide a long-term P balance for the farm. More investigations on a regional level and comparisons of the results with two kinds of regions with different types of the farm (one dairy-young stock mixed farm, and another one specialized-animal farm) in the future might give new insights on environmental protection. It would be useful to do a critical analysis of different strategies from a higher system boundary, and therefore to find a better solution on a global level.

Four P use efficiency strategies evaluated in this study illustrate that nutritional changes such as the ration of maize silage in the diet and management changes such as outsourcing young stock can be made to improve the labor income. Throughout the results of this study, reducing the P content of concentrates gave a relatively better economic outcome compared to reference situation, and it is also relatively easy to implement. The primary aim of this strategy is to reduce the P content of dairy cows on their daily ration, as many of them were fed above P requirement (Klootwijk et al., 2016; Rotz et al., 2002; Smith et al., 2016). Based on the result of this strategy, dairy cows were fed 14.3% above P requirement, which was improved by around 6.5% compared to reference situation in which the dairy cows were fed 20.8% above P requirement. Herein, it indicated that it would be possible to improve the P use efficiency of the animal and increase the economic performance of the farm by feed management.

Increasing the maize silage in daily diet has a negative impact on the labor income result of the farm. Although the price for maize silage is lower than the price of concentrates, the total costs of purchased feed has not decreased. The reason is maize silage has a relatively lower rumen degradable protein value, then a great amount of concentrates still need to be purchased to meet the protein requirements of animals. From the environmental aspect, with more maize silage, the P use efficiency was indeed improved. Middelaar et al. (2013) also showed that replacing grass and grass silage with maize silage was an option to decrease greenhouse gas emissions. From the economic aspect, due to the restriction on the acreage of maize land, there was no additional maize land purchased in this study for the implementation of this strategy. The on-farm roughage production was a limiting factor for this strategy; otherwise, the farmer needed to buy additional maize silage which was harmful to the economic situation of the farm. It could be interesting to do further study on this strategy to find a neutralization between the ration of maize silage and grass silage. For policymakers, the result of the study might provide them a new point of view on feeding strategies for environmental protection.

Outsourcing all the young stock to another farm gave a good result on improving P use efficiency. It brought a positive impact on the environment with the introduction of new manure policy. Although the number of dairy cows increased, but these extra dairy cows were fed with feedstuff which was previously used by young stock. All the young stock was outsourced, therefore, the input of the farm such as concentrates did not increase. More dairy cows resulted in the increase of the P output (milk, sold animals) of the dairy farm. Therefore, the P use efficiency was improved. From the economic aspect, this strategy significantly increased labor income, and the final labor income after the implementation of this strategy was more than twice the labor income in the reference situation. So this strategy is very promising from both environmental and economical aspects. However, this strategy might not become widely used because most of the Dutch dairy farms are dairy-young stock mixed farms from origin. And outsourcing young stock also involves the feasibility, so further research is needed to support this strategy.

Increasing the barn capacity is one of the considerations after the abolition of milk quota in practice. With more dairy cows at the farm, it is a way to maximize the milk production at the farm. However, from the result of this study, it did not give an ideal outcome. The P use efficiency was even lower compared to the reference situation. The reason is that although the output of the farm was more extensive compared to reference situation, the input from outside of the farm increased as well. P inputs of the purchased maize silage and concentrates was much higher compared to the reference situation. The P use efficiency of the animals was not improved, therefore, with more cows at the farm, the P use efficiency of the farm was insufficient. Increasing P use efficiency on the herd level gives the potential to improve the efficiency of the entire farm and therefore improve the performance on higher levels. The introduction of new manure policy brought restrictions on the P excretion of the farm. From an environmental point of view, it was not favourable to increase the barn capacity of the farm. But from the economic aspect, increasing barn capacity has a good performance in increasing the labor income, the final labor income after the implementation of this strategy was nearly twice the labor income in the reference situation. So farmers need to weigh the pros and cons between environmental impact and economic results.

Based on the results of sensitivity analysis, it can be concluded that more stringent P quota restrict has a significant negative impact on labor income, and a relatively loose P quota restrict can increase the labor income. However, it is possible that the P quota becomes more limited in the future (USDA Foreign Agricultural Service, 2017), so it is of great importance for famer to improve the P use efficiency of the dairy farms. A higher milk price can significantly increase labor income, and a lower milk price can significantly decrease the labor income. The labor income of the farm with a 15% lower milk price is even negative. In recent years, the volatility of the milk price in the EU is keep increasing due to decreasing governmental intervention (Holmer, 2015). So the labor income is greatly affected by the changing milk price. If the milk price increased to the highest level of 2013–2014, farms could grow unlimited, provided that the availability of external inputs such as labor, land, barn capacity, feed, and purchased P quota at current prices were also unlimited.

The results of sensitivity analysis indicate that the higher maize silage price and higher concentrates price can result in the decrease of labor income. Data from the European Commission shows that the maize silage price has decreased in the past 5 years (EU Commission, 2017), this would bring positive impact on the labor income of dairy farms. However, the price of concentrates keeps increasing (CLAL, 2018). So the balance between concentrates and forage in the dairy diet needs to be measured according to price changes, both to meet the nutritional requirements of the animal and to minimize the costs of purchasing the feed. The lower purchased price of farmland results in an increase of labor income, this is because the cost of farm expansion of the farm has become lower. More animal can be kept in the farm which will increase the revenue from milk sale and livestock sale. The increased land increases the application room of the farm, so although the increased animals will bring in increased excretion, a part of the excretion can be applied on the additional land. So from economic aspect, it may be promising to have long-term rental contracts to get a lower land price.

In the future study, it would be of great interest to evaluate these strategies based on the optimization model that is not simplified. With more activities and constraints included, the economic results might be different from the results of this study, and would be more reliable.

5. Conclusion

This study evaluates four potential strategies to improve P use efficiency after the introduction of new manure policy. Strategy 1 is decreasing the P content of concentrates, Strategy 2 is increasing the ration of maize silage, Strategy 3 is outsourcing young stock and Strategy 4 is increasing barn capacity. All of these strategies have some influences on P use efficiency and labor income of the farm.

From environmental aspect, all strategies were beneficial for the improvement of P use efficiency except Strategy 4 which is increasing barn capacity. Strategy 1 which is decreasing the P content of concentrates is the most promising strategy compared to others on improving P use efficiency. On the economic side, all strategies have better financial performance compared to reference situation except Strategy 2 which is increasing the ration of maize silage. Strategy 3 which is outsourcing young stock results in the highest labor income. This would be of interest in future studies to find the balance between environmental impact and the economic result of P use efficiency strategies.

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Appendix 1. Detailed changes in this study

	Changes
Strategy 1: Reducing P content of concentrates (Compared to reference)	1. For normal protein concentrates, P content is changed from 4.3 g P/kg dry matter to 3.5 g P/kg dry matter, the price is changed from 234.4 euros/ton to 240/8 euros/ton. 2. For high protein concentrates, P content is changed from 4.6 g P/kg dry matter to 3.8 g P/kg dry matter, the price is changed from 251.9 euros/ton to 266.7 euros/ton.
Strategy 2: Increasing the use of maize silage (Compared to reference)	Based on the reference situation, the requirement on maize silage of dairy cows is increased by 1 kg per day per cow.
Strategy 3: Outsourcing the young stock (Compared to reference)	1. All the requirements of on farm young stocks are 0, including the requirement for concentrates and maize silage. The labor for young stock turns to 0. The original labor are used for dairy cows. 2. Adding outsourcing cost in sheet (€2.5 *30 days *12 months =€900/animal)
Strategy 4: Increasing barn capacity (Compared to reference)	1. Changing the barn capacity from 90 to 120